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Assessment of interactions between quality of urban landscape and human health, the case study in a Central European city

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Abstract: Due to important changes of urban landscape under rapid urbanization, the elaboration of a systematic diagnosis for assessing qualities of urban environment and health is urgently needed in order to develop then, a sustainable management of cities that could preserve the integrity of human life. For the last decade, industrial and domestic heating activities as well as, increases of vehicle use and road traffic are considered as the main anthropogenic sources of air pollution that had worsened considerably air quality in most large European cities, including Poland. Accordingly, numerous air quality assessment systems have evidenced that episode of exceeding levels of particulate matter < or equal to 10 µm (PM_{10}) and nitrogen dioxide (NO_2), the main pollutants associated with traffic emissions have been commonly observed in Polish urban areas and were shown to be associated with the occurrence of asthma in sensitive groups of populations such as children. Assessing consequences of anthropogenic crisis linked to road traffic on childhood asthma requires the need of elaborating both risk and vulnerabilities assessment methods as well as, methods of risk-management in order to reduce health-risk and restore a better living for exposed population. The present study deals with the question of childhood asthma-risk linked to pollutants PM_{10} and NO_2 in 3 different areas of Cracow (central and eastern parts with high traffic, residential south-eastern part with low traffic). Levels and spatial dispersions of PM_{10} and NO_2 for the period 2001-2005 within these areas were estimated by using the specific traffic air dispersion model CALINE4; daily measurements of both pollutants from fixed air quality monitoring stations respectively located in each area and meteorological parameters as well, were taken into account. In order to calibrate input parameters such as pollutants and meteorological parameters in CALINE4, a preliminary study of Cracow urban ecology and landscape has been conducted. Preliminary results show that the urban landscape and urban ecology influence the geographical repartition and concentration levels of traffic air pollution around road. Indeed, density, structure and nature of urban network, meteorological conditions and place of living of sensible children are factor that may play in final, a role in asthmatic children exposure to air pollutants. Levels and spatial distribution of PM10 and NO2 concentrations within selected areas show the predominance of pollution from traffic in the last decade and appear to be dependent on both air mass stability classes and 2 main wind directions (East, West). The most vulnerable areas to air pollution emitted by traffic are found respectively, in the narrow high dense urban network associated with heavy traffic close to the historical downtown, near roads located in East-West direction of the wind, near the linking roads of the two downtowns of Cracow (The historical downtown and Nowa Huta) and near the bypass. Conversely, the characteristics of main low dense urban network, large roads, setting of residence areas far from the roads constitute a non-negligible landscape advantage in the protection of air quality. Large vegetation areas found in the three studied areas may also play the role of an ecological buffer of air pollution from traffic, especially in the most vulnerable areas. For instance, the green belt "Planté", rare in other European downtowns and settled around the historical downtown, may protect this heritage and crowded area from air pollution emitted by high dense traffic in Alea Krasinskiego. In Nowa Huta, the second "downtown" of Cracow, are found preserved large vegetation areas "Bognié" near the residential areas and in suburbs such as Prokocim district, are located large vegetation areas near the main busy roads that may be also involved in regulating air pollution from

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road traffic. This great advantage of ecological buffer in the landscape of Cracow could be used by planners to reorganize transportation in Cracow and improve air quality in this city.

Key words: urban air pollution, nitrogen dioxide, particulate matter, childhood asthma

Introduction

For the last decade, industrial activities, increases of vehicle use and road traffic along with heating processes are considered as the main anthropogenic sources of air pollution that had worsened considerably air quality over most European cities. Accordingly, numerous air quality assessment systems have evidenced that episodes of exceeding levels of air pollutants including, nitrogen dioxide (NO_2) and particulate matter ≤ 10 μm in diameter (PM_{10}) have been commonly observed and were shown mainly occuring in urban areas (EEA 2007, 2009). World Health Organization (WHO) has estimated also, that more than half of the worldwide urban population is often exposed to high air pollution levels and about 800 000 premature deaths (4 to 8% of annual deaths) can be attributed each year to urban air pollution (WHO, 2002). Estimates from the European Environment Agency (EEA) indicate also that from 1990 to 2004, up to 43% of the European urban population was exposed to PM10 concentrations exceeding the EU air quality limit value (EEA, 2007). Because air pollution appears obviously concentrated at certain locations and results from several origins, heterogeneity of air pollutant dispersion related to several local sources of emissions has to be spatially discerned over urban areas. Such spatial variability in ambient air concentrations are quite of importance as it may lead to a disparity of both short and long term exposure of population to air pollutants and may generate disparities in health risks between closed areas of a city. Health effects of air pollution has been evidenced in many Western and Northern European countries through numerous epidemiological studies and have linked in most cases, the occurrence of respiratory and cardiovascular diseases with air pollutants such as NO_2 and PM_{10} (Schwela, 2000; Katsouyanni et al., 2001; Bessagnet et al., 2005; Kukkonen et al., 2005). Severe health effects of these pollutants on asthma, Chronic Obstructive Pulmonary Disease or on cardiovascular risks have also been reported in Poland (Jędrychowski, 1997, 1999, 2000; Lubiński et al., 2004, Rabczenko et al., 2005) and corroborate with the most elevated concentrations of particulate categories including PM10 in this country in comparison with measurements in 25 urban areas of 6 CEE countries (from Central European Study on Air pollution and Respiratory health (CESAR), Houthuijs et al., 2001). Coal combustion which represents the main energy carrier in Poland for electricity and heat production were considered as the main emission sources of PM_{10} and sulphur dioxide (SO_2) from the 50’s to the 90’s. Due to the introduction of Polish and European environmental laws during the 90’s, emissions from large power and cogeneration plants or other industrial facilities were controlled and efficiently lowered by various types of air-pollution control devices and new mode of production. Despite this great improvement, emissions from small residential units using the poorest and the cheapest types of fuel or even wastes for heating purpose, still remain today an uncontrolled source of pollutant in a large number of Polish cities (Pacyna et al., 2007). Furthermore, due to a constant rise of density and uses of vehicles in Poland, traffic is becoming as in many European cities, the new main local source of pollution that contributes to the overall state of pollution and leads to an alteration of air quality. Extreme episodes of air pollution result not only from sudden increases of emissions from co-existing industrial, domestic and traffic sources but also depend on factors such as topography, narrow and deep street canyons that favour for a given meteorological condition, the accumulation of pollutants. Unfavourable local meteorological conditions (very low temperature, low wind speeds, thermal inversions) are also implied in the occurrence of air pollution events. For example, most of winter episodes in Europe and in Poland caused by coal (e.g. Cracow, Juda-Rezler, 2006; Houthuijs et al., 2001) or wood combustion for heating (e.g. Oslo, Kukkonen et al., 2005), as well as increased traffic emissions were shown to be due to unfavourable winter meteorological conditions. In Polish cities, local sources of PM_{10} that include the coal-fired boilers of public and industrial power generation, cogeneration and district heating plants, as well as individual low-power boilers were shown to be highly dependent on changes in air temperature, insulation, force and direction of winds and precipitation (Wojdyga, 2008). Taken together, understanding the close relationships between patterns and uses of urban landscape, the meteorological conditions and the state of air pollution and their resulting human health impact, requires to elaborate and validate an integrative and multidisciplinary approach in order to assess a sanitary risk. This is particularly true for asthma, a respiratory disease which displays a high and a prevalence in urban areas (4 to 10% of residents are affected) all over Europe, including Poland and which was shown to be associated with PM_{10}, NO_2 and SO_2. Health impacts of such pollutants on the sensitive group of asthmatic children require urgently the development of methods that allows to evaluate the biological risks linked to air pollution. This method should be able to analyze and integrate the complex interactions developed between the diverse anthropogenic sources of pollutants and their local concentrations, the environmental parameters involved in the dispersion of these pollutants and the biological parameters of exposed population. The combination of air dispersion models adapted to industrial, domestic or traffic sources with Geographic Information System (GIS) should constitutes a relevant method to characterize the interactions developed between all these parameters at various spatial and temporal scales.

