INVOLVEMENT OF THE CITIZENS IN THE ASSESSMENT OF ATMOSPHERIC CONTAMINATION IN AN URBAN-INDUSTRIAL AREA

Ana Rita Rosa Justino

Instituto Superior Técnico
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ABSTRACT

This study aimed to evaluate the perception of air quality by the population in an urban residential area nearby an industrial zone of Seixal municipality (Portugal) and to assess possible local sources of air pollution that may explain settled dust events that occurs occasionally. For the latter, two different but complementary strategies were used.

Firstly, settled dust from one of those events that gathers concerns among local population was collected and analysed to understand possible sources of pollution. Additionally, in order to engage the population and maximise their availability, a biomonitoring technique using strawberry plants was employed within the population to assess the air quality levels and also to identify potential pollution sources. Overall, a total of 48 strawberry plant samples were distributed to the citizens in the selected area for a period of three months aiming to create pollution maps to identify hot spots of pollution. After exposure, strawberry leaves were analysed by micro-X-Ray Fluorescence (micro-XRF) technique and the settled dust was analysed by micro-Particle Induced X-ray Emission (micro-PIXE) to provide their chemical characterisation.

To assess the perception of air quality and its level of importance, a questionnaire was distributed among the population (from both the study area and the remaining country) and it determined a high awareness and knowledge of the population towards the problematic of air pollution, with 94% of the population considering air pollution as one of the biggest environmental concerns.

The analysis of the settled dust showed that Cr was correlated with Fe and Mn, indicating their common source, which may be iron and steel industries, since these elements are typically tracers of such type of industries. Focusing on these tracers, their pollution maps using the biomonitoring data were created and confirmed their high levels nearby the industrial area that have a steelwork. Using the biomonitoring data, Cr and Fe also showed a strong association emphasizing the steel and iron industry contribution to the local air quality. Therefore, this specific industry is highlighted as one of the main contributors to the degradation of local air quality.

Keywords: Air pollution, awareness settled dust, biomonitoring, strawberry plant, industry

1. INTRODUCTION

Ambient air pollution has become a growing concern, mostly due to the rapid urbanisation, industrialisation and traffic. In Europe, it is perceived as the second biggest environmental concern (after climate change) and poses as the most important environmental risk to human health (EEA, 2019). Exposure to ambient air pollution is associated with a variety of health impacts such as cardiovascular diseases, cancer, respiratory diseases and mortality (Krewski et al., 2005; Pope III et al., 2003).

People's understanding and response to ambient air pollution are vital to recognize the best adaptation measures concerning the protection of public health (Oltra & Sala, 2016). Thus, it is important to consider people's perception and behavioural changes, and also have in consideration their perception that varies among groups and individuals (Pantavou, Lykoudis, & Psiloglou, 2017). The studies of air quality perception have not shown an association between the perceived air quality and the concentration of measured pollutants (Brody, Peck, & Highfield, 2004). Instead, air quality perception seems to be influenced by sensory experience, awareness and knowledge, the emotions it provides (such as nuisance), communication and risk perception (which takes into account the psychological, social and cultural factors) (Brody et al., 2004; Oltra & Sala, 2014).

Specifically, in urban-industrial areas, there is a large concentration of people and emissions associated with traffic and industrial activities. Thus, this type of areas can exhibit a higher level of pollution and have a higher impact (Almeida et al., 2005). So, there is a need to study industrial regions concerning air pollution to recognize and clarify the emission sources, therefore contributing to solving the environmental problems (Lage, 2016), particularly in areas where events of air pollution occurs occasionally (such as, particulate matter (PM) pollution events).

Standard sampling methods to monitor PM are usually instrumental methods, typically expensive and requiring specialized personnel. Moreover, these are not very convenient or feasible for use in remote areas (due to the possibility of the equipment being vandalised or stolen) or to collect simultaneous samples on multiples sites (Canha et al., 2014). Biomonitoring compared to instrumental methods presents advantages such as the ability to perform high-density sampling at any temporal and spatial scale at low cost and maintenance (Almeida et al., 2012).

Biomonitoring is the use of organisms and their response to changes in the environment. It can be based on the evaluation of the anatomic, morphologic and physiologic characteristics or the analysis of trace elements in the living organisms, such as lichens, mosses or plant leaves (Hofman et al., 2013). The use of strawberry leaves (*Fragaria ananassa*) can be ideal in areas with high anthropogenic sources (Hoodaji et al., 2012). The particle accumulation efficiency of the leaves is influenced by plant species (evergreen or deciduous), specific leaf characteristics (leaf size, shape, roughness, wax layer) and leaf area density (Castanheiro et al., 2020; Hofman et al., 2017).

