



**HAL**  
open science

## Deconstruction of annoyance due to air pollution by multiple correspondence analysis

Milena Machado, Jane Meri Santos, Séverine Frère, Phillipe Chagnon,  
Valdério Reisen, Pascal Bondon, Márton Ispány, Ilias Mavroidis, Neyval Costa  
Reis

► **To cite this version:**

Milena Machado, Jane Meri Santos, Séverine Frère, Phillipe Chagnon, Valdério Reisen, et al.. Deconstruction of annoyance due to air pollution by multiple correspondence analysis. *Environmental Science and Pollution Research*, 2021, 28 (35), pp.47904-47920. 10.1007/s11356-021-13958-8. hal-03209912

**HAL Id: hal-03209912**

**<https://centralesupelec.hal.science/hal-03209912>**

Submitted on 15 Aug 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

[Click here to view linked References](#)

1        **Deconstruction of annoyance due to air pollution by multiple correspondence analyses**

2

3        Milena Machado<sup>a\*</sup>, Jane Meri Santos<sup>b</sup>, Severine Frere<sup>c</sup>, Phillipe Chagnon<sup>c</sup>, Valdério  
4        Anselmo Reisen<sup>d</sup>, Pascal Bondon<sup>f</sup>, Márton Ispány<sup>g</sup>, Ilias Mavroidis<sup>d</sup>, Neyval Costa Reis  
5        Junior<sup>b</sup>

6

7        <sup>a</sup> Instituto Federal de Ciência e Tecnologia do Espírito Santo, Guarapari, Brazil

8        <sup>b</sup> Department of Environmental Engineering, Universidade Federal do Espírito Santo,  
9        Vitoria, Brazil

10       <sup>c</sup> Université du Littoral Côte d’Opale, Maison de la Recherche em Science de l’Homme,  
11       Dunkerque, France

12       <sup>d</sup> Hellenic Open University, School of Science and Technology, Greece

13       <sup>d</sup> Department of Statistics, Universidade Federal do Espírito Santo, Vitoria, Brazil

14       <sup>f</sup> Laboratoire des Signaux et Systems (L2S), CNRS-Centrale Supélec-Université Paris-  
15       Sud, Gif sur Yvette, France

16       <sup>g</sup> University of Debrecen, Debrecen, Hungary

17       \* Tel: +55 (27) 988527717, e-mail: milenammm@ifes.edu.br

18 ***Abstract***

19

20 Annoyance caused by air pollution is a matter of public health as it can cause stress and  
21 ill-health and affect quality of life, among other burdens. The aim of this study is to apply  
22 the multiple correspondence analyses (MCA) technique as a differential tooling to  
23 explore relationships between variables that can influence peoples' behaviour concerning  
24 annoyance caused by air pollution. Data were collected through a survey on air pollution,  
25 environmental issues and quality of life. Face-to-face survey studies were conducted in  
26 two industrialized urban areas (Vitoria in Brazil and Dunkirk in France). These two  
27 regions were chosen as their inhabitants often report feeling annoyed by air pollution and  
28 both regions have similar industrial characteristics. The results showed a progressive  
29 correspondence between levels of annoyance and other active variables in the "air  
30 pollution" factor group: as the levels of annoyance increased, the levels of the other  
31 qualitative variables (importance of air quality, perceived exposure to industrial risk,  
32 assessment of air quality, perceived air pollution) also increased. Respondents who  
33 reported feeling annoyed by air pollution also thought that air quality was very important  
34 and were very concerned about exposure to industrial risks. Furthermore, they often  
35 assessed air quality as horrible and they could frequently perceive air pollution by dust,  
36 odours and decreased visibility. The results also showed a statistically significant  
37 association between occurrence of allergies and high levels of annoyance.

38

39 ***Keywords:*** *air pollution, perceived annoyance, behaviour, health impacts, Multiple*  
40 *Correspondence Analysis.*

## 41 **1. Introduction**

42  
43  
44 Air pollution can cause various health impacts, such as respiratory and cardiovascular  
45 diseases, hypertension and cancer among others (WHO, 2014; Lercher et al., 1995; Llop  
46 et al., 2008; Nascimento et al., 2017; Souza et al., 2018). In addition to the direct health  
47 effects caused by the exposure to pollutants, air pollution may also cause annoyance  
48 (Amundsen et al., 2008; Machado et al., 2018; Orru et al., 2018b). The concept of  
49 annoyance can be complex and extremely subjective as it can be experienced as a  
50 perception, an emotion, an attitude or a mixture of these (Berglund, Berglund & Lindvall,  
51 1987). Lindvall and Radford (1973) defined annoyance as “a feeling of displeasure  
52 associated with any agent or condition known or believed by individuals or groups to  
53 adversely affect them”. Annoyance can be associated with negative emotions, such as  
54 anger, disappointment, dissatisfaction, helplessness, anxiety and agitation, and  
55 behavioural/social changes, such as interference with intended activities (Blanes-Vidal  
56 et al., 2012). Furthermore, the World Health Organization (WHO, 2005) defines health as a  
57 “state of complete physical, mental and social well-being and not merely the absence of  
58 disease or infirmity”. Therefore, annoyance caused by air pollution can be considered as  
59 a health problem and an ambient stressor that affects the quality of life.