Using a dispersion model, the aim of our study is to assess locally the spatio-temporal variability in PM_{10} and NO_2 concentrations in the representative Central European city of Cracow, by considering the anthropogenic origin of pollution (traffic in a first step), meteorological and urban landscape parameters that are involved on the occurrence of low or high levels of these 2 air pollutants. Results should also allow us to delineate ultimately, spatial patterns of population exposure to PM_{10} and NO_2 according to the 3 urban sectors we selected and to relate some specific health effects, childhood asthma more specifically, to this spatio-temporal distribution of exposure.

Anthropogenic sources of pollution, air pollution and urban landscape in Cracow

Agglomeration of Cracow (755.000 inhabitants) located in South-East of Poland with a surface area of 327 km^2, displays a density of population of 2300 inhabitants/km2 (Central Statistical Office of Poland, 2009). The city, split by Vistula river is characterized by a continental weather (cold and dry winter, warm and rainy summer) with an average of precipitation of 367 mm and of temperature of 9.4 °C. Surrounding by Carpathian mountains in South and by Sudetes mountains in North, Cracow is influenced by a particular topographical situation that generates often stable condition of air masses which in final, lead to a weak dispersion of pollutants. As observed in many Polish cities, air quality was affected in Cracow by several phases of anthropogenic activities that includes first, strong emissions of SO_2, PM_{10}, NO_2 due to a high development of industrialization and urbanisation (years 50s-90s) and then, a drastic reduction of SO_2 and PM_{10}, due to economical structural changes and restrictive environmental laws (years 90s to nowadays) (Kühne, 2000-2001; Lach et al., 1994-1995). Due to the close location to the highly industrialized Upper Silesian and Ostrava regions, Cracow is submitted to these regional sources of pollutants that are transported to the city under certain meteorological conditions. Surrounding local sources of pollutants such as, steelwork (Nowa Huta, the second largest steel plant in Poland) and thermal power plants contribute also, to the degradation of air quality over the city. In the meantime, raised PM_{10} and NO_2 levels from road traffic were observed concomitantly with the growing development of the car fleet (Brodowska et al., 2003; Pakula et Wicherek, 1988). Furthermore, coal-burning which is used for winter domestic heating purpose in the densely populated old districts of the town, represents one of the most dominant source of pollution during this season. As described for other European cities, air quality in Cracow is also influenced by growing vehicular traffic that occurs between peripheral areas, the historical centre and the Nowa Huta district (Brodowska et al., 2003; Pakula et Wicherek, 1988). Resulting poor air quality in Cracow was shown to be related consequently, to an increase of daily mortality as well as to increases of prevalence and of exacerbation of respiratory diseases, including asthma (Indulski et Rolecki, 1995; Jędrychowski et al., 1997; Jędrychowski, 2000). In such case, one of sensitive groups of population represented by asthmatic children were shown to be particularly affected by contrasted areas of pollution in Cracow (Jędrychowski et al., 1997, 2003; Szczeklik et al., 2001). Importance of anthropogenic sources of particulate and gaseous pollutants in the events of pollution can be partly drawn from the PM10 and NO2 measurements from a network of 8 fixed-air quality monitoring stations (Polish Voïvodeship Environment Protection Inspectorates) dispersed in Cracow (from Stations 0 to 7, fig. 1).

Complete daily measurements of PM10 and NO2 performed during 1999-2008 were collected from Stations