In an urban-industrial area in Seixal municipality (Portugal), where a dense residential area co-exists, occasional settled dust events have increased the population's concerns regarding the impacts of the air pollution events on their health and welfare. Therefore, a need to understand the potential sources of these events along to understand the local air quality has emerged among local authorities.

The present study aims to answers this problem: evaluate local air quality and to identify potential pollution sources and, simultaneously, understand the citizens' awareness regarding the air quality.

To achieve these goals, an integrated approach was created and employed focusing on:

i) Assessment of citizens' perception on air quality (using questionnaires);
ii) Chemical analysis of settled dust to identify potential sources;
iii) Biomonitoring of air pollution using strawberry leaves (in a citizen science-based project) to map local air quality and to identify hot spots of pollution.

2. METHOD

2.1. Study site

This study was carried out in the Seixal municipality (Portugal), located in the Setúbal peninsula and belonging to the Metropolitan Area of Lisbon. Seixal has a population of 166403 inhabitants and an area of 95,5 km^2 (Pordata, 2019). Figure 1 shows the location of the study site which is the "União de Freguesias do Seixal, Arrentela e Aldeia de Paio Pires" (UFSAAPP), a parish in the municipality of Seixal. This study site contains a high density of industries, in particular steelworks and other metallurgic industries.

2.2. Assessing air quality perception by questionnaires

A questionnaire was created to assess the Portuguese population's perception of air quality. The first part inquired about the participants' demographic characteristics and the second part focused on the perception towards air quality (AQ), followed by a section regarding the knowledge of air pollutants and their sources, as well as the sources of information and knowledge of applicable regulations for controlling air quality.

The questionnaire was available online from 1st of February to 26th of June of 2020 and a total of 1134 answers were gathered.

2.3. Sampling

2.3.1. Settled dust

When a settled dust event occurred at the study site on 15th January 2019, samples were