60  
61 Although a significant number of studies linking air pollution and human health risks  
62 exist in the literature (for example Oglesby et al., 2000; Llop et al., 2008; Stenlund et al.,  
63 2009; Egondi et al., 2013; Orru et al., 2018), comparatively, there are few studies  
64 exploring perceived annoyance caused by air pollution as a health risk and its influencing  
65 parameters. According to Jacquemin et al. (2007), there are factors or groups of  
66 qualitative variables that can be determinants of the perceived annoyance, such as  
67 sociodemographic factors, health symptoms, location of residence and perception of  
68 levels of particulate matter.

69  
70 One way to better understand the relationship among qualitative variables related to  
71 annoyance is through the technique of correspondence analysis. Multiple Correspondence  
72 Analysis (MCA) is a multivariate analysis technique for categorical data that allows to  
73 graphically assess the differences, similarities and relationships between variables and  
74 their response categories (Benzécri et al., 1973; Greenacre & Blasius, 2006).

75  
76 The objective of the present work is to analyse and compare the relationships between  
77 qualitative variables determining the nuisance caused by air pollution. Although the MCA  
78 technique has not been applied before in relation to air pollution, it is a well-valued  
79 technique for exploring qualitative variables related to annoyance caused by air pollution  
80 and health risks. The MCA is developed here to evaluate the datasets from two surveys  
81 conducted in different urban and industrialized regions, namely Dunkirk (France) and  
82 Vitoria (Brazil), which have many characteristics in common.

## 83 84 **2. Materials and methods**

### 85 86 **2.1. Characteristics of the regions**

87  
88 The study was conducted in two distinct urban industrialized regions located in coastal,  
89 port and industrial areas (Figure 1 and Figure 2): Dunkirk (France) and Vitoria (Brazil).  
90 This allowed for the comparison of the annoyance levels observed in two regions with

91 similar characteristics and provided further insight into the relationship between  
92 annoyance and air pollution effects.  
93 Despite the geographic and socioeconomic differences between these regions, both are  
94 exposed to high levels of air pollution and their inhabitants often report annoyance due to  
95 air pollution to their local authorities. According to a report concerning the industrial risk  
96 perception in Dunkirk (Calvo-Mendieta et al., 2008, Hellequin et al, 2010), air pollution  
97 is cited as the first environmental problem by its inhabitants, followed by water and soil  
98 pollution. In Vitoria, according to the local environmental agency more than 24% of the  
99 complaints refer to air pollution (Machado et al., 2018). In 2009, Dunkirk and Vitoria  
100 signed an international cooperation agreement to develop a variety of events, organizing  
101 projects in the realm of environment, culture, economy, port activities, urban  
102 development and university research (Les ateliers, 2010).

### 103 104 *2.1.1. Dunkirk*

105  
106 The metropolitan region of Dunkirk (MRD) has about 210,000 inhabitants, is the third  
107 largest port in France and an industrialized region containing steel, food, pharmaceutical  
108 and chemical industries, an oil refinery and also a nuclear power station for electricity  
109 production (risk's source). The climate is oceanic, that is strongly influenced by the wind:  
110 summer breeze sometimes contributes to increase sunshine hours, but there are also  
111 episodes of "squalls" accompanied by penetrating winter rains (Boyouk et al., 2011;  
112 Salvador et al., 2016). The anthropogenic activities present potential sources of  
113 particulate matter, which is the main cause of complaints by the resident population in  
114 this region (PPA, 2002). Measurement of air pollutant concentrations are being carried  
115 out by air quality monitoring stations distributed according to the French national  
116 guidelines (ADEME, 2002), which implement European Union Directives 96/62/EC and  
117 99/30/EC.

118  
119 According to the Protection Plan of the Atmosphere (PPA, 2002), the emission inventory  
120 of MRD clearly shows that the industrial sector is the largest emitter of pollutants. For  
121 particulate matter (PM<sub>10</sub>) the main sources in the region are industries, incineration plants,  
122 collective and individual heating, followed by road transport. In PPA (2002) there are  
123 measures established for local industries, to prevent and reduce the dispersion of particles,  
124 such as spraying water on stock piles, watering paths and storage areas, as well as  
125 changing the conditions of discharge.

