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The Influence of Urban Form on Environmental Quality within a Medium-Sized City

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Abstract

This paper presents the relations established between urban morphology and variations in observed air quality within a city centre. A dataset from four monitoring stations in a medium-sized city was collected and clustered by the amount of traffic-generated air pollutants. For each cluster, the relationship between the configuration of the open spaces and average PM_{10} concentration was established. Results show the impact of urban geometry on the outdoor pollutant concentration, concluding that increasing Sky View Factor and Ratio of Open Spaces lead to a decrease in the PM_{10} concentration.

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Keywords: urban form; urban pollution; PM_{10}; Urban air pollution;

1. Introduction

Global population growth has led to an increase in the number of people living in urban areas. As a consequence, stress concerning space, ecosystems, infrastructures, facilities and personal lifestyles has increased. Problems related to the quality of life in the cities are increasingly relevant, especially with regards to environmental issues. Urban air quality can have severe impacts on people who use outdoor spaces within a city. Besides the existing sources, urban

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Nomenclature

s'	sum of area of all the open spaces radius [m^2];
s_i	coverage area of buildings [m^2];
ROS	Ratio of Open Spaces [-];
SVF	Sky View Factor [-].

air quality can directly be linked to the configuration of open spaces defined by street networks, building heights and their attributes. Thus, the role of urban planners can be crucial in order to ensure outdoor air quality in open spaces.

Urban form is related to urban geometry that can be analysed using different tools. The Sky View Factor (SVF), as well as the Ratio of Open Spaces (ROS) are considered by many authors [1] to be appropriate parameters to describe urban geometry. SVF is defined as the degree to which sky is visible for each given point. It is a dimensionless measure between zero and one, representing totally obstructed and free spaces, respectively [2]. The SVF is mainly influenced by the geometrical features of buildings and vegetation and is directly related to the height-to-width ratios of the streetscapes.

The importance of urban form on sustainable development has been mostly recognized since the 1990s [3, 4]. These concerns have been incorporated into various urban policies. For example, the European Commission advocates the compact city as the most sustainable urban form and a number of countries, such as the Netherlands and the UK have implemented more sustainable urban policies in order to reduce pollutant emissions [5]. According to Tang et al. [6] the concentration of pollutants in the atmosphere may vary over time and space in the following way: the compact urban form, which is characterized by intensive land use and urban complex geometries can generate complex traffic emissions and, therefore, uneven distribution of air quality; the local topography, which can promote the movement of air masses; meteorological conditions: a stable atmosphere limits the dispersion of pollutants and leads to the formation of pollution peaks; the thermal structure of the atmosphere: the location of the inversion layer can also limit the dispersion of pollutants.

The research of the influence of urban form on the variation of particulate matter concentration (PM_{10}) on an urban scale is the main purpose of this paper. The urban form is measured by the Sky View Factor and the Ratio of Open Space. Data on PM_{10} concentrations were obtained from a monitoring system in the city of Braga, Portugal and includes a period of five years. The monitoring stations are located at four points in the city centre.

2. Case study

Braga is the third-largest city in Portugal. The city is located in the Northwest region of the country and, according to the last census [7], the urban population is about 120,000 inhabitants. The centre presents an organic form, with irregular and narrow roads and buildings typically with two or three floors maintaining the medieval identity. Following a tendency observed in other European cities, the city of Braga has created an infrastructure for environmental data acquisition and a web based platform as a public information system. Some of the innovations introduced in this platform include using a mobile instrumented unit, extensive use of simulation software to create long-term pollution (air and noise) maps, and presenting information through a geographical interface developed using Google Maps technology [8].

2.1. Site location

In the city of Braga, four monitoring points (Figure 1a) were selected. At each point, a reference area of 200 x 200 m was defined from the point of measurement as shown in Figures 1 b) - e).