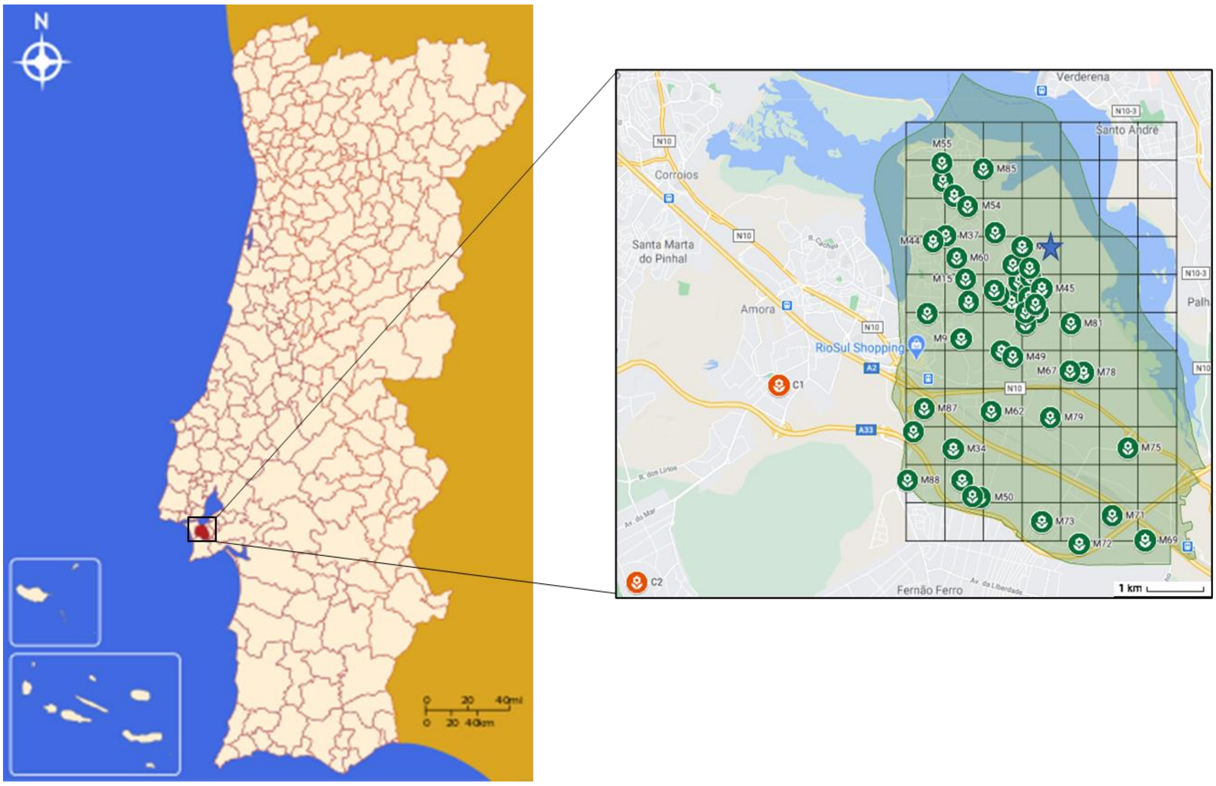

***Figure 1** – Location of the study area within the municipality of Seixal (Portugal) and its delimitation (green area) and the location of the steelwork (blue star) and representation of the grid for the biomonitoring with the strawberry leaves (in green icons the strawberry leaves samples and in orange icons the reference strawberry plants)*

collected from the surface of recently washed (previous or same day that the sampling occurred) graves of the local cemetery.

2.3.2. Biomonitoring of air pollution with strawberries leaves

Firstly, a grid was created in the study area (shown in Figure 1) with 6.87 km x 4.56 km squares in all the UFSAAPP area to identify the ideal sites of exposure of the biomonitors.

In order to engage the population with the biomonitoring programme, a local meeting was held on February 1st 2020 with all the interested population in order to explain all the phases of the study and which needs and procedures were expected from the population on taking care of the strawberry plants during the exposure period. A total of 78 strawberry plants were distributed among the volunteers on that day. During the exposure period, the strawberry plants were placed in a ground or first floor to avoid vertical variation; they were watered without getting their leaves wet (which retains the pollutants) and were remained in their original pots, without any type of fertilizer (in order to not influence the results). At the end of the exposure period, five branches of each strawberry plant were collected, giving priority to the largest leaves, without touching their surface.

The exposition of the strawberry plants took place from 1st February until 16th of June. After exposure, loss of some samples was verified and only a total of 50 samples were gathered. The spatial distribution of the collected samples is displayed in Figure 1 (left, green icon).

At the lab, the strawberry leaves were cleaned, lyophilized and grinded to powder. Pellets with a 12 mm diameter of each sample were created and sent to the Institute of Nuclear Research of the Hungarian Academy of Sciences for analysis.

2.4. Chemical analysis

For the settled dust study, micro-Particle Induced X-ray Emission (micro-PIXE) was used to determine 29 chemical elements of its composition.

For analysis of the strawberries' leaves, micro-X-Ray Fluorescence (micro-XRF) technique was used to assess the concentration of 25 chemical elements. Afterwards, a GIS software was used for creating maps of the chemical elements' spatial distribution.

2.5. Statistical analysis

Statistical testes were carried out using the supplement XLSTAT of Microsoft Excel. Chi-square tests of independence were used to examine if participants' gender, age, educational level, monthly income, among others were associated with the participant's level of concern of air quality and the evaluation of the air quality.

3. RESULTS AND DISCUSSION

3.1. Evaluation of the citizens' perception of air quality

The conducted survey allowed to compare results between two populations: the general (citizens that reside in all districts of the country, except in the study area) and the UFSAAPP (citizens that only reside in the study area).
The results showed large differences between them. It was observed that UFSAAPP population showed a higher concern regarding air pollution in comparison with the general population (with more than 94% of the UFSAAPP population considering it the main environmental concern). This higher concern was also demonstrated by their significant knowledge of possible pollutants and higher need to search for information about the topic*.* Furthermore, UFSAAPP population considered industry as the main source of air pollution (with 33.9% of the answers), followed by car traffic (18.4%). This trend was not found in the general population, where traffic was appointed as the main pollution source (24.6%) followed by the industry (only with 6.2%). This fact highlights the concern and awareness that the local population has regarding industry as a pollution source.

Figure 2 provides the perception of state of the air quality by the citizens in different levels (country, municipality and neighbourhood), considering two types of citizens: general and UFSAAPP population.

