Atmosphere pollution caused by traffic and the necessity to adapt to effects of climate change. A case study for Bucharest

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Abstract. In the last couple of years, the quality of urban and periurban environment has suffered changes, being constantly influenced by a series of factors like: increasingly heavier traffic, sound pollution, certain activities that have an impact on the atmosphere. Road transport contributes to photochemical smog, acid rain, as well as accentuates the greenhouse effect (global warming). In this context, the present paper represents a part of the results obtained following a documentary and experimental study undergone in interior and periurban areas of Bucharest municipality, regarding tropospheric response times to increasingly anthropic pressure caused by vehicle transport activities, by correlating measurements results of nitrous oxides (NOx) and carbon monoxide (CO) emissions with those of simultaneous traffic monitoring. A representative case study is presented for downtown Bucharest. Also, an analysis is presented regarding meteorological parameters variation (annual average temperature and total rainfall) for downtown and periurban areas in Bucharest metropolis. The obtained results have highlighted the fact that road traffic is the main source of pollution in Bucharest and it has an important contribution to increasing climate change.
Key Words: traffic, atmospheric pollutants, correlation coefficient, global warming, climate parameters.

Introduction. The climate represents the weather's multiannual regime, resulted from radiative factors interaction, atmosphere's general circulation and the complexity of physical and geographical conditions. The climate is defined as an average state of the atmosphere associated with average continental conditions, from oceans, glaciers, vegetation etc. and is calculated at a 30 year interval (according to the World Meteorological Organization). Climate change implies systematic deviation from the average state that defines a climate to a new average state – a new climate (NMA 2016; MEWF 2015). Climate change can be caused by natural internal factors (changes that appear inside the climate system or because of interaction between its components) as well as external natural factors (variation of energy emitted by the sun, Earth's orbital parameter variation – Milancovici parameters, volcanic eruptions) or anthropic external factors (Ardelean & Niculita 2008). The most important anthropic sources of atmosphere pollution are auto vehicle transport activities, the industry and thermoelectric power plants. The emissions resulted from these sources are a heterogenic mixture of gases and material particles. This way, the natural composition of tropospheric air gets modified. Some pollutant gases absorb a part of the infrared radiation reflected of the earth's surface determining the greenhouse effect. The continuous increase of greenhouse effect gases concentration (GHG) like carbon dioxide, methane, nitrous oxides, chlorofluorocarbons, etc., has led to the appearance of energy accumulations within the geo system. These manifest by average temperature increase in the low troposphere, ocean waters upper stratum, as well as by atmosphere and planetary ocean current changes. According to the Intergovernmental Panel on Climate Change (IPCC 2014) of the United Nations, global warming is lately becoming an aggravated phenomena, and human factor is the one to blame, its contribution exceeding 95% of all pollution sources. The increase of the global annual temperature determines other changes like: sea level increase, changes in rainfall rhythm and quantity, an increase in number and intensity of extreme phenomena, glacier melt, species extinction, agricultural production changes, the reappearance of diseases considered to be eradicated and others. Romania has ratified the UN's Framework Convention regarding Climate Change (UNFCCC) by Law nr. 24/1994, and the Kyoto Protocol UNFCCC by Law nr. 3/2001.

In Paris, during 30 Nov – 12 Dec 2015, The Conference regarding climate change took place. The Paris Agreement has been negotiated, its text representing a consensus of all 195 participating states. This agreement will become mandatory when it's signed by at least 55 countries, whose pollutant emissions combined represent more than 55% of global greenhouse gas emissions. The main objective of the agreement is represented by the limitation of average global temperature increase to max 2^oC, comparative to the preindustrial level. The agreement also states zero greenhouse effect gases emissions in the second half of the 21st Century. Romania's position is reflected in the overall position agreed by the European Union. The southern and southeastern regions of Europe are the most vulnerable to effects of climate change (IPCC 2014). The urbanization rate in these regions is one of the highest in Europe. The urban environment directly contributes to impact accentuation of climate change on ecosystems, different sector activities and last but not least on public health.