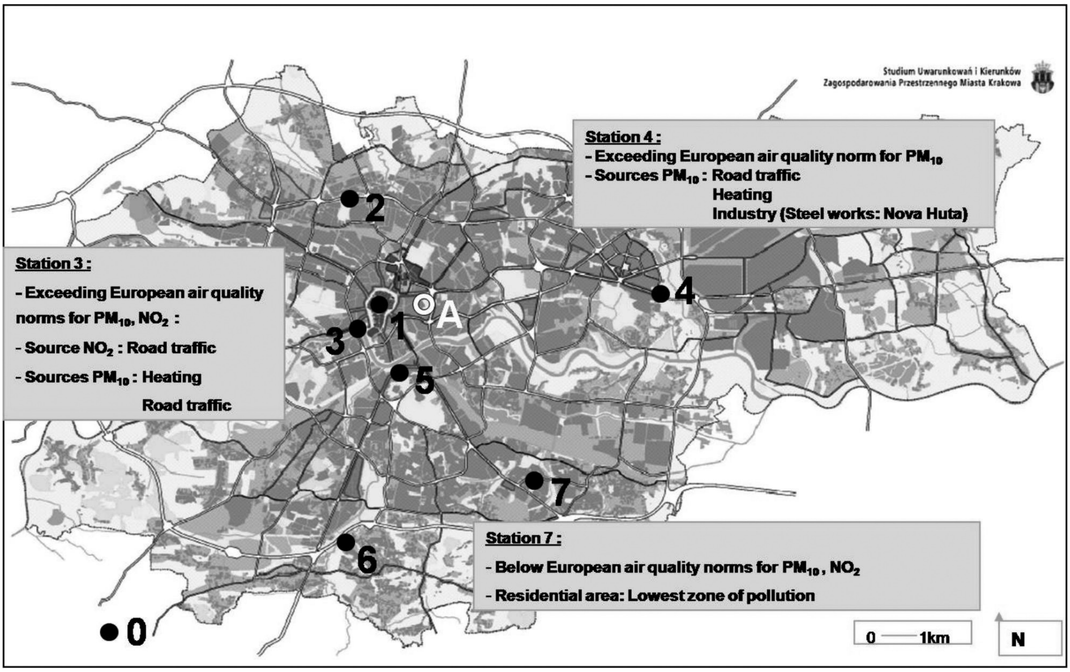

Fig. 1. Location of air quality monitoring stations in Cracow (from Station 0 to 7)
Data of Department of Cartography and Geographic Information Systems, Spatial Management Department, Cracow city council (I. Jędrychowski ; Pracownia Kartografii i Systemów Informacji Przestrzennej, Biuro Planowania Przestrzennego Urządu Miasta Krakowa)

3, 4, 7. For each air monitoring station, annual concentrations of both pollutants were calculated from the average of daily values of each year over the period 1999-2008 or 2000-2001 (for Station 7). Results were then expressed as percentage of thresholds of annual EU air quality norms, respectively: 50μgm^{-3} for PM_{10}; 52μgm^{-3} for NO_2 in order to assess exceeding levels of both pollutants. Anthropogenic sources of PM_{10} and NO_2 are indicated for each station. Local meteorological parameters were collected in both Station 4 and the meteorological station A.

In this study, we have focused however, our analysis on complete daily PM_{10} and NO_2 measurements performed during 1999-2008 in Stations 3, 4, and on those collected from Station 7 only during 2000-2001 (measurements were discontinued). Provided PM_{10} mass values were determined on filter-based samples following 24-hrs collection and analysed following beta radiation absorption as, NO_2 concentrations were determined by chemiluminescence using Thermoenvironmental Instruments analyzers. Characteristics of the 3 selected zones around these stations which are representative of urban sectors of Cracow are as follow: 1) a central sector situated in a dense urban network around Station 3, which is located near the historical centre and in the middle of a main traffic road (Alea Krasingskiego) with a high traffic volume. This sector is not only, mostly exposed to traffic emissions but also, is influenced by domestic heating in winter (Juda-Rezler, 2006) ; 2) an eastern sector with a high urban network density located on the outskirts of Nowa Huta and around Station 4. This sector is influenced by the proximity of a large steelwork, as well as by road traffic. Through coal burning, domestic heating is also participating as a source of pollution; 3) a residential south-eastern sector located in the low density outskirts of Prokocim that include Station 7. This sector is under the influence of both low road traffic and domestic heating sources. Considering PM_{10}, the central part of the city (Station 3) and the Nowa Huta district (Station 4) are characterized by a threshold that overtake each year, respectively from 140 to 260 % and from 120 to 160 % the permissive limit of annual PM_{10} air quality norm whereas, this threshold remained constantly much below this norm in Station 7. A highly dense traffic road located close to stations 3, 4 and/or house heating represent mostly the anthropogenic sources responsible for the introduction of these 2 pollutants at elevated levels, although the influence of the steelwork near Station 4 cannot also be neglected. In contrast, comparison of NO_2 thresholds between three stations revealed that only, the historical central part of the city (Station 3) displays levels that over exceed by 130 % the annual EU norm of this pollutant. As NO_2, is considered to be a marker of traffic pollution, the exceeding NO_2 values in station 3 may be attributed to a high volume of car emissions that may prevail rather more than in station 4. The extremely low percentage of EU norms for both pollutants in Station 7 indicates that this urban area constitutes the one of the lowest polluted part of Cracow. Prevailing meteorological conditions that play locally an important role in the dispersion of these pollutants and the generation of polluted events were determined by applying principal component analysis (PCA) on PM_{10}, NO_2 and temperature, precipitations, wind speed and direction parameters. PCA analysis was performed on these latter parameters collected during the appropriate 1999-2008 period, either from Station 4 or from Station 3 and the meteorological station A (Institute of Geography and Spatial Management, Jagiellonian University). Although not treated here, SO_2 considered as a marker of combustion of coal rich in sulphur (industrial or domestic sources) was also included in the PCA analysis in order to assess the influence of meteorological parameters on the levels of these 3 unhealthy urban pollutants. As represented in table 1 and not considering wind direction, 3 main groups of pollution can be distinguished depending on meteorological parameters and affect similarly, local levels of pollutants in Stations 3 and 4. In the first group, the strongest PM_{10}, NO_2, SO_2 levels were reached under negative temperature and at both lowest wind speed and precipitation. The second group, characterized by strong decreases of PM_{10} and SO_2 and to a much less extent of NO_2, is associated by a strong rise of temperature, a moderate rise of wind speed and an increased precipitation, at least for Station 4. Finally, higher precipitation associated with higher temperature and wind speed constitute the third group of pollution in which, PM_{10}, SO_2 , NO_2 remains at their lowest levels. In contrast to these results, wind directions that prevail in the 3 groups of pollution differed completely from Station 3 to Station 4 and this may due characteristics of urban topography and of green areas surrounding each zone.

Table 1. Principal component analysis of daily concentrations of PM_{10}, NO_2, SO_2, temperature, wind speed, wind direction measured at 12 hr and precipitation (2000-2008)

	PM_{10} (μgm^{-3})	NO_2 (μgm^{-3})	SO_2 (μgm^{-3})	Temperature (°C)	Wind Speed (ms^{-1})	Wind Direction (°)	Precipitation (mm)	State of Pollution
	24hr	24hr	24hr	24hr	24hr	At 12hr	24hr	
Station 3	166	80	48	-1.5	0.8	60-270 ENE-W	0.3	High
Station 4	109	46	35	- 0.6	0.6	156-287 SSE-WNW	0.3	
Station 3	60	74	17	13	1.4	90-135 E-SE	0.04	Medium
Station 4	27	30	11	6	1.9	240-296 WSW-WNW	1	
Station 3	45	61	17	9	1.8	240-300 WSW-WNW	1.8	Low
Station 4	49	29	13	12	0.7	169-189 SSE-SSW	1.8	
From : data given by the Voďvodship Inspectorate for Environmental Protection of Cracow and the Institute of Geography and Spatial Management of Jagiellonian uUniversity of Cracow								

PCA analysis was performed on pollutant and meteorological data collected either from Station 4 or Stations 3 and A. Taken together, these results show that under a certain combination of temperature, wind speed and precipitation, as well as some specific wind direction, residents are respectively exposed to high, medium or low levels of PM_{10}, NO_2, SO_2 that might in return, affect their health.