The main difference between populations is that, at local level (neighbourhood), 61.3 % of the UFSAAPP population considers their air quality as bad or very bad, while only 9.5% of the general population considers the same air quality in their neighbourhood. This fact shows the high level of awareness and sensibility of the UFSAAPP population regarding the topic of air quality.

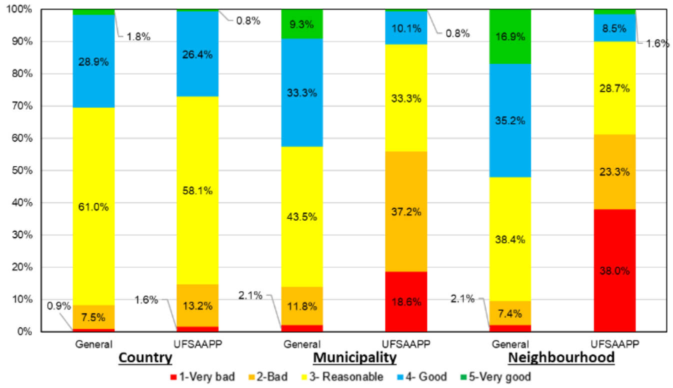

Figure 2 - *Assessment of air quality's perception in Portugal, municipality and their neighbourhood for the general and UFSAAPP population*

3.2. Chemical characterisation of the settled dust events and potential sources

Chemical characterisation of the collected settled dust and its analysis is already thoroughly described elsewhere (Justino et al., 2019). In order to identify potential sources, the chemical composition of the settled dust was compared with profiles of particulate matter from different types of environments (urban, rural, industrial with steelworks and road settled dust). It was found that Fe and Ca were in agreement (with less than 30% of variability) between the studied settled dust and industrial environments with steelworks. Moreover, strong and significant correlations were found for Cr with Fe and Mn, indicating their common source, which may be iron and steel industries, since these elements are typically tracers of such type of industries.

It is important to highlight the known short lifetime of coarse particles, such as the studied settled dust, which indicates that the origin of the emission of this settled dust is located nearby. Taking in account these issues, it is plausible to indicate the nearby industrial area as a potential source of the studied settled dust.

3.3. Biomonitoring of air pollution with strawberries leaves

3.3.1. Chemical composition

Table 1 presents the mean values for mass fractions of major and trace elements found in the samples of strawberry leaves by the micro-XRF analysis.

The major elements (>1% of the total mass) were, by decreasing order: Ca (50.7%), K (33.8%), Mg (3.4%), Cl (3.0%), Si (1.9%), Na (1.6%), Fe (1.2%), P (1.1%) and S (1.0%).

Table 1 *- Elemental mass fraction of the strawberry leaves (where n is the number of samples analysed)*

	Elements	n	Mass fractions ($\mu g.g^{-1}$)			%
			Average ± σ	Min	Max	
Major	Ca	48	102000 ± 15000	53000	129000	50.7
	K	48	67900 ± 22000	36500	126000	33.8
	Mg	48	6810 ± 1120	4580	9960	3.4
	Cl	48	6080 ± 4930	1010	29750	3.0
	Si	48	3770 ± 1940	1060	9550	1.9
	Na	48	3230 ± 1250	1160	9660	1.6
	Fe	48	2410 ± 1750	480	10870	1.2
	P	48	2230 ± 1030	960	6090	1.1
	S	48	1900 ± 680	1000	3820	1.0
Trace	Al	48	514 ± 129	321	841	0.3
	As	48	546 ± 495	71	2563	0.3
	Ba	48	572 ± 154	196	855	0.3
	Br	48	172 ± 56	75	389	0.1
	Co	43	22.5 ± 14.4	1.0	55.0	<0.1
	Cr	30	44.9 ± 52	4.0	274.0	<0.1
	Cu	48	42.1 ± 12	25.0	79.0	<0.1
	Mn	48	894 ± 628	256	4503	0.5
	Ni	20	7.38 ± 5.16	1.00	17.00	<0.1
	Pb	38	38.9 ± 25.1	3.0	109.0	<0.1
	Rb	48	177 ± 47	100	318	0.1
	Se	48	73.9 ± 16.2	28.0	108.0	<0.1
	Sr	48	906 ± 243	269	1328	0.5
	Ti	48	206 ± 169	62	935	0.1
	Zn	48	360 ± 163	210	953	0.2
	Zr	48	154 ± 68	42	347	0.1

3.3.2. Ratios and spatial distribution

The population of the study area believes that the industry is the main source of pollution, in particular, the steelwork (as confirmed by the citizens' perception of air quality outcome). Therefore, the present study will target and analyse the typical chemical elements for iron and steel industries, such as Cr, Mn Fe and Zn (Calvo et al., 2012). As shown previously, these elements were also present in the chemical composition of the studied settled dust and presented correlations, with exception of Zn.