### 126 127 *2.1.2. Vitoria*

128  
129 The metropolitan region of Vitoria (MRV) has about 1,500,000 inhabitants (IBGE, 2010)  
130 and is located on the south-eastern coast of Brazil (Figure 2). The MRV climate is  
131 classified as tropical, hot and humid, characterized by long summers (usually October to  
132 April) and high temperatures, with maximum temperatures occurring usually in  
133 December and January. Winter is weak, with average temperature of the coldest month  
134 about 18°C, the cold sensation existing occasionally related to the occurrence of cold  
135 fronts. The prevailing wind direction is north-easterly which contributes to the dispersion  
136 of pollutants emitted from the main large industries in the area towards the city (Andréão  
137 et al., 2019).

138  
139 The MRV comprises a large port system, heavy vehicular traffic and an industrial park  
140 that includes, among others, steel production, pelletizing, quarry, cement and food

141 industries, chemical industries and an asphalt plant, that are all potential sources of air  
142 pollution (Santos et al., 2017). In recent years, the region of Vitoria has experienced a  
143 process of economic growth and increased industrial production as well as urban  
144 development (IJSN, 2015). To monitor the air quality in the Vitoria region, eight air  
145 quality monitoring stations, set in different locations in MRV, are managed by the state  
146 environmental agency. According to Santos et al., (2017) the major contributor sources  
147 of total particles in Vitoria are resuspension due to vehicular traffic in paved and unpaved  
148 roads, followed by industrial emissions (mainly the pelletizing and steel industries) and  
149 vehicles exhausts. Machado et al. (2018) found that most of the complaints about air  
150 pollution are related to nuisance from particles.

## 151 **2.2. Measured air quality levels**

152  
153 Recent studies have shown that fine ( $\leq 2.5 \mu\text{m}$ ,  $\text{PM}_{2.5}$ ) and ultrafine particles ( $\leq 0.1 \mu\text{m}$ ,  
154  $\text{PM}_{0.1}$ ) are associated with diseases in the lower respiratory system (Farfel et al., 2005,  
155 Souza et al., 2017). Inhalable particles ( $\leq 10 \mu\text{m}$ ,  $\text{PM}_{10}$ ), that also include fine and ultrafine  
156 particles, also pose severe public health concerns, such as upper respiratory system  
157 disturbances and in some cases persistent nuisance (Vallack and Shillito, 1998;  
158 Amundsen et al., 2008; Blanes- Vidal et al., 2012; Machado et al., 2019).

159  
160 Table 1 shows some descriptive statistics of 24-hour average  $\text{PM}_{10}$  concentrations  
161 measured at the air quality stations in Dunkirk during the year 2008 (Atmo Nord-Pas-de-  
162 Calais, 2009). As can be seen from this table, the mean concentration levels differ  
163 significantly among stations. The largest standard deviations were observed for the  
164 concentrations measured in the stations: Fort Mardyck, St Pol Mer Nord, Grande-Synthe  
165 and Mardyck. This is due to the large variability between the minimum and maximum  
166 concentration values registered in these stations. The 24-hour average  $\text{PM}_{10}$   
167 concentrations surpassed in several occasions the respective WHO annual air quality  
168 guideline, which is  $50 \mu\text{g}/\text{m}^3$  (24h mean) (WHO, 2005).

169  
170 Table 2 presents the descriptive statistics of 24-hour average  $\text{PM}_{10}$  concentrations measured during 2011  
171 at the air quality monitoring stations located in MRV, except at Vila Velha-Centre station,  
172 which in 2011 did not register enough data (min70%) for analysis. As can be seen, the  
173 largest standard deviation (variability between the minimum and maximum concentration  
174 values) are measured in the stations: Laranjeiras, Vila Velha-Ines and Cariacica. At all  
175 air quality stations, the 24-hour mean is higher than the WHO annual air quality guideline  
176 for  $\text{PM}_{10}$  (WHO, 2005). As in the case of Dunkirk, the  $\text{PM}_{10}$  data show the occurrence of  
177 high concentration peaks during the year.

## 178 **2.3. The surveys**

179  
180 A survey was conducted at the MRD in 2008 with a representative sample of 518 people  
181 (over 18 years old) interviewed using face-to-face questionnaires. The respondents were  
182 chosen at random at urban communities grouped into 10 sub-regions: Bourbourg,  
183 BrayDunes/Leffrinckoucke, Téteghem, Coudekerque Branche, Gravelines, St Pol sur  
184 Mer, Grand Synthe, Petite-Synthe, Dunkirk and Malo/Rosendael. The sample size was  
185 proportionally distributed according to gender, geographic location (near or far from  
186 industries/port area), and socio-professional category.