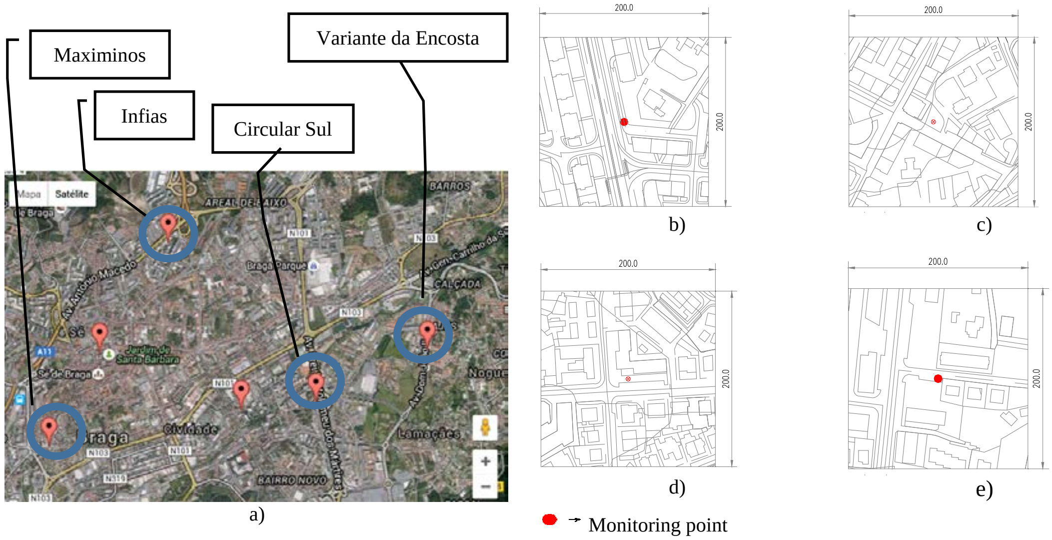


Fig. 1. (a) locations of monitoring points; Reference areas: (b) Circular Sul; (c) Infias; (d) Maximinos; (e) Variante da Encosta.

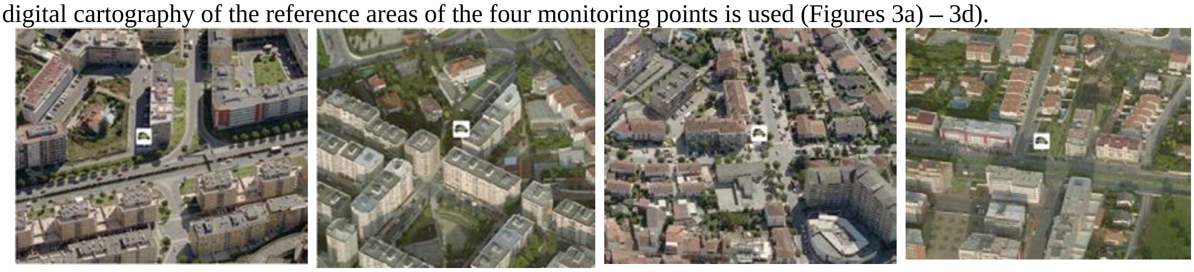
2.2. Analysis methods

A field measurement of PM_{10} was taken using a portable Particulate Monitor installed in a mobile monitoring unit from an urban environmental monitoring and information system called SmarBRAGA. The mobile unit takes measurements in a specific location of the city (GPS technology), and transmits them through wireless communication to a web platform. (Figures 2a)-2c)).

a) b) c)

Fig. 2. Examples of the functioning of data acquisition infrastructure: (a) mobile unit in operation; (b) measurement of particles in loco; (c) measurement of noise.

According to the methodology used by Monteiro [9], SVF's were calculated in an ArcGIS/ESRI platform where digital cartography of the reference areas of the four monitoring points is used (Figures 3a) – 3d).



a) b) c) d)

Fig.3. Aerial view of monitoring points: (a) Circular Sul; (b) Infias; (c) Maximinos; (d) Variante da Encosta.

The Index of Porosity or Ratio of Open Space is, according to Huang et al. [10], calculated from Eq. (1) shown below:

$$ROS = \frac{s'}{\sum_i s_i} \times 100 \quad (1)$$

Where s' is the sum of area of all the open spaces within the urban studied area (m^2) and s_i is the coverage area of buildings (m^2). An urban area consisting of urban forms with higher open spaces has higher levels of ROS. This indicator is also called the ratio of open spaces. The calculation of the physical characteristics of buildings in the four urban reference areas was taken using AutoCAD.