Global warming is tightly linked to pollution registered in high density population (Florides & Christodoulides 2009). According to the European Environment Agency (EEA 2013), circa 75% of EU population resides in urban areas. The urban/rural separation line is more and more difficult to establish. Presently, the periurban areas are expanding a lot faster than interior city areas. Road traffic represents the main source of pollution specific to urban and bordering areas. The transport sector already consumes approximately half of the entire global oil quantity (Harish 2012). From specialty literature we can see that research regarding traffic pollutant emissions in different countries has been performed (Nwyanya & Offili 2013; Ardelean 2014; Peptenatu et al 2010), as well as the effects of pollutants on human health (Brauer et al 2013) and biodiversity. Studies should be continued, studies regarding the increase of imission levels in urban and periurban areas, as a basic element in elaborating a strategy of traffic fluidization, modernizing road infrastructure and diminishing effects by adapting to climate change. Given the gravity of these observed aspects within some areas of Romania, like Bucharest, a study had to be performed, that would follow in time simultaneous evolutions of average values of climate parameters: temperature and pluviosity, in downtown Bucharest, as well as within the periurban of this representative urban congestion.

Material and Method. This paper has two analyses that have as their purpose: study of troposphere response reaction at increasing man-made pressure exerted by transport activities with auto vehicles through correlation of the imissions measurements results with simultaneous monitoring of traffic and analysis of emphasizing the adverse effects of climate change. The data used in these studies are the result of measuring processes in real time, ran with measuring stations that form the monitoring network for air quality located in the Centre of Bucharest and weather stations located both in the center and on the outskirts of Bucharest.

Results and Discussion. In Europe, transport operations represent the second most important source of greenhouse gas emissions (23.4%), after energetic sector (28.9%) (Lepert & Brillet 2009). Pollutant gas emissions are directly correlated to consumed energy.

Mobile sources generate direct greenhouse gas emissions: carbon dioxide (CO_2), methane (CH_4) and nitrous protoxide (N_2O) by burning different types of fuels. Indirect emissions are also generated: carbon monoxide (CO), non-methane volatile organic compounds ($NMVOC_S$), nitrous oxides (NOx), sulfur dioxide (SO_2) and material particles (MP) (Gavrila et al 2013). Road traffic emissions come from internal burn of fuels like gasoline, diesel, liquefied petroleum gas and natural gas (MEWF 2015).

Figure 1 presents road traffic contribution to the total atmosphere emissions, recorded in Europe (EEA 2016). Out of the total emissions coming from transport activities, road traffic has an important contribution to atmosphere pollution by nitrous oxides (NO_X) (33%) and carbon monoxide (CO) (23%).

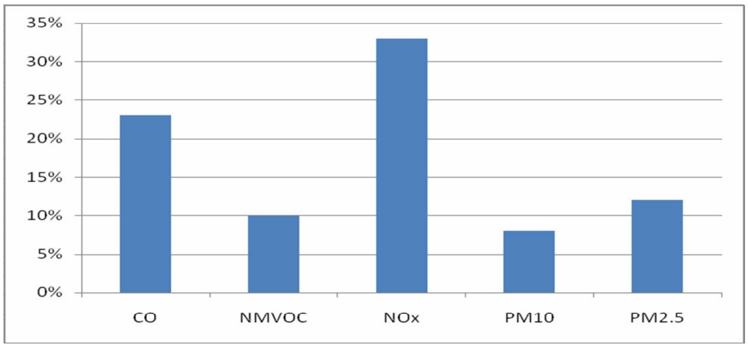

Figure 1. Road traffic contribution to the pollution of the atmosphere.