Firstly, the spatial distribution of the elements was analysed as shown by Figure 3, and it is possible to observe spots of higher concentrations of all these elements that overlap with the location of the industrial area that contains the steelwork.

Since the spatial distribution can be associated with the iron and steel industry, the next step was to evaluate the ratios between the chemical elements of the biomonitors and compare them with the ones found in the collected settled dust (Justino et al., 2019). Figure 4a) shows the relationship between Cr and Fe in the strawberry leaves and the Cr/Fe ratio of 0.05 found in the settled dust. The relationship between these two elements in strawberry leaves is very good (r^2=0.85), which highlights their common source. In this case, it is evident a deviation between the tendency lines of the ratios in strawberry leaves (blue) and the settled dust (black), which can be explained by the contribution of other source for the Fe levels in the strawberry leaves, such as a crustal constitution, since Fe is also a typical element associate to it (Belis et al., 2013; Calvo et al., 2012).

Likewise, Figure 4b) shows the relationship between Zn and Fe in the strawberry leaves and the ratio found in the settled dust (Zn/Fe=0.01). These elements present a very weak correlation with only r^2=0.14. However, and similarly to Cr and Fe, the tendency lines present a deviation that can be due to the contribution of other source than the industry. One of the possible sources can be due to traffic (with Zn as a typical element), which is plausible since the studied area is considered as urban-industrial type with a high traffic intensity.

Lastly, the relationship between Mn and Fe in the strawberry leaves was also studied and compared with the ratio found in the settled dust (Mn/Fe=0.14), as shown by Figure 4c). It is possible to observe that no association between