2.3. Results

According to the procedures described above, results and measurements made at four points located in the city of Braga are presented.

2.3.1. Road traffic data

The road traffic statistics provided by SmarBraga were obtained by counting and estimates for March, 2008. Data is presented for each of the different measuring points by vehicle class in periods of time. The statistical traffic data are related to each time period where the PM_{10} measurement was made. Table 1 shows a traffic extract used in the four selected monitoring points.

2.3.2. PM_{10} data

PM_{10} concentrations are relative to the period from May, 2008 and April, 2012. The data identified as null were ignored and only the measurements with positive concentration values were considered. Therefore, for each monitoring point, traffic data were associated to the corresponding time period of the PM_{10} measurement. An extract of the collected and processed data is presented in Table 2.

2.3.3. SVF and ROS data

The Sky View Factors calculated at each monitoring point are presented in Table 3. The physical characteristics and the ROS calculated of each reference area are presented in Table 4.

Table 1: Road traffic data extract, hourly average.

Time [h]	Circular Sul		Infias		Maximinos		Variante Encosta	
	Total Veh/h	Heavy %	Light Veh/h	Heavy %	Light Veh/h	Heavy %	Light Veh/h	Heavy %
08h-09h	5640	5.5%	963	2.3%	616	1.6%	112	3.6%
09h-10h	4077	6.4%	820	3.8%	566	3.9%	109	1.8%
10h-11h	3241	7.6%	626	4.8%	444	7.0%	93	15.1%
11h-12h	3167	8.1%	523	4.8%	368	3.8%	67	16.4%
12h-13h	4245	4.4%	745	3.1%	578	4.5%	74	1.4%
13h-14h	4834	5.1%	836	2.3%	540	4.3%	67	6.0%
14h-15h	4606	6.1%	766	3.7%	496	4.6%	90	20.0%
15h-16h	3966	7.1%	436	5.0%	319	7.5%	61	3.3%
16h-17h	4160	5.4%	389	6.7%	495	4.4%	155	0.0%
17h-18h	5176	5.1%	832	5.8%	658	3.2%	193	2.6%
18h-19h	5999	3.7%	908	5.0%	754	1.5%	225	2.7%
19h-20h	5262	2.1%	503	4.8%	727	2.2%	246	0.4%
20h-21h	3584	1.1%	675	1.3%	506	0.8%	166	0.0%
21h-22h	3017	1.1%	518	1.0%	310	1.0%	99	0.0%

Table 2: PM10 concentration data extract, hourly average.

Circular Sul			**Infias**			**Maximinos**			**Variante da Encosta**		
Date	Hour	PM_{10} (μg/m^3)	Date	Hour	PM_{10} (μg/m^3)	Date	Hour	PM_{10} (μg/m^3)	Date	Hour	PM_{10} (μg/m^3)
09-12-11	12:28	83.6	30-11-11	12:06	31.1	13-10-11	12:09	83.6	09-01-12	12:19	49.7
21-12-11	16:34	74.4	19-12-11	12:13	83.3	20-10-11	12:05	24.7	12-01-12	12:14	55.7
05-01-12	17:10	38.6	29-12-11	16:55	75.4	22-11-11	12:11	24.8	17-01-12	12:11	37.9
13-01-12	17:03	88.2	09-01-12	17:26	101.8	12-12-11	12:05	47.7	20-01-12	16:11	24.5
18-01-12	17:13	42.5	12-01-12	16:57	87.8	22-12-11	12:04	84.1	01-02-12	16:24	36.4
24-01-12	12:03	74.8	16-01-12	17:01	34.9	06-01-12	16:49	61.0	10-02-12	12:03	45.4
30-01-12	17:18	49.3	17-01-12	16:31	47.8	11-01-12	12:43	52.7	15-02-12	16:45	25.0
07-02-12	12:05	25.0	23-01-12	12:01	32.3	16-01-12	12:16	33.7	22-02-12	16:40	15.9
14-02-12	12:05	19.8	27-01-12	16:47	17.6	19-01-12	12:08	47.5	27-02-12	16:38	38.0
22-02-12	12:16	84.2	07-02-12	16:25	21.4	24-01-12	16:13	20.8	05-03-12	12:15	11.6
27-02-12	12:13	83.3	15-02-12	12:11	25.2	30-01-12	12:01	68.0	19-03-12	12:17	28.4
22-03-12	12:07	34.8	23-02-12	12:11	42.6	06-02-12	16:18	19.4	28-03-12	12:07	20.7

Table 3: Summary of results of the calculation of SVF.