According to the European Environment Agency (EEA 2016), between the years of 1990 and 2013 the transport sector has accomplished some significant decreases of atmosphere pollutant emissions: carbon monoxide and non-methane volatile organic compounds (both aprox. 83%), nitrous oxides (35%), sulfur oxides (36%) and suspension powders (35% in the case of PM2.5 and 27% for PM10).

According to the National Inventory Report, elaborated by The Ministry of Environment, Water and Forest (MEWF 2015) – Romania's Greenhouse Gas Inventory 1989-2013, greenhouse effect gases emissions have dropped by 64.85% in 2013, in regards to 1989. In Romania, an increase in annual average temperature is predicted to be close to the ones specific to Europe (between 0.5^{o}C and 1.5^{o}C for the 2020-2029 interval), as against 1980–1990. From a pluviometric standpoint, over 90% of the used models estimate an increase in draught periods during the summer, especially in southern ast southeastern areas.

In Figure 2 it can be observed the contribution of different energy sectors to the accentuation of the greenhouse effect. The situation corresponds to total emissions recorded at Romania's level, in 2013 (MEWF 2015). Transport sector occupies 2nd place (19.60%), after heavy energy consumption industries (33.06%) and before manufacturing industries and construction (18.20%).

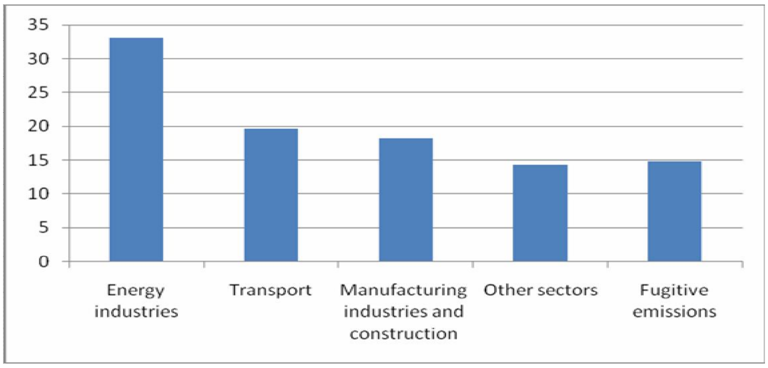

Figure 2. Energy sectors contributing to global warming.

Figure 3 presents an analysis of indirect greenhouse gases variation discharged in the air atmosphere in Romania, in 1989-2013 interval, and to which road traffic had an important contribution. Nitrous oxides emission (NO_x) has continuously decreased, from 559.14 kt in 1989 to 233.48 kt in 2013. Carbon monoxide emission (CO) has not followed the same trend, peaks being recorded in 2000 (3654.66 kt), 2007 (3509.52 kt) and 2003 (3186.52 kt). These peaks can also be linked to the high number of second hand cars purchased in this interval.

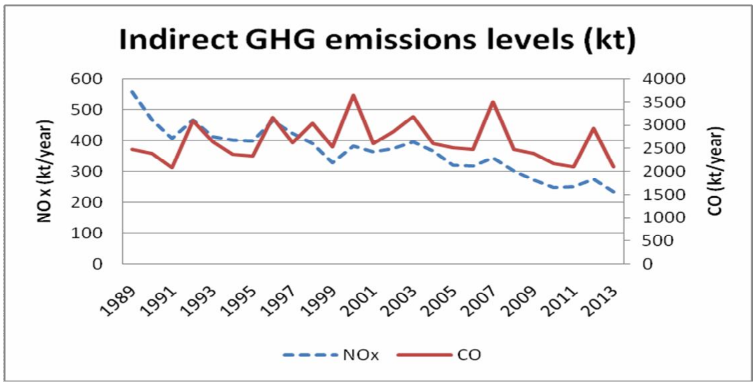

Figure 3. Indirect greenhouse gases emissions.

There is no data referring to the contribution of every type of transport mean to Romania's recorded pollution (Alpopi & Colesca 2010). There is information regarding the contribution of road traffic to climate change by converting to CO_2 equivalent of directly and indirectly implicated pollutants to the accentuation of the greenhouse effect.