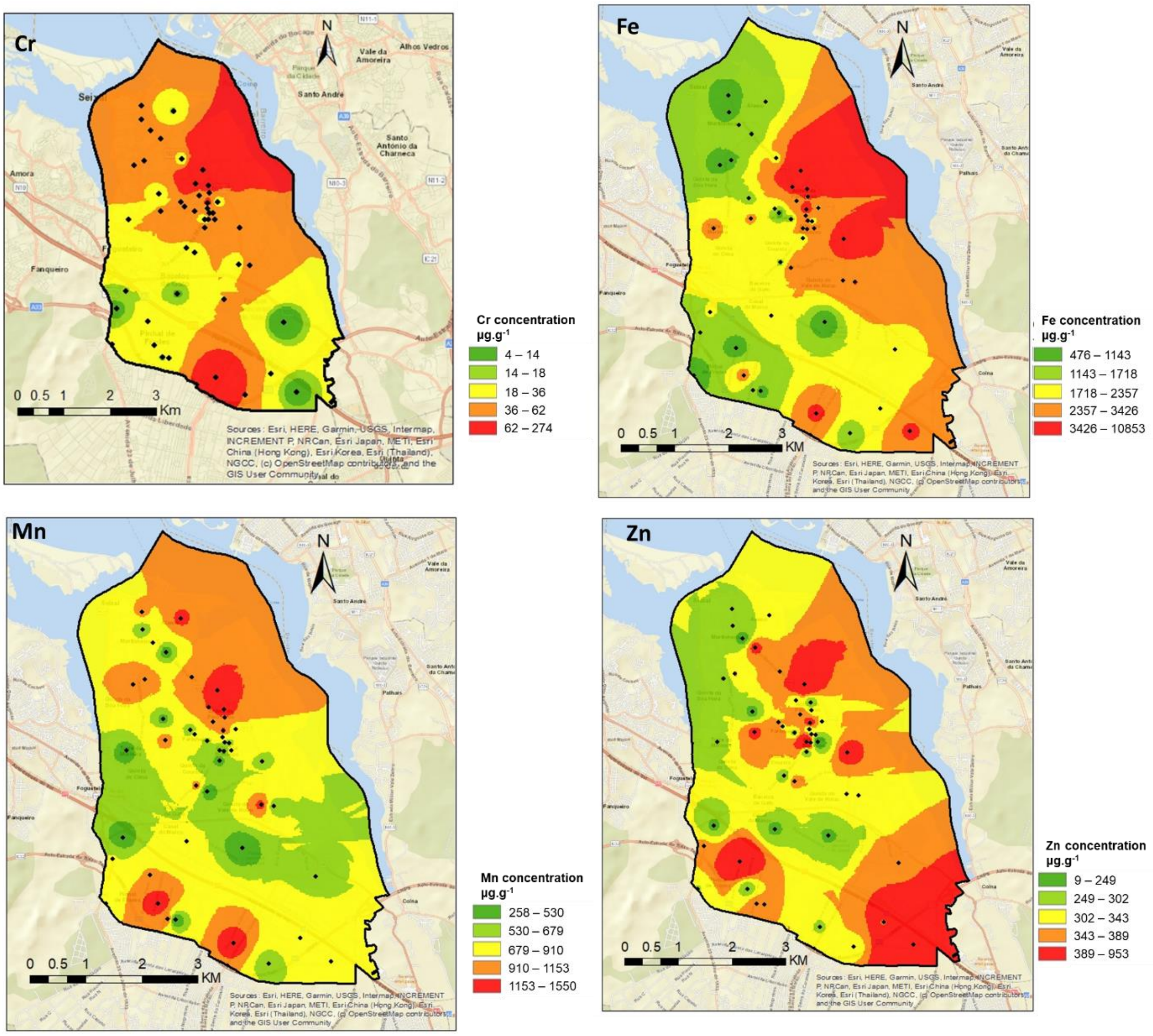

Figure 3 – *Spatial distribution for the elements Cr, Fe, Mn and Zn measured on the strawberry leaves (in µg.g^{-1})*

these elements in the strawberry leaves is found, with a very weak correlation (r^2=0.12).

In all these figures, it is possible to observe a similar trend between the ratios found between strawberry leaves and the studied settled dust, which indicates the influence of the same source for both studies.

3.3.3. Gradient of concentration with the distance to the steelwork

Another interesting aspect to analyse is the evolution of the elements' concentration with the distance to the steelwork in order to assess the behaviour of these elements.

Therefore, it was defined a point in the middle of the steelwork industry and considered circles with increments of 1 km radius with center on the middle point of the steelwork industry. The elements' concentrations in the strawberry leaves were displayed taking into account the considered circles, as shown by Figure 5, showing the trends with the distance from the steelwork industry. It was possible to verify a high decrease of the concentration for the elements Fe and Cr as the distance increased, with these elements showing a decrease of 49% and 57% in their concentrations, respectively, when considering a distance of more than 3 km from the steelwork (and comparing with the levels found nearby the steelwork).

Regarding Fe, comparing the average level found in the strawberry leaves in the 1 km radius with the furthest reference strawberry leave (C2), it showed an enrichment of 4.59. Simultaneously, comparing the sample inside the steelwork with the same reference strawberry leave, the ratio between them is 13.9 showing a high enrichment and indicating the