Monitoring points	SVF (%)
Circular Sul	83.65
Infias	64.90
Maximinos	76.35
Variante da Encosta	78.11

Table 4: Physical characteristics of the selected urban forms.

Monitoring points	Reference area (m2)	Coverage area (m2)	Open spaces area (m2)	ROS (%)
Circular Sul	4000	3826.8	36173.0	90.43
Infias	4000	12294.0	27706.0	69.26
Maximinos	4000	7815.9	32184.0	80.46
Variante da Encosta	4000	13080.0	26920.0	67.30

2.4. Analysis and discussion

In order to obtain highly reliable data by eliminating data from unrepresentative situations, such as measurement errors, puffs (areas with very high concentrations even though not representative) of pollution, abnormal weather conditions, data is rejected which moves away from the mean ± 95%. The data obtained was related to traffic classes and, for each class, the respective PM_{10} average was obtained. In order to establish a relationship between urban form and the PM_{10} concentration, the emission source had to be ensured (in this case road traffic at the four monitoring points) to present emission levels of the same order of magnitude. To this end, an adjustment of the PM_{10} concentration was used by linear regression. The equations of the straight lines determined by linear regression analysis are then used to determine the PM_{10} concentration for average traffic values and for the four monitoring points (Table 5). The conversion to the equivalent number of vehicles was made using PM_{10} emission factors from light and heavy vehicles. According to Silva et al. [11], the PM_{10} emission factors calculated in the city of Viana do Castelo were 0.20997 gr PM_{10}/km and 0.01823 gr PM_{10}/km for light and heavy vehicles, respectively, and the equivalence factor of heavy vehicles was 11.518. By spatial proximity, the same equivalence factor was adopted in this study.

According to the procedures described above, results and measurements made at four points located in the city of a field measurement of PM_{10} was taken using a portable Particulate Monitor installed in a mobile monitoring unit.

Table 5: PM10 concentrations and vehicles equivalent.

Monitoring points	Vehicles equivalent (vehic/h)	PM_{10} (μg/m^3)	Adjustment by linear regression
Circular Sul	300	19.70	y = 0.0452x + 27.325 R^2=0.9295
	500	20.30	
	700	20.90	
Infias	300	40.82	y = 0.0033x + 18.792 R^2=0.9900
	500	49.80	
	700	58.80	
Maximinos	300	27.80	y = 0.004x + 26.604 R^2=0.9753
	500	28.60	
	700	29.40	
Variante da Encosta	300	26.07	y = 0.0076x+23.790 R^2=0.7269
	500	27.59	
	700	29.11	

3. Conclusions

This paper aims to address the problems of the urban environment as an area of interaction between urban forms and PM_{10} concentrations.

It can be concluded that the increase in SVF and ROS leads to a decrease in the concentration of PM_{10}. Thus, the measuring point located at Infias registered higher PM_{10} concentration values as, in this case, the low dispersion of this pollutant is influenced by a large number of obstacles that prevent the area of sky view, a characteristic of a low SVF value. The measuring points Circular Sul and the Variante da Encosta are characterized by having the highest values of SVF and also those with lower measured PM_{10} concentrations. From the analysis of Fig. 4, it can be observed that there is a decrease in PM_{10} concentration in the urban environment as SVF increases. This relation can be translated, for example, by a decrease in 33 μg/m3 of PM_{10} per 1000 equivalent vehicles for an increase of 10% in SVF. This conclusion highlights the potentiality of this index as a planning tool to be used for regulations of new building constructions. From the analysis of Fig. 5, it can be observed that there is a decrease in the PM_{10} concentration in the urban environment as ROS increases. This relation can be translated, for example, by a decrease of 16.3 μg/m3 of PM_{10} per 1000 equivalent vehicles to an increase of 10% in ROS.