Thus, the interval of 1989-1999 is characterized by a pass to market economy, period in which CO_2 equivalent emissions have recorded decreases. Between the years of 2000 and 2013, continuous increases have been recorded of circa 8200 kt CO_2 equivalent in 2000 to circa 14000 kt CO_2 equivalent in 2013. This tendency is determined by the increase of auto vehicles and volume of merchandise transported. The year 2009 was characterized by a slight decrease because of the economic crisis. Road traffic is the source of almost half (48.87%) of the total greenhouse effect gases emissions (MEWF 2015).

According to data provided by The Direction of Driving Licenses and Vehicle Registration, institution that is in subordination of The Romanian Government, national Romanian auto park has summed at the end of 2015, approximately 6.60 million units, a rise of 5.26% compared to the similar period of the precedent year, when it summed 6.27 million units (DDLVR 2015).

Statistic data have shown that out of the total of 6.600.325 vehicles that were driven on national roads at the end of 2015, 1.152.147 were registered in a representative urban congestion for Romania – Bucharest, out of which 956.664 were cars. Table 1 presents the general situation of the auto park in Bucharest, registered at the end of 2015.

Table 1

Auto park structure in Bucharest

Auto type	*Bus*	*Special auto*	*Tractor*	*Cars*	*Utility vehicles*	*Vans*	*Motor-bikes*	*Motor-cycles*	*Others*
Nr.	4.068	11.197	6.379	956.664	133.463	4.476	4.749	15.688	15.463

Out of the total number of recorded vehicles in Romania at the end of 2015, circa 2.56 million had an age over than 12 years, decreasing with 12.31% compared to the same period of 2014. The capital is amongst the first 10 cities, at a European level regarding the number of cars per a thousand inhabitants. In 2015 circa 455 cars to the thousandth of inhabitants were recorded in Bucharest, while at a national level, the grade of motorization was of circa 200 cars to the thousandth of inhabitants. Italy's capital is the best motorized European city, with 649 cars registered to the thousandth of inhabitants. In Paris, for example there are 390 cars to the thousandth of inhabitants, Budapest and Amsterdam are of the most "aired" capitals from a number of cars standpoint (public transport and biking are encouraged).

Evaluating road traffic contribution to the urban troposphere pollution - Case study

Elements that influence pollutant emissions. Emissions resulted from road traffic have overcome the ones resulted from industrial activities. The relative part resulted from auto vehicle transport out of the global emission balance is becoming more and more important in urban congestions (Sanjurjo-Sánchez & Alves 2012). The high pollution potential of this source is because of pollutant emissions that occur at ground level as well as the source's mobility which determines a large pollutant covered surface. Emissions vary based on auto vehicle type, used fuel, the type of engine that comes with the vehicle, working regime, as well as wear and tare of the vehicle.

Six physical elements can influence green house gases emissions: used fuel burn efficiency, green house gases emission associated with used fuel, transport activity size, chosen means of transportation, occupancy level of the auto vehicle and auto park (economic agent) or personal vehicle renewal frequency. For developed countries, where road traffic is dominant, it is expected that green house gas emissions resulted from this source to overtake ones resulted from urban challenges (Nwanya & Offili 2013). In addition, Romania's road transport sector is directly influenced by inadequate infrastructure, a pretty old auto park and with a cilindric capacity a lot over necessity and the lack of an adequate strategy for traffic fluidization. These factors will determine an accentuation of global warming.

Experimental study. During the experimental study, we evaluated the impact of pollutant emissions generated by auto vehicles on imissions recorded in an area with intense road traffic – downtown Bucharest municipality. Bucharest city is the highest urban congestion in Romania, its population is 1.943.981 (BMMO 2015), (a density of approximately 8.168 inhabitants/sqkm), which represents circa 9% of Romania's total population and over 16% of the country's urban population.