Assessing urban pollution using air dispersion model: the example of CALINE4

Urban air quality is generally assessed through measurements performed routinely at fixed station located at specific place of a city. Although, this monitoring process provide valuable data, it doesn't give any insights on how pollutants are dispersed and are spatially distributed around monitoring stations, as well as how urban topography, anthropogenic sources and meteorological parameters can influence levels and distribution of pollutants. Use of air dispersion models adapted to anthropogenic sources of pollutants can fulfil this gap and might allow to estimate locally, the spatial repartition of particulate or gaseous pollutants. For instance, plumes of pollutant emissions can be estimated using the air dispersion model Aermod whereas, the model CALINE4 can be apply to estimate more specifically, road traffic emissions of pollutants. As this latter anthropogenic source is an increasing source of pollution due to the development of car fleet, we first chose to apply CALINE4 (CALifornia LINE Source Dispersion Model, version 4) in order to assess the dispersion of both PM_{10} and NO_2 from this anthropogenic source within the surroundings of Stations 3, 4, 7 (fig. 2). Because lack of complete data before 2001 and beyond 2005, various parameters restricted to the period 2001-2005 were introduced into CALINE4, as already described by Méline et al., 2011. Briefly, estimation of PM10 and NO2 concentrations emitted in 1 hour by road traffic was assessed by CALINE4 in 43 intersections distributed among the 3 stations areas (fig. 2).

Six meteorological cases (A-NE, A-SW, B-NE, B-SW, C-NE, C-SW) represented in table 2 were furthermore determined from Pasquill-Gifford stability classes elaborated meteorological parameters (Pasquill, 1974) and associated with 2 main North East and South West wind directions. The 3 Pasquill-Gifford stability classes designated A, B, C characterize the conditions of atmospheric stability that play an important role in the dispersion of pollutants. The Pasquill-Gifford stability class B, characterized by both a moderate instability of air masses and dispersion properties is found to be the most frequent one (50%) while, frequencies of class A (extreme instability of air masses with large vertical/horizontal dispersion) and C (slight instability of air masses with weak vertical/horizontal dispersion) remain low (respectively 5 and 10%).

Table 2. Elaboration and characterization of meteorological cases

Meteorological case	Daytime Pasquill-Gifford stability class (A, B, C)				
	Temperature (°C)	Solar elevation angle (°)	Daytime cloud cover (8/8)	Wind speed (ms^{-1})	Direction of wind (°)
A-NE	[25 - 26]	> 60	4/8	1	68-110
A-SW	[25 - 26]	> 60	4/8	1	242-271
B-NE	[12 - 14]	]15 ; 35]]35 ; 60]	[4/8 ; 7/8] [5/8 ; 7/8]	1	96-103
B-SW	[12 - 14]	]15 ; 35]]35 ; 60]	[4/8 ; 7/8] [5/8 ; 7/8]	1	268-275
C-NE	[10 - 14]	]15 ; 35]]35 ; 60] > 60	[4/8 ; 7/8] [5/8 ; 7/8]	2	81-90
C-SW	[10 - 14]	]15 ; 35]]35 ; 60] > 60	[4/8 ; 7/8] [5/8 ; 7/8]	2	276-286

From: PASQUILL F., 1974 ; STUETZ R., 2001

From: data given by the Voďvodship Inspectorate for Environmental Protection of Cracow and the Institute of Geography and Spatial Management of Jagiellonian University of Cracow

The meteorological cases were elaborated using meteorological data from both Station 4 and Station A from the period 2001-2005. These meteorological cases are based on the combination of Pasquill-Gifford stability class (A, B, C) defined by temperature, solar elevation angle, cloud cover, wind speed parameters and 2 main wind directions, North East and South West (NE or SW). Pasquill-Gifford stability classes A, B, C are characteristic of conditions of atmospheric stability that influence the dispersion of pollutants.

Traffic density and road network data provided by the Public Infrastructure and Transportation Service of Cracow (ZIKiT– Zarzad Infrastruktury Komunalnej i Transportu w Krakowie), as well as from our own investigation, were collected from the 43 crossroads. For this latter purpose, we recorded the number of vehicles of each category (cars, trucks, motorcycles, buses) at each road linked to the 43 crossroads, by counting vehicles every 15

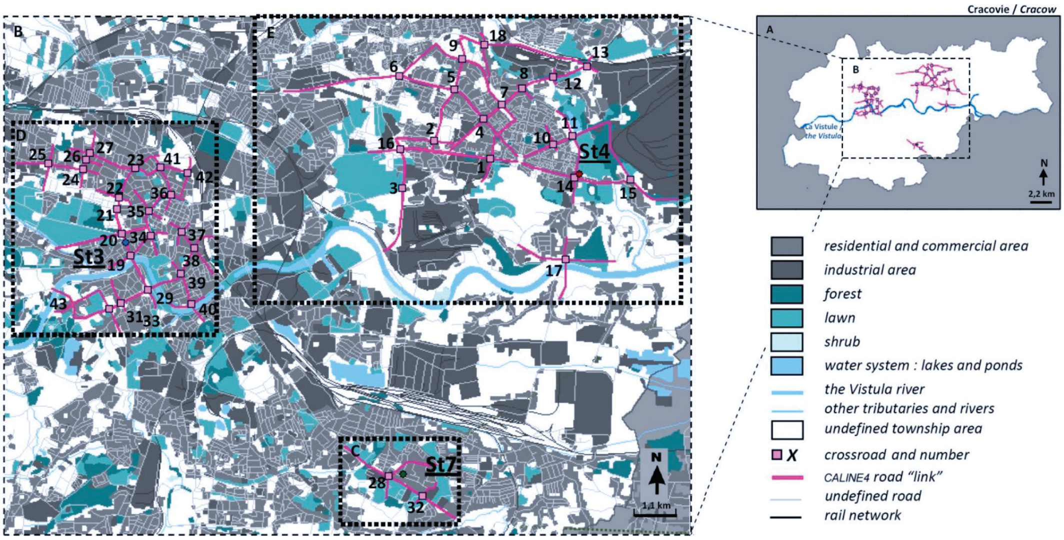

Fig. 2. Location of the 43 crossroads and corresponding roads (B), distributed within surrounding areas of Stations 3 (D), 4 (E), 7 (C) and used by CALINE4 to estimate PM_{10} and NO_2 emitted in average, in 1 hour over the period 2001-2005 by road traffic in Cracow (A)