190 A separate survey was conducted in the MRV in 2011; the sample size was determined  
191 by using a simple random sampling with proportional allocation method (Cochran, 1977)  
192 totalling a representative sample of 515 respondents (over 16 years old), which were  
193 distributed proportionally in the sub-regions around the eight air quality monitoring  
194 station: Laranjeiras, Carapina, Ibes, Jardim Camburi, Vitoria-Centre, Enseada do Sua,  
195 Cariacica and Vila Velha-Centre. It should be noted that the locations of the eight  
196 monitoring stations in the MRV were originally planned according to the population  
197 density and the proximity to the main industrial sources, vehicular sources and port area.

198

199 The questionnaire used in the MRD in 2008 was adapted and applied in the MRV region  
200 in 2011. A piloting questionnaire was used for a pre-test to ensure stability over time and  
201 internal consistency. The main questions selected, for the analysis in this study, are  
202 displayed in Table 3.

203

204 The surveys contained questions concerning socioeconomic and demographic factors  
205 such as age, level of education, occupation, habits, gender and location of residence (see  
206 Table 3). These were closed-ended questions providing answer options based on a Likert  
207 scale. To quantify nuisance, categorical scales were prepared and applied according to  
208 the context of each question (for example, “*Do you feel annoyed by air pollution?*”, with  
209 the categorical answer options: *not annoyed, slightly annoyed, very annoyed, extremely*  
210 *annoyed* and “*do not know*”).

211

212 Categorical scales are often applied in studies on annoyance caused by particles, odour  
213 and noise, such as in the studies conducted by Passchier & Passchier (2000) and Klæboe  
214 et al. (2000), for instance. Atari et al. (2009) adopted five-point categorical and numerical  
215 scales to measure annoyance caused by odour. Blanes-Vidal et al. (2012) adopted a  
216 qualitative scale with five intensity levels (not annoyed, slightly annoyed, moderately  
217 annoyed, very annoyed and extremely annoyed) to measure annoyance caused by  
218 ammonia. Llop et al. (2008) measure the annoyance caused by air pollution from outdoor  
219 sources (such as smoke, gas and particles) by categorizing annoyance through a scale  
220 including: not (0), slightly (1-3), moderately (4-7) and extremely (8-10) annoyed. To  
221 measure the perceived annoyance, the qualitative answers were recorded in a categorical/  
222 ordinal 4-point scale (1 for not annoyed; 2 for slightly annoyed; 3 for very annoyed; and,  
223 4 for extremely annoyed) to facilitate the interpretation of results by the Multivariate  
224 Correspondence Analysis (MCA) technique. Table 3 presents the questions listed in both  
225 surveys, the variable from each question and the factor groups of variables. For all  
226 questions the answer option "not know" (NK), was also included.

227

### 228 **3. Multiple Correspondence Analysis (MCA)**

229

230 MCA is a multivariate data analysis technique applicable to a large set of categorical  
231 variables (Greenacre, 2007). MCA, as the counterpart of PCA for categorical variables,  
232 became standard for the analysis of questionnaires (Le Roux & Rouanet, 2010). MCA is  
233 used to detect and represent data graphically (by the scatterplot) as a set of points with  
234 respect to two perpendicular coordinate axes: the horizontal axis often referred to as the  
235 *x*-axis and the vertical one as the *y*-axis. The objective of this technique is to analyse  
236 graphically the relationships between variables, response categories and objects, by  
237 reducing the dimensionality of the data set (Crivisqui, 1995; Lebart et al., 1984). The  
238 graphical representation can be made for individuals, for the variables, for the response  
239 categories as well as for the categories and individuals (Le Roux & Rouanet, 2010).

240

241 To apply MCA in the present study, data were initially organized in an Excel table  
242 containing respondents versus questions: the lines represented the respondents  
243 participating in the survey and the columns represented the questions listed in the applied  
244 questionnaire (each filled cell is the response category (answer) chosen by each individual  
245 for each question). The questions are categorized variables with finite number of response  
246 categories. For example, considering the question "Do you feel annoyed with air  
247 pollution?", the variable "annoyance" has the following response categories (with their  
248 encodings): not annoyed (ANNOY-1); Slightly annoyed (ANNOY-2); very annoyed  
249 (ANNOY-3); extremely annoyed (ANNOY-4), as well as the possibility of "no  
250 response/not known (NR/NK)" (ANNOY-9/99). Each respondent can choose one and  
251 only one response category for each variable or question. If the individual of line 1  
252 answered "very annoyed" to the above question, the variable cell was filled with the  
253 "ANNOY-4" category, and so on for all the individuals for each variable.

254

255 According to Le Roux & Rouanet (2010), the interpretation of the MCA outcome is based  
256 on the observation of the cloud of points, which is defined as a finite set of points in a  
257 geometric space. The cloud of points can represent variables, response categories and  
258 individuals. In this work, the cloud of points represents the response categories. The great  
259 advantage of MCA is the possibility to reduce the multi-dimensional space in an optimal  
260 subspace that allows the study of the scatterplot and the consequent analysis and  
261 interpretation of results. The generated graphs allow to visually assess whether all the  
262 variables of interest have associations among them and how they are associated.