Data regarding downtown imissions were taken from the National Agency of Environment Protection, which has in its administration The National Air Quality Monitoring Network (NAQMN). Bucharest is a component of region 8 from NAQMN (Bucharest – Ilfov).

The network is formed out of 8 fixed air quality monitoring stations, of different categories, to be found in the urban area as well as its adjacent area.

The stations are of traffic type (Cercul Militar al Armatei, Mihai Bravu), industrial (Drumul Taberei, Titan, Berceni) and peripheral (Balotesti, Magurele and Lacul Morii). Every station is equipped with real time measuring analyzers for the following pollutant concentrations: $NO/NO_2/NO_x$, CO, SO_2, O_3, benzene, suspension particles, as well as meteorological sensors.

The air quality monitoring station with which the objectives of this paper were achieved is of a traffic type (it follows the contribution of road traffic to atmosphere pollution), it's located downtown, close to Piata Universitatii, on 32-34 Calea Victoriei (Figure 4).

Cuantifying day emissions generated by road traffic have been done with the help of a special software IMPACT-ADEME. This software allows estimating the consumed fuel quantity and the main pollutants resulted from a flow of auto vehicles for which the distribution is known and in the conditions of an also known road infrastructure. Direct indicative measurements have been done in a point located at the limit area of traffic contact – 24 Nicolae Balcescu blvd., on an intense ridden artery, close to the big Piata Universitatii intersection, implicitly close to the imissions measurement station. The methodology used by the Romanian Auto Registry (alternate measurements on both driving directions) has been respected.

Figure 4. Traffic type station.

Correlation studies. The study of troposphere reaction to an always increasing anthropic pressure determined by road transport activities consisted of correlating results from imissions measurements with those of simultaneous road traffic monitoring.

Figures 5 and 6 present the overlap of Nitrous Oxides (NO_x) and Carbon Monoxide (CO) emissions evaluated as resulted from road traffic, on N. Balcescu blvd., close to the big intersection at Piata Universitatii, with imissions measured with the help of the traffic station.

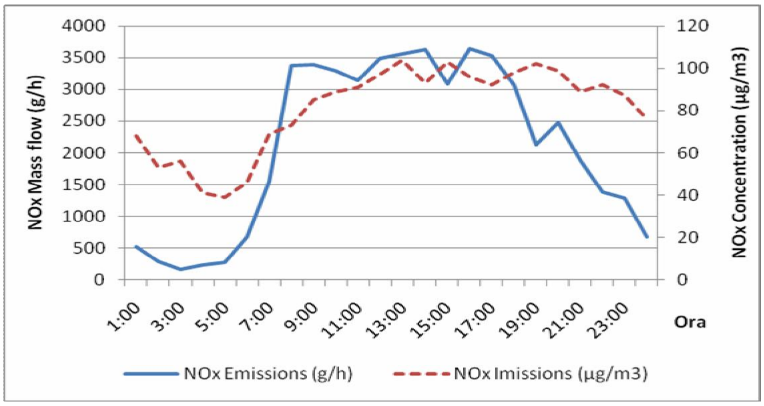

Figure 5. NO_x emissions - imissions.

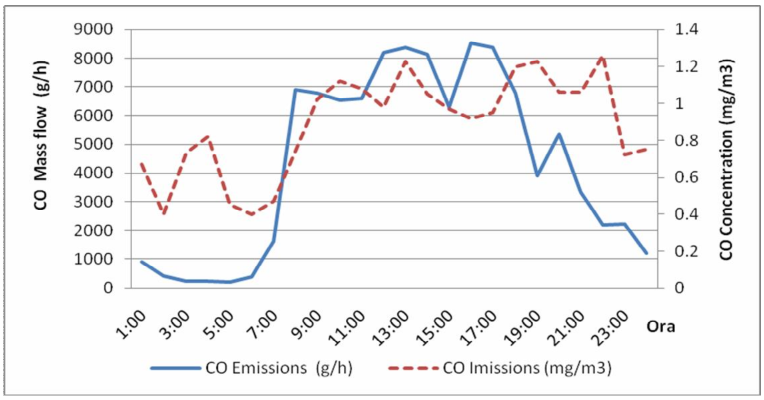

Figure 6. CO emissions – imissions.