minutes from 1.30 PM to 4.30 PM (rush hour) and during several days in May, chosen randomly from 2001 to 2005. Determination of an average number of vehicles per hour (all vehicle categories included) was then calculated for each of the 43 crossroads and results show that, the highest numbers (≥ 3500 vehicles/hr) were reached at crossroads 19, 20, 21, 22, 23 (peaks of > 5000 vehicles/hr at crossroads 19, 20) close to Station 3 and in the major road Aleja Krasinskiego. High number of vehicles ranging from 3000 to 3500 vehicles/hr was also observed in crossroads 4, 5, 6 and 16 (4000 vehicles/hr) in the Nowa Huta- Station 4 district. This location corresponds to busy roads that connect the Nowa Huta sector to the central parts of Cracow or that bypass these parts of the city (see Méline et al., 2011). Other crossroads, including those located near Station 7 (28, 32) were found however, to display a much lower traffic density (from 1000 to 3000 vehicles/hr). Additionally to traffic density, a composite emission factor (g/mile) that represents the quantity of pollutants emitted per unit of distance was introduced to CALINE4 and calculated from a set of parameters (vehicle class, age, fuel type, motor operating mode, average speed of vehicles) and meteorological conditions. The deposition velocity and deposition settling of PM_{10} and NO_2 were settled respectively to 0.18 cm/s and 0.1 cms^{-1} and the photolysis rate constant which, estimates the photochemical reactions between NO_2, NO and O_3, was fixed to 0.004 s^{-1}. All others urban characteristics (georeferencing, road width and height, type of urban infrastructure and urban network density) of the 43 crossroads and their adjacent roads (167 roads) were also included into CALINE4. Estimation of green areas (forest, lawn, shrubs) surrounding the 3 air monitoring stations was performed and introduced into the GIS, as such areas can play a role in the dispersion of road traffic pollutants. Study of the modelling zone of Station 7 shows that this area is surrounded by mostly lawn that represents 24% of the total surface (fig.2) whereas, the zone of Station 3 is linked by its western part, to a mixed forest and lawn areas that represent respectively 9.5 and 14% of whole modelling surface. It should be pointed out that, a green belt "Planté" surrounds the eastern part of the high dense road traffic Alea Krasinskiego. The zone of Station 4 is characterized by a low percentage of both forest and lawn areas (respectively, 5.2 and 11%) but with a main large area (Bognié); all these areas are not contiguous to main busy roads (fig. 2). In CALINE4, the background pollution was determined for each modelling area by calculating the average of annual averages of PM_{10} and NO_2 concentrations (2001-2005) measured at each air monitoring station. However, as Station 3 is located in a heavy traffic road, low values measured at adjacent Station 1 in the historical centre were used as the background value for this station. It should be pointed out, that the large difference of concentrations observed between Stations 3 and 1 suggest that the green area "Planté" which separates the 2 zones, may buffer the pollutants originating from station 3. Background values of PM_{10} were respectively 47, 52, 44 μgm^{-3} in areas of Stations 3, 4, 7 and equal to 30 μgm^{-3} for all areas, when NO_2 background were calculated. Taking into account of all introduced parameters, CALINE4 dispersion modelling was then performed on a support grid constituted by a regular mesh of 50 m of longitude and latitude. Mean hourly concentrations of PM_{10} and NO_2 were finally assessed for each meteorological case and depending on NE and SW wind direction for the period of 2001-2005. Estimated concentrations of both pollutants were integrated into GIS in order to elaborate layers of pollutant information, as described by Méline et al. 2011.

Estimation of road traffic PM_{10}, NO_2 concentrations and dispersion by CALINE4

In figure 3, is illustrated one example of the representation of PM^{10} concentration estimated by CALINE4 within the 3 areas of Stations 3, 4, 7 and under the meteorological case B and NE wind direction. In such case, elevated PM10 concentration were found in the area of Station 3 (maximum 57 μgm^{-3}) and reached a higher level in the area of Station 4 (maximum 68 μgm^{-3} at crossroad 16). In contrast, estimated concentration in the area of Station 7 was low and close to those of the PM_{10} background pollution. These results are for the most part in agreement with the traffic density calculated for the crossroads within the 3 areas, although with a higher density of traffic near Station 3, a higher PM_{10} concentration should be expected and superior somewhat, to the concentration estimated within area of Station 4 which displays a less dense traffic. Orientation of road network (parallel or perpendicular to the wind direction), that favours removal or the trapping of PM_{10}, might be at the origin of this difference. PM_{10} concentrations were also assessed by CALINE4 under the meteorological cases A and C with NE, SW wind direction, as well as considering all combined meteorological cases. The comparison of estimated PM_{10} concentration under cases A and C with case B reveals that, this latter most frequent meteorological condition displays the highest estimated values of concentration (not represented).
Focusing on the crossroad 16 represented in figure 4A, it could be observed first, that the extension of PM_{10} levels estimated under Pasquill-Gifford Class B is balanced on one side of the street depending on NE or