263

264 The size of the scatterplot depends on the number of information points in each row or  
265 column, minus one. If the number of columns is related to  $K$  categories of responses of  $Q$   
266 variables, the maximum dimensionality of the scatterplot of categories is given by:

267

$$(K_1 - 1) + \dots + (K_q - 1) + \dots + (K_Q - 1) = (K_1 + \dots + K_q + \dots + K_Q) + (-1)Q = K - Q \quad \text{Eq.1}$$

268

269 The dimensionality reduction is normally made to  $R^2$ , to facilitate interpretation of the  
270 cloud of points (scatterplot). Le Roux and Rouanet (2010) define the middle point of the  
271 cloud of points in the following way: Let  $P$  be any point in space and  $(M^k)_{(k=1,2,\dots,K)}$  the  
272 points of categories for the scatterplot. The midpoint of the cloud point is the  $G$  point by  
273 the vector  $\overrightarrow{PG}$  as:

273

$$\overrightarrow{PG} = \frac{1}{n} \sum \overrightarrow{PM^k} \quad \text{Eq.2}$$

274

275 Point  $G$  does not depend on the choice of point  $P$ , i.e., whatever the chosen point  $P$  is,  
276 point  $G$  is always the same. Thus, point  $G$  is defined as the average of the coordinates of  
277 all points given by:

$$G = \frac{1}{n} \sum M^k \quad \text{Eq.3}$$

278

279 The distance between points depends on the different response categories for each  
variable. The lower the frequencies of the response categories are, the greater the distance



280 between points. Let  $n_{kk}^i$  be the number of subjects who chose both categories  $k$  and  $k'$ ,  
 281 then the square of the distance between  $M^k$  and  $M^{k'}$  is:

$$d^2(M^k M^{k'}) = \frac{n_k + n_{k'} - 2n_{kk}^i}{n_k n_{k'} / n} \quad \text{Eq.4}$$

282 As more categories  $k'$  and  $k$  are chosen for the same individuals, as shorter the distance  
 283 between  $M^k$  and  $M^{k'}$  is, and as closer two category points are, the stronger is the  
 284 association between them. As lower the frequency for category  $k$  is, the farther from the  
 285 centre the point  $M^k$  is. The less frequent the category of response is, the more it  
 286 contributes to the overall variance of the cloud of individual points. And the less frequent  
 287 the standard of responses of an individual is, the more it contributes to the total variance  
 288 (Le Roux and Rouanet, 2010).

289  
 290 The first principal axis of a cloud of categories can be defined as the line passing through  
 291 the midpoint of the cloud. The second main axis is perpendicular to the first one and is  
 292 also passing through the midpoint of the cloud of categories points. The same process is  
 293 followed to define the third axis, the fourth axis, and so on. There are no set rules for the  
 294 number of axes to be analysed (Grenacre, 2006). In this study, it appears that the first two  
 295 axes hold the highest percentage of the total variability of the data. Therefore, scatter plots  
 296 of categories are formed from the first two axes.

297  
 298 The results of the MCA can be confusing depending on the number of variables. Because  
 299 of this, the values of the contributions generated from the application of MCA  
 300 “collaborate” in the interpretation of the axes (Le Roux and Rouanet, 2010). Therefore,  
 301 in the present work, the contribution of each category as well as the summation are  
 302 analysed to identify the variable that contributes most to the interpretation of a particular  
 303 axis.

304  
 305 It is possible to select rows and columns that will generate the active points and also the  
 306 illustrative points (supplementary points). The active points are responsible for  
 307 determining the orientation of the principal axes, providing the necessary information for  
 308 the construction of the optimal cloud of category points. However, it is possible to include  
 309 more information which is represented by supplementary or illustrative points. The  
 310 supplementary points may be plotted on the map along with the active points, and they  
 311 are useful in interpreting features discovered in the primary data, but do not contribute to  
 312 the construction of the axis (Grenacre, 2007). The supplementary points are used to  
 313 represent information about the phenomenon under study and invariable information over  
 314 time, such as sex, race, or information for infrequent categories.

315  
 316 According to Le Roux & Rouanet, (2010), the contribution of a category point to  
 317 construct a particular axis defines the importance of this point for this same axis. Through  
 318 the coefficients of this contribution, it is possible to identify which categories (or points)  
 319 should be considered for the interpretation of each principal axis. The relative  
 320 contribution constitutes the axis contribution to the variance of the individual point, the  
 321 quality of representation of a point corresponds to the sum of the squared cosines of axes  
 322 1 and 2 (see Table 4 and Table 8). The test values assist the interpretation, but they don't  
 323 contribute to the total variance and are interpreted as how well represented the  
 324 supplementary points are (Greenacre, 2007) (see Tables 5, 6, 7 and 9).