In order to analyze the relationship between the *emissions* prognosed to be resulted from road traffic and *imissions* measured and recorded in the study area, the “r” corelation coefficient between the two parameters (x and y) was calculated, using the following relation (Hütte 1995):

$$r = \frac{S_{x,y}}{S_x * S_y} = \frac{S_{x,y}}{\sqrt{S_{x,x}} * \sqrt{S_{y,y}}} = \frac{\sum_i (x_i - x_{av})\ (y_i - y_{av})}{\sqrt{\sum_i (x_i - x_{av})^2} * \sqrt{\sum_i (y_i - y_{av})^2}}$$

in which x_{av} and y_{av} are average day values for the two parameters.

The correlation coefficient between *NO_x emissions* evaluated as resulted from road traffic and respectively *NO_x imissions* is ***0.772***, which means that *the two analyzed parameters are directly correlated*.

The correlation coefficient between *CO emissions* evaluated to be resulted from road traffic and respectively *CO imissions* is ***0.649***, which means that *the two analyzed parameters are directly correlated.*

Results interpretation. Following the processing of measurements results and analysis the following conclussions have been taken:

- imission measurements corresponding to NO_x and CO pollutants (representative for road traffic) concentrations in the atmospheric air have emphasized the existence of a direct conditional link in relation to hourly traffic flows;
- indirect green house gas emissions estimated as resulted from road traffic represents the main pollution source in the analyzed area;
- imission values fluctiations can be the effect of some disruptive factors intervention, which have a random character namely: unitary emission level (in strong connection with the auto traffic structure and with the degree of wear and tare of the vehicles), circulation flow, modifying street architechture and local meteorology which influences pollutants dispersion;
- the positive and pretty high values of correlation coefficients are due also to buildings in the area, characterized by a high plane and vertical development. These prevent pollutant dispersion and atmosphere autopurification (the canion effect).

Climate parameters evolution in urban and periurban areas – Case study. Given the contribution of road traffic to the accentuation of the greenhouse effect, a study has also been performed, that presents the evolution of main meteorological parameters associated with global warming, for the same urban congestion – Bucharest. The most used indexes for characterizing a climate have as variables temperature (T) and pluviosity (P) (Popescu & Popescu 2000). The pluviosity is defined as the average rainfall, expressed in mm, fallen in a certain place.

Even if Bucharest is located in a temperate climate area, it is affected by continental air masses, coming from neighbouring areas. The annual temperature average in this big urban congestion is about 10 – 11^{o}C (BMMO 2015). Weather stations from which the measured data was processed (Birsan & Dumitrescu 2014) are located in the city's downtown (Bucharest – Filaret) as well as periurban area (Bucharest – Afumati) (Figure 7). The periurban is the result of continous urbanization, this is the reason why it can be considered an urban – rural interface, with influences from both areas.

Figures 8 and 9 present the results of statistical processing of obtained data from continuous measurements with daily time steps, performed during the 1994-2013 interval, for average temperature and pluviosity weather factors.

1. Bucharest - Filaret
2.Bucharest - Afumati

Figure 7. Localization of weather stations.