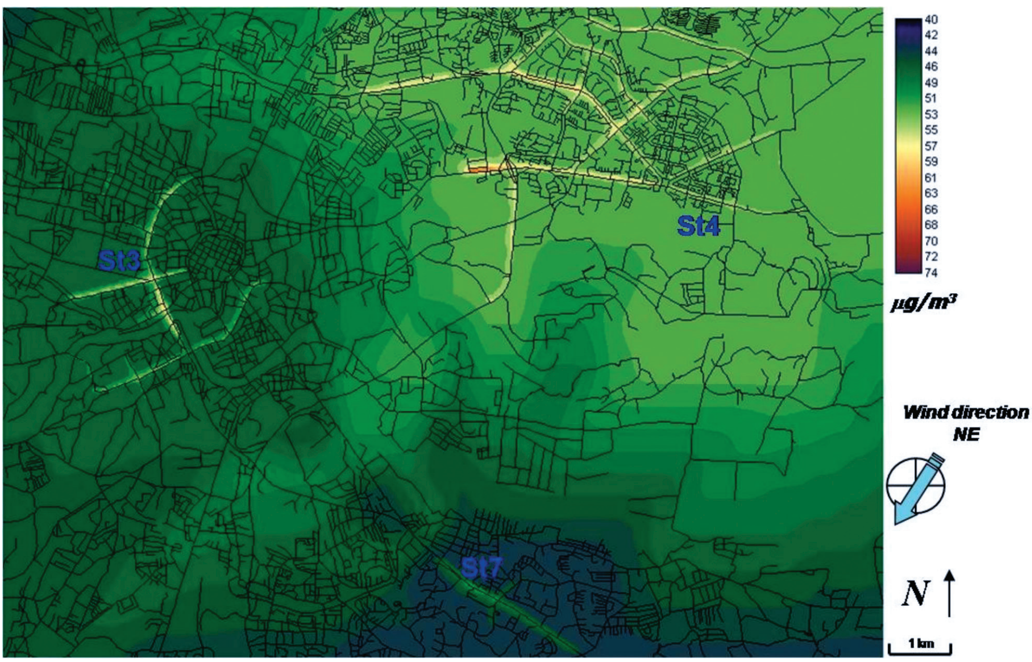

Fig. 3. Representation of the distribution of PM10 concentrations estimated by CALINE4 in 3 selected urban areas around Stations 3, 4, 7 and under the meteorological case of Pasquill-Gifford stability class B associated to the North East (NE) wind direction. Mean hourly concentration determined for the period 2001-2005 is represented
Layer of basemap of Geographic Information System and Cartographic Department, Spatial Planning Department of Cracow City Council

SW wind direction and second, that dispersion of this pollutant reach rather an higher distance under NE than under SW wind direction (fig. 4B: distance from the centre of the road B-NE: 90 to 165m vs B-SW: 70 to 75m). Consequently, to the higher dispersion of PM_{10} under NE wind direction correspond a low estimated concentration of this pollutant and inversely, the low dispersion under SW wind direction is associated to high estimated values of PM_{10} concentration (fig. 4B).

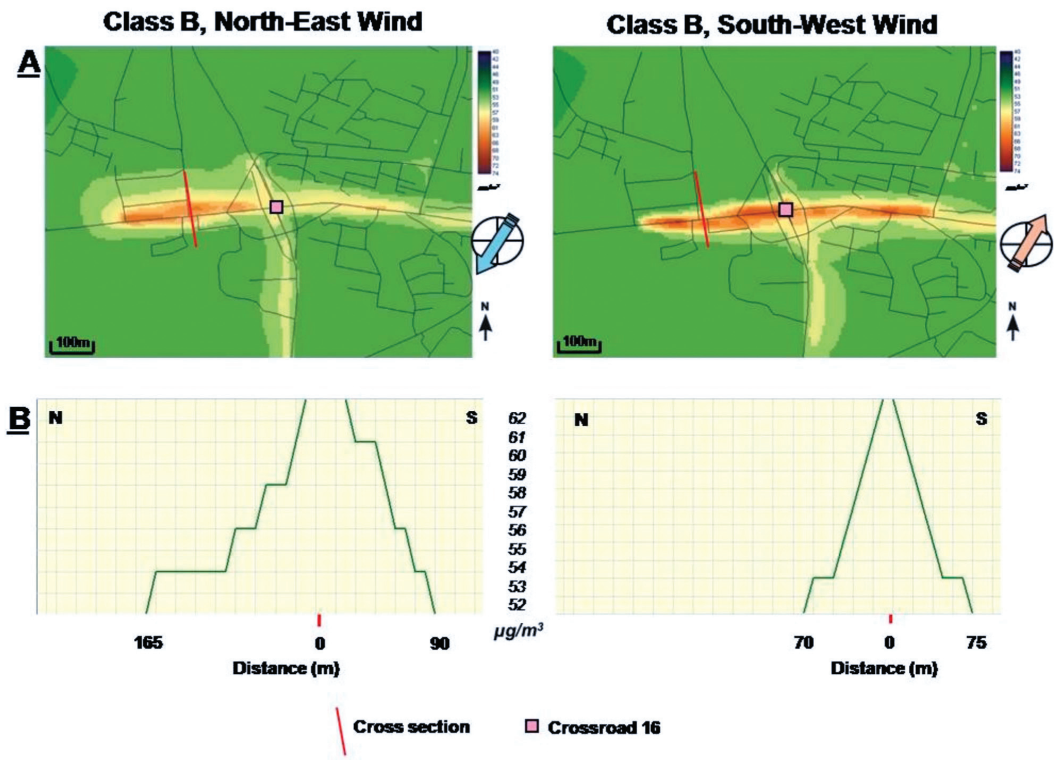

Fig. 4. Comparison of: A) PM_{10} concentration estimated at crossroad 16 by CALINE4 under the meteorological case associated to Pasquill-Gifford Class B and under either the North East (NE) or South West (SW) wind direction; B) of PM10 dispersion around the street under NE or SW wind direction. N and S correspond respectively, to North and South direction of the cross section close to crossroad 16.
From: layer of basemap of Geographic Information System and cartographic department, spatial planning department of Cracow City Council

The assessment by CALINE4 of NO_2 concentration under the meteorological case B and NE wind direction shows that from the background concentration (30 µgm^{-3}), estimated levels range from > 50 µgm^{-3} to higher levels of 85-105 µg/m3; the highest level > 120 µgm^{-3} being represented in figure 5 at crossroad 16 located in the area of Station 4. As for PM_{10}, the fact that NO_2 concentration at the area of Station 3 remains lower to the concentration estimated in the area of Station 4, might be due to a difference of road direction towards wind direction that can remove or trap NO_2. Similarly to PM_{10}, estimation of NO_2 concentrations under the meteorological cases A and C and NE or SW wind directions were found inferior to those evaluated in the most frequent case B (not shown). As also represented in figure 6A, extension of NO_2 to the west or east side of the road adjacent to crossroad 16 depends respectively, on NE or SW wind direction. Furthermore, a large dispersion (distance: 130 to 230 m) and a lower NO_2 concentration are observed under the NE wind direction whereas, the lower dispersion under the SW wind direction (distance: 80 to 90 m) leads to a concentrated zone of NO_2 (fig. 6B). It should be pointed also that, NO_2 dispersion for other crossroads were in average (125.4 ± 64.4m, max: 381 m) higher than the average PM_{10} dispersion (66.8 ± 48.5 m, max: 284 m). The stronger extension of NO_2 on both sides of the road has to be related to its gaseous properties as the more dense particulate matter is less sensitive to be dispersed.