325  
326  
327  
328  
329  
330  
331  
332  
333  
334  
335  
336  
337  
338  
339  
340  
341  
342  
343  
344  
345  
346  
347  
348  
349  
350  
351  
352  
353  
354  
355  
356  
357  
358  
359  
360  
361  
362  
363  
364  
365  
366  
367  
368  
369  
370  
371  
372  
373  
374

To generate each MCA stage, active and supplementary variables were defined and the number of factors to compose the factorial plans was set. This decision was based on the analysis of the population composition. There is no set of rules defining how many factorial plans should be scanned in graphics (Le Roux & Rouanet, 2010). To facilitate interpretation, a decision was made to select the first two factorial plans (axis 1 and 2) to compose the correspondence graph or the cloud of points (scatter plot). The coordinates for the axes F1 and F2 are those of the position of each category in the scatter plot. The proportion of the variance of the cloud due to a point is called the contribution of the point to the cloud. The sum of the category contributions for each variable shows which variable contributes the most to the cloud and also to each axis. The representation's quality is expressed by the value of squared cosines (the higher the square cosine value, the higher the quality of representation).

Table 3 presents all questions, the name of each variables to represent these questions and the factors groups represented for each variable/question. The variables selected to all response categories were unified to a single database as the results of both surveys, since the goal is to analyse differences and associations among annoyance caused by air pollution. The sociodemographic and local variables are considered in order to compare differences and similarities between the respondents' opinions in the two study areas. It is important to note that in the first MCA (Figure 3) the active variables selected are nominal/ ordinal while the supplementary variables are nominal.

**4. Results and discussion**

Tables 4 to 9 present the numerical results obtained using the MCA from a matrix intersection of respondents (rows) and their responses to the five questions (columns) of the questionnaire (factor group named as in Table 3). For each active or supplementary variable, the response options (categories), encoding, frequency and percentages, coordinates of the two axes (F1 and F2), contributions in the construction of the two axes and the squared cosine values are presented.

In Table 4 the sum of the category contributions for each variable shows the active variable “annoyance” contributes the most to the cloud and also to each axis (annoyance contributes 27.9% to the axis F1 and 25.9% to F2). Figure 3 is the correspondence graph (scatterplot) with the coordinates of axes F1 and F2 generated for the active variables shown in Table 4 (“air pollution”) and the supplementary variables shown in Table 5 (“local”). The axes F1 (52,67%) and F2 (18,25%) explain about 71% of the variability from the database, considering all active variables simultaneously, which is considered as an excellent performance (Le Roux & Rouanet, 2010).

In Figure 3 analysing the direction from right to left on the F1 axis, there is a progressive tendency for increased levels of annoyance as indicated by the position of the respective categories (ANNOY1-not annoyed, ANNOY2- slightly annoyed, ANNOY3-very annoyed and ANNOY4-extremely annoyed). The same progressive tendency (from categories 1 to 4) can be observed for the variables: importance of air quality (IMP1-not important, IMP2- slightly important, IMP3-very important, IMP4-extremely important); industrial risk perception (RISK1-not exposed, RISK2-slightly exposed, RISK3-very exposed, RISK4-extremely exposed); assessment of air quality (AIRQ1-excellent AIRQ2-good, AIRQ3-bad, and AIRQ4-horrible); and also, to the air pollution perception

375 variable (PPOL1-never, PPOL2-sometimes, PPOL3-often, PPOL4-always). The axis F1  
376 can be interpreted as defining (from the right to the left) a scale of “perceived annoyance”,  
377 and the axis F2 appears to oppose moderate response categories (lower side) to both  
378 extremely positive and extremely negative responses.

379  
380 Continuing in Figure 3, the scatter plot can also be interpreted through the parabolic shape  
381 of the cloud of points of the chart from the bottom to the centre, setting categories for  
382 “slightly” and “very” levels, while the upper right corresponds to the “not” level and the  
383 upper left to the categories represented by the level “extremely”. Such a pattern of  
384 responses suggests what is known in the literature as the “Guttman effect” (Greenacre &  
385 Blasius, 2006) or “horseshoe effect” (Van Rijckevorsel, 1987 *in* Greenacre & Blasius,  
386 2006) due to its parabolic shape or arch. This is a structured form of the distribution of  
387 the categories of annoyance levels, which are arranged in a hierarchical way, from those  
388 who do not report nuisance (upper right), to those who express moderate annoyance  
389 (vertex of the parabolic) and arriving at extremely annoyed level (top left).