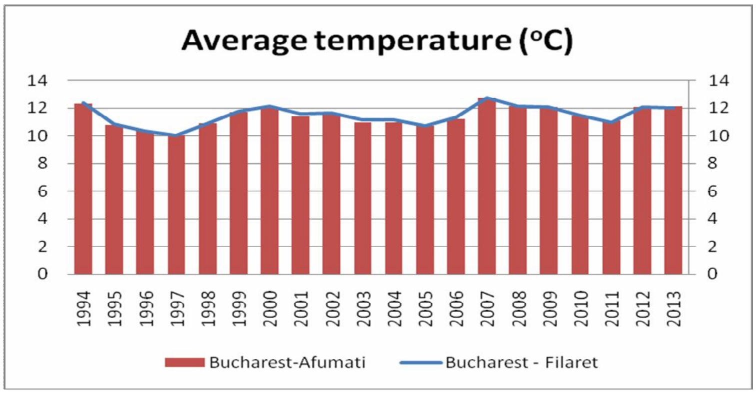

Figure 8. Average annual temperature variation.

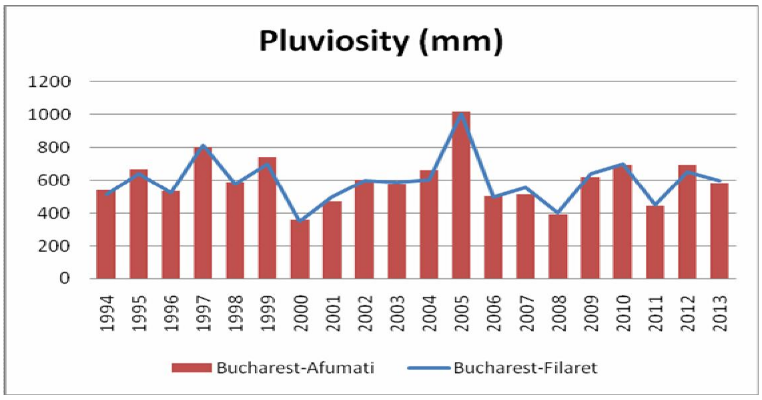

Figure 9. Rainfall quantity variation.

From analyzing the measured data and interpreting the two synthesis graphics the following were concluded:

- the allure of average temperature curves from the two stations is close; the values were slightly higher in case of the station located downtown (multiple thermic energy sources exist); the relatively small differences can be explained also by high intensity traffic which characterizes both areas: downtown area and E85 european raod which passes through Afumati and ties Bucharest city of Urziceni;

- we can see a slight tendency of annual average temperature increase on both stations; in the 1998-2005 interval the values have come close or even surpassed 11 ^{o}C (ex: year 2000; Filaret – 12.12 ^{o}C and Afumati-12.09 ^{o}C); starting with 2006 a proximity to 12 ^{o}C was recorded (the peak is represented by 2007 with an annual temperature average of 12.75 ^{o}C on both stations);

- under the aspect of rainfall regime, we can observe a decreasing tendency in annual rainfall; the highest value was recorded in 2005 and was of 1002.2 mm at Filaret and 1020.4 mm at Afumati; the poorest year in rainfall was 2000 with 352 mm at Filaret and 360 mm at Afumati;

- slightly higher rainfall quantities in the periurban area are also determined by strong air masses instability which characterize this area.

Conclusions. Urbanization and road traffic intensifying determine local or episodic situations of strong exposure to different pollutants; representative are Nitrous Oxides (NO_x) and Carbon Monoxide (CO).

By correlating the results of indicative imission measurements with those of simultaneous road traffic monitoring and pollutant dispersion parameters influence, the contribution of road traffic to the urban troposphere pollution was declared as important.

The effects of climate changes are felt also in Bucharest, in the urban as well as periurban area, reason for which adopting a local strategy to adapt to global warming is imposed.

The emergence and development of new residential centers, in areas neighbouring Bucharest, was not followed by a corresponding modernization of the road infrastructure.

Urban development has a strong European dimension. Expanding cities is determined also by external factors like demographic changes, the need of mobility and climate changes.

The cities vulnerability to climate change impact must determine local and central authorities to rethink the urban design and management, as well as encourage, through special programs, auto vehicles purchases that use non pollutant, substitute energies.

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