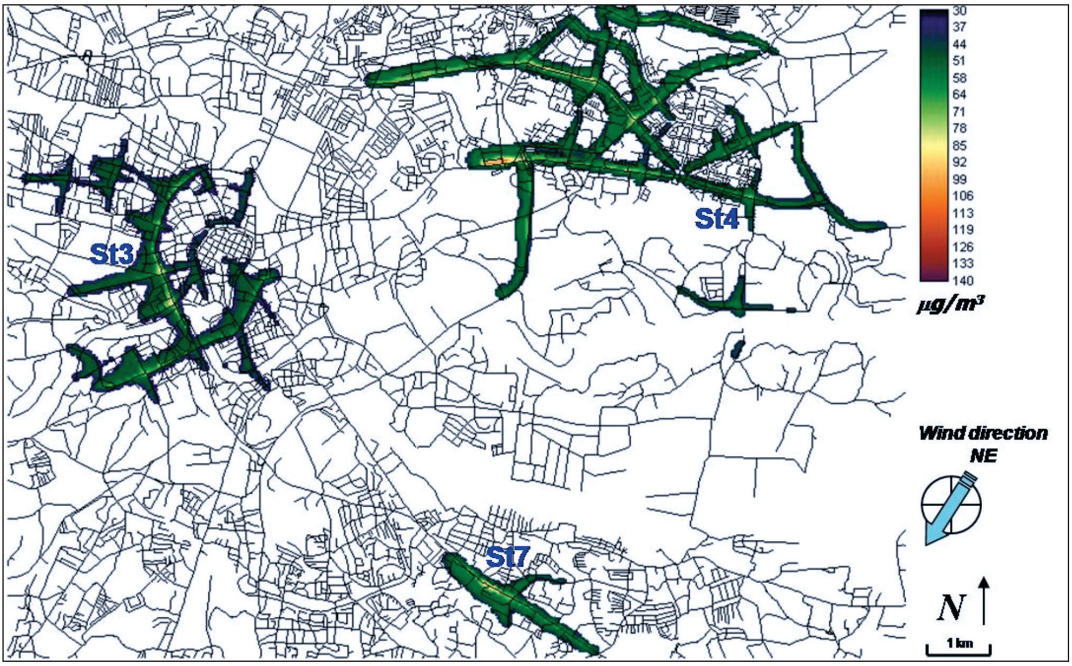

Fig. 5. Representation of the distribution of NO_2 concentrations estimated by CALINE4 in 3 selected urban areas around Stations 3, 4, 7 and under the meteorological case associated to the Pasquill-Gifford stability class B and the North East (NE) wind direction. Mean hourly concentration, determined for the period 2001-2005 is represented

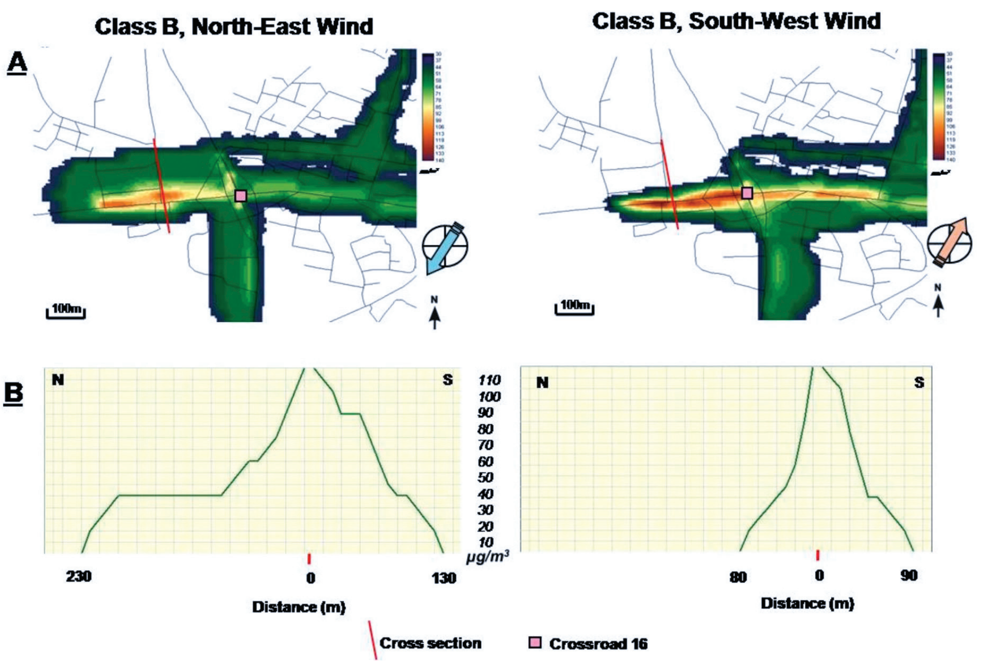

Fig. 6. Comparison of: A) NO_2 concentration estimated at crossroad 16 by CALINE4 under the meteorological case Pasquill-Gifford B under, either the North East (NE) wind or South West (SW) direction; B) of NO_2 dispersion around the street under NE or SW wind direction. N and S correspond respectively, to North and South direction of the cross section close to crossroad 16

Layer of basemap of Geographic Information System and Cartographic Department, Spatial Planning Department of Cracow City Council

CALINE4 assessment of PM_{10} and NO_2 concentration and relationship to childhood asthma

All estimated PM_{10} and NO_2 data determined by CALINE4 for each of the meteorological cases A, B, C or from a combination of these 3 cases, were finally integrated into GIS and were constitutive of layers of pollutant information that has to be related to childhood asthma. For this purpose, epidemiological data were collected from clinical file and interviews from 1000 children (7 years average, sex ratio 51:49) living within the 3 selected modeled urban areas (fig. 7). Epidemiological data include information on home address, type of asthma (GINA classification) and others pathologies (cancer, cardio–vascular,…), medication treatment (type, dose, frequency) as well as on functional respiratory parameters (Forced Expiratory Volume in 1 s. (FEV1), Peak Expiratory Flow (PEF), Forced Vital Capacity (FVC)). Diagnosis of asthma for each children has been established from these characteristics. Odd ratio (OR) were determined by a multivariate logistic regression analysis between the main factors (gender, family history, allergy, infectious diseases) and NO_2 or PM_{10} concentrations estimated by CALINE4 in the 3 modeled areas and under the combination of the 3 meteorological cases A,B,C and all wind directions. From this analysis, any significant association between PM_{10} concentration and childhood asthma factors were determined and such result can be partly explained by limited dispersion of PM_{10} assessed by CALINE 4 around road. Nevertheless, significant relationships could be evidenced between NO_2 [OR: 1.10 (95 % CI 0.41 ; 2.95) ; OR 2.13 (95% CI 1.02 ; 4.45)] and gender [OR 1.62 (95% CI 1.01 ; 2.60)], age [OR: 0.84 (95% CI 0.47 ; 1.50) ; OR 0.50 (95% CI 0.26 ; 0.96) ; OR 3.11 (95% CI 1.04 ; 9.35)], family history of asthma [OR 3.57 (95% CI 2.12 ; 6.03)] and asthma. Moreover, preliminary results that have to be confirmed, show that the NO_2 relationship with childhood asthma is dependent on the meteorological case (A, B or C) used to determine the concentration of this pollutant and under certain wind direction.