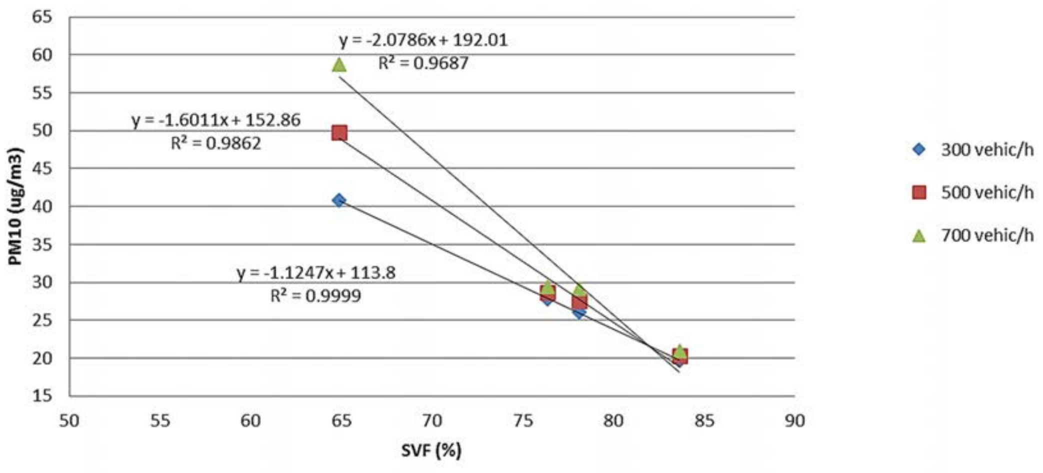


Fig. 4 Sky View Factor index vs. average PM_{10} concentration.

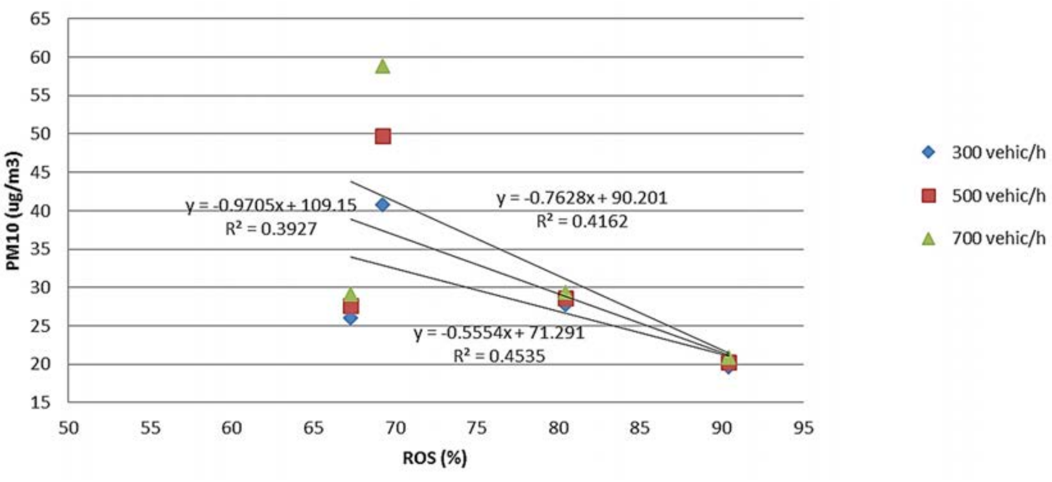


Fig. 5. Porosity index vs. average PM10 concentration.

The ROS index of building blocks is a common parameter for design approval in public regulation agencies, although it has never been considered as an acoustical tool. These findings also suggest that this index should assume an acoustical profile concerning building regulations. In this study, the meteorological condition was not considered.

Given the lack of meteorological data and its importance, namely the wind velocity in the dispersion of pollutants, this is an area where further analysis will be considered in the future.

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