390  
391 Also, in Figure 3 the joint progression of annoyance levels and other active categories  
392 from right to left in axis F1 indicates that an individual who reported being extremely  
393 annoyed due to air pollution also thought that the air quality was extremely important,  
394 felt extremely exposed to industrial risks, assessed air quality as horrible and always  
395 perceived air pollution by dust/odour/air visibility. Another possible pattern visible in  
396 Figure 3 is the “battery effect” which is often observed in survey analysis, where the  
397 respondents choose similar answers without necessarily considering the content of the  
398 questions. However, these questions were not presented in the same order to the Dunkirk  
399 and the Vitoria inhabitants as selected for this analysis. Furthermore, the response options  
400 presented for the question concerning the assessment of air quality were ordered in such  
401 a way that they express “opposed feelings” in relation to the response to other questions,  
402 causing the respondent to give due regard before answering.

403  
404 Table 5 presents the categories for the sub-regions/areas where the respondents live, the  
405 code for each location, the frequencies and percentages of responses, the coordinates for  
406 each response category and the test values for the axes F1 and F2 related to the  
407 supplementary variables of the “Local” group. The test value is an indication of the  
408 significance of the obtained results (5% p-value or 1.96 p-value in absolute terms)  
409 (Crivisqui, 1995). The test value was calculated as the distance from each point to the  
410 origin of the axes F1 and F2, in numbers of standard deviations.

411  
412 It is important to observe the negative test values in Table 5, since the negative values in  
413 axis F1 correspond to the local variables or the area where people have reported to be  
414 very annoyed, while positive test values correspond to the area where people have  
415 reported little or no annoyance by air pollution. According to the correspondence graph  
416 in Figure 3, the locations where respondents reported being very annoyed due to air  
417 pollution correspond to the localities that have negative test values (on the left part of the  
418 F1 axis): Grande Synthe (LOCAL-D7) where the location is at -2.699 standard deviations  
419 from the mean point (origin) on axis F1; Petite-Synthe (LOCAL-D8) test value = -3.11;  
420 Jardim Camburi (LOCAL-V4) test value = -4.138 and Enseada do Sua (LOCAL-V6) test  
421 value = -4.812. These regions are geographically close to the main industrial sources in  
422 both regions. The residents in these sub-regions reported intense levels of annoyance;  
423 they also reported being very exposed to industrial risk, often assessed the air quality as  
424 “horrible” and perceived high levels of air pollution due to dust/odour/ visibility in their

425 neighbourhoods. It is very interesting to note that a comparison between the air quality  
426 results shown in Tables 1 and 2, for both urban areas, shows that the PM<sub>10</sub> concentrations  
427 are high, with peaks indicated by the maximum concentration, which suggests that the  
428 annoyance is not related only with this variable.

429  
430 Figure 4 shows the correspondence graph between the active variables in the “air  
431 pollution” group and the supplementary variables in the “sociodemographic” group. In  
432 this graph, the local variables were removed to facilitate visualization of the  
433 correspondence with sociodemographic variables: gender, age, occupation and level of  
434 education. Visually, the most important supplementary variables are close to the origin  
435 of the graph.

436  
437 Table 6 shows the results (frequency, coordinates and test value) for the correspondence  
438 graph in Figure 3 by each response category of sociodemographic variables. For MRV, it  
439 is possible to see that women reported being more annoyed than men, while in MRD this  
440 same association was not significantly. Consequently, in MRV women felt more exposed  
441 to industrial risk, assessed air quality as more important and perceived air pollution by  
442 dust/odour/visibility more than men. According to Fisher et al. (1991), the gender  
443 differences are noticeable especially in relation to environmental risks. Explanations are  
444 linked to the roles of women in society, which -even in our evolving societies- are most  
445 often oriented towards health and children. Gustafson (1998) also discusses this  
446 difference between men and women in relation to their roles in society and the power  
447 relations that exist between them. For example, women are more sensitive to  
448 environmental risks because they take care of their homes and children and clean the  
449 house normally more frequently than men, especially in more conservative societies.

450  
451 Regarding Figure 4, in MRD there was no significant correspondence visible between the  
452 age categories and the annoyance categories. However, in MRV it is possible to visualise  
453 a progressive relation between age (AGE-V1, AGE-V2, AGE-V3, and AGE-V4) and  
454 levels of annoyance. As age increased, the levels of annoyance, the importance of air  
455 quality, the perceived exposure risk, the assessment of air quality, and the perceived air  
456 pollution also increased. This association can be confirmed considering the test values in  
457 Table 6. Respondents older than 34 years (AGE-V3, AGE-V4) are associated to being  
458 very or extremely annoyed more than younger respondents (AGE-V1, AGE-V2).  
459 Normally, older people are more sensitive to health problems since they belong to the  
460 more sensitive population sub-groups (it should be noted that children do not participate  
461 in the survey and the responses of women were discussed above). They also experience  
462 the effects of air pollution more often, such as when removing dust (particles) for house  
463 cleaning, so they report being more concerned with annoyance caused by air pollution.  
464 Although this association is not so clear in Dunkirk compared to Vitoria, it should be  
465 noted that the results of Lercher et al. (1995) and Klæboe et al. (2000) suggest that older  
466 age is a determinant of perceived air pollution.