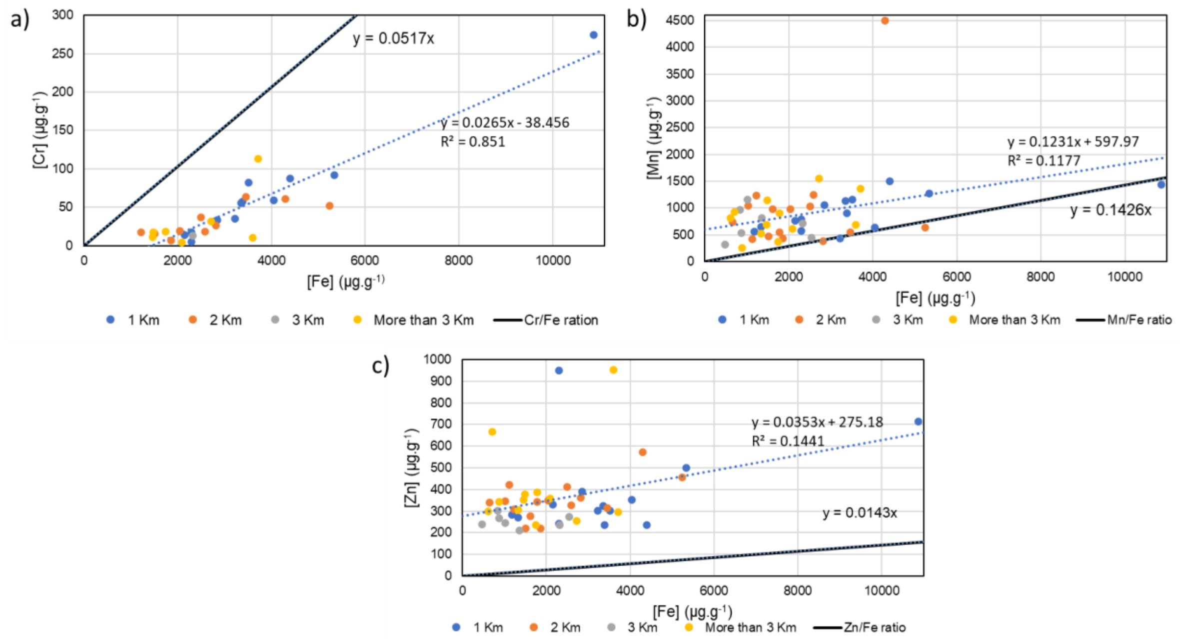

***Figure 4** – Relationship between the elements a) Cr and Fe b) Mn and Fe and c) Zn and Fe for the strawberry leaves and the black lines stand for the ratios of the same elements found in the settled dust.*

possibility for Fe to be associated with the steelwork.

For Mn, its concentration is constant in the first two km away from the steelwork and starts to decrease slightly by the 2 km distance.

Finally, Zn showed an increase of its concentration after 3 km away from the steelwork. From its spatial distribution (Figure 3), it is possible to verify high concentrations in certain strawberry leaves located far away of the steelwork. These samples were located nearby the highway, which may indicate traffic as a possible source since this element is also associated with mechanical abrasion of tyres and brakes (Almeida et al., 2006; Belis et al., 2013).

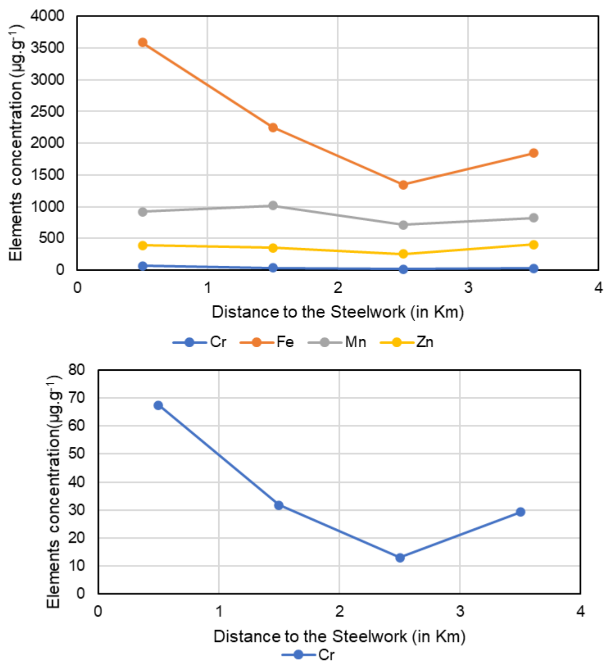

***Figure 5** - Concentration of the elements (in µg.g^{-1}) Cr, Fe, Mn and Zn considering the steelwork's distance (top), with a highlight for the element Cr (bottom)*

4. CONCLUSIONS

This study allowed to assess the perception of the air quality in the study area and compare it with the general population, where it was highlighted the high level of concern, awareness and knowledge about the topic of the population of the study area when comparing with the general population.

Using the two complementary strategies (analysis of the settled dust from pollution events and the biomonitoring of air pollution using strawberry leaves), it was possible to identify the industrial area with the steelwork as a potential source of air quality deterioration.

In the settled dust, the elements Cr, Fe and Mn were associated, indicating a common source. These elements are typically associated with iron and steel industries. Based in the biomonitoring approach using strawberry leaves and evaluating the spatial distribution of the elements, it was found that these elements presented higher levels in the industrial area. In particular, an association between Fe and Cr was found (typical of emissions from iron and steel industries), along with a decrease in their concentrations as the distance to the steelwork increased. These facts indicates the possibility of the steelwork being one of the main sources for the degradation of the local air quality.

Further studies focusing on the assessment of levels of fine particulate matter (PM2.5), taking in account its health hazard, should be conducted by reference methods in order to evaluate its compliance with national legislation. Moreover, target mitigation measures should be employed in the steelwork in order to promote an improvement of the local air quality.

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