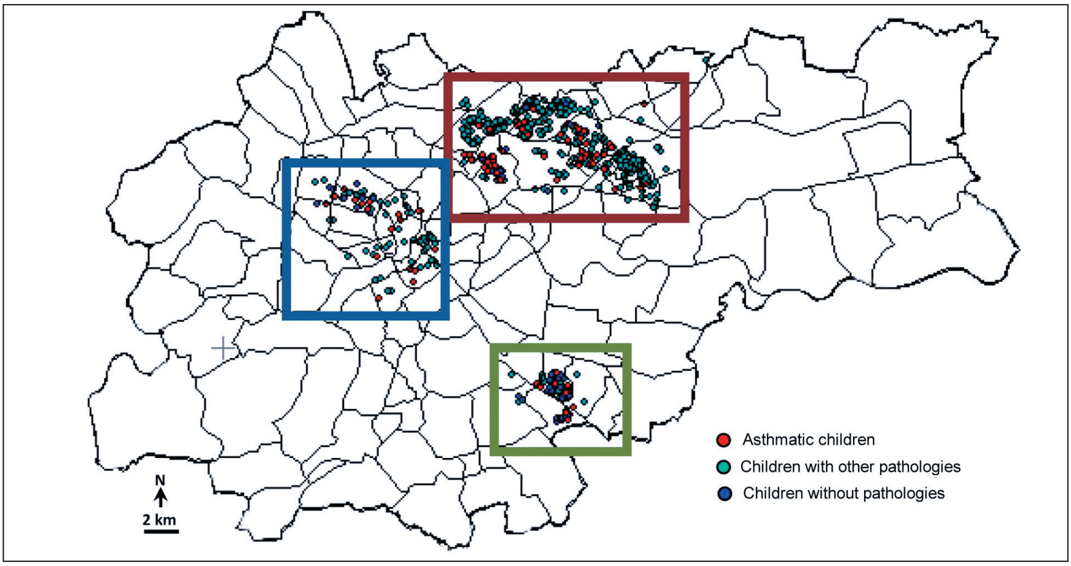

Fig. 7. Respective distribution and location of asthmatic children, children with other pathologies than asthma and healthy children (without pathologies) within the 3 urban areas of Cracow that were used to assess road traffic PM_{10} and NO_2 concentrations by CALINE4.
From: layer of basemap of Geographic Information System and Cartographic Department, Spatial Planning Department of Cracow City Council
From: Epidemiological data of inquiry conducted by Clinical and Environmental Allergology Department of Jagiellonian University of Cracow

Interest of air dispersion model and GIS to assess health effects of urban pollutants

Because of recent and rapid changes of urban landscape management and of strong anthropogenic activities, it becomes obvious that the introduction of a new integrative methodology is highly required for a better knowledge and understanding on how, air pollutants from several sources can affect quality of life and human health. The method we propose, is to combine an air dispersion model with GIS in order to integrate and to assess complex interactions developed between a source of pollution (road traffic in this case), meteorological and topographical parameters involved in the dispersion of pollutants and biological parameters of exposed population (asthmatic children). We chose to test this approach in the Central European city of Cracow, which like many other Polish cities, urban sources such as, industrial and/or domestic activities (coal burning) and the recent raised road traffic are responsible for the release of numerous pollutants. Considering PM_{10}, NO_2, SO_2 issued from these sources we showed that locally, the combination of several meteorological parameters modulate the levels of these pollutants. To an association of low temperature, wind speed and precipitation with some wind direction corresponds, strong levels of these 3 pollutants. The lowest levels are however obtained, when increases of temperature, wind speed and precipitation are reached locally. So, if intensities of pollutant sources are preponderant in the occurrence of episodes of pollution and can be controlled ultimately, it is evident that meteorological parameters exert also, a strong influence. The spatio-temporal distribution of PM_{10} and NO_2 that was estimated at crossroads of 3 urban areas by the air dispersion model CALINE4 was taking into account of the influence of these meteorological parameters. Estimation of both pollutant concentrations was determined following the elaboration of 3 meteorological cases based on respective association of Pasquill-Gifford classes A, B, C and NE and SW wind direction. We found that the highest PM_{10} and NO_2 concentrations were assessed under the most frequent meteorological case B (50%, 2001-2005); this case reflecting a moderate instability of air masses and moderate vertical/horizontal dispersion. Levels of estimated concentrations of both pollutants under cases A, B, C were found for the most part, related to the traffic density measured at crossroads, although observed differences between 2 areas may be explained by a difference in urban road network direction vs wind direction. Dispersion and concentration of PM_{10} and NO_2 on both side of the road were shown to be dependent either on NE and SW wind direction. Furthermore, a wider extension and lower concentrations of both pollutants were assessed under a NE wind direction as inversely, the SW wind direction conducts to a smaller extension and higher concentrations of PM_{10} and NO_2. Moreover, for all meteorological cases tested, the dispersion of NO2 was always found in a higher extent on both side of the road, than for PM_{10}. Such results show that CALINE4 and GIS highlight the urban landscape, meteorological and road traffic conditions that modulate the levels exposure of human population to PM_{10} and NO_2. The health effects of both pollutants could be then studied by assessing their effects on resident asthmatic children distributed within the 3 CALINE4 modelled areas. Taking into account of PM_{10} and NO_2 concentrations estimated under all combined meteorological cases, no significant effect of this former pollutant on asthma was found, while a NO_2 health effect was evidenced. Further preliminary results that have to be confirm, indicate that under some meteorological cases and wind direction, NO_2 increased the risk of asthma. In conclusion, the integrative study we propose on the assessment of the effect of road traffic pollutants on childhood asthma is relevant as it allows, to evaluate a biological risk taking account of all involved urban landscape, anthropological and meteorological parameters in the degree of air pollution. From such approach, it should be considered a new management of strategic roads where atmospheric pollution accumulates, in order to improve air quality and limit the exposure of residents to road traffic pollution.

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