467  
468 Regarding occupation, in MRD the unemployed (OCCUP-D2) and student (OCCUP-D4)  
469 are on the right side of the F1 axis, so, they are associated to being slightly or not annoyed  
470 by air pollution. In Vitoria, however, the categories associated to being very and  
471 extremely annoyed by air pollution are the retired group (OCCUP-V3) and also the  
472 unemployed (OCCUP-V2) on the left side of the F1 axis. This association is significant  
473 for the retired group (test value = -3.44) in Vitoria and can be justified because generally

474 they are the group with older age that are also associate to being very and extremely  
475 annoyed by air pollution (see Table 6).

476

477 Considering the corresponding graph (Figure 4) and the test values for the “level of  
478 education” categories in MRV (Table 6), it is possible to see that the university group  
479 (EDUC-V4) is on the high levels of annoyance side of the axis F1. This result  
480 corroborates with Klæboe et al. (2000) that suggested that the education level was a  
481 determinant of perceived air pollution.

482

483 Figure 5 is the correspondence graph between “Air pollution” and “Health” groups. The  
484 supplementary variables selected were “health problems” and “health effects”. People  
485 who report “no” (HEFE-1) occurrence of health problems caused by air pollution are also  
486 the ones who are “less annoyed”. And people who answered “yes” (HEFE-2) to  
487 occurrence of health problems are associated to “being very annoyed”. In table 7, the test  
488 value = -5.113 for the variable health problems caused by air pollution, indicate the same  
489 association, people who answered “no”(HEFE-1), as shown on the right part of the graph,  
490 tend not to feel annoyed by air pollution, while those who responded “yes”(HEFE-2), as  
491 shown on the left side of the graph, tend to report being extremely annoyed by air  
492 pollution.

493 For the group of people that answered “yes” (HEFE-2), the main problems reported were  
494 lung/respiratory (HPROB-1), allergies (HPROB-3), asthma attacks (HPROB-5) and  
495 stress (HPROB-7). However, this correspondence are not significant for all, because only  
496 the test value= -2.85 for health effects, indicate that people who reported being  
497 very/extremely annoyed by air pollution were associated to the ones who reported  
498 allergies (HPROB-3). Although previous epidemiological studies have shown that certain  
499 levels of particulate matter concentrations can cause such health effects and increase the  
500 number of hospitalizations for respiratory problems (Pope III, 1991; Schwartz, 1991;  
501 Braga et al., 2001; Garçon et al., 2006; Llop et al., 2008), in this analysis no  
502 correspondence was found with annoyance and health effects.

503 In order to further explore these survey data, the MCA between the groups of factors  
504 “Cause” and “Local” was carried out and the active variables “source”, “METEO”,  
505 “season” and “day/night” as well as the supplementary variables “Dunkirk” and “Vitoria”  
506 were selected for analysis. Table 8 presents the summation of the coordinates,  
507 contribution and squared cosine values for each response category. It can be observed that  
508 the categories grouped under “METEO” and “SEASON” contribute significantly to the  
509 F1 axis. And the categories under “SOURCE” contribute significantly to the F2 axis. The  
510 summation of the contributions of the other response categories as well as the value of  
511 the squared cosines for the F1 and F2 axes can confirm such affirmations.

512

513 Figure 6 presents the correspondence graph between the factor groups “Cause” and  
514 “Local”. Analysing the active variable “METEO”, the respondents that answered “no” to  
515 the question regarding the influence of meteorological conditions on the perception of air  
516 pollution (METEO-2) are located on the right part of the F1 axis, while the left part of the  
517 F1 axis indicates the respondents who answered “yes” (METEO-1). Analysing the active  
518 variable “SEASON,” the left part of the F2 axis corresponds to the yes (METEO-1)  
519 category. It is possible to see a progressive tendency from spring (SEASON-4), to

520 summer (SEASON-1), to autumn (SEASON-2), to winter (SEASON-3). That is, the  
521 respondents that reported “yes” to the question about the influence of meteorological  
522 conditions on the perception of air pollution also perceived a progressive effect of  
523 seasonality from spring and summer to autumn and winter. As shown in other studies (for  
524 example Castanho & Artaxo, 2001; Albuquerque et. al., 2012; Andreão et al., 2019)  
525 meteorological conditions have a major influence on the suspended particle  
526 concentrations, which can suggest that meteorology is another determinant that affects  
527 the perception of air pollution.

528

529 Regarding the active variable “SOURCE”, it is possible to observe the response category  
530 “source industry” (SOURCE-2) on the upper-right part of the graph and the categories  
531 “building” (SOURCE-4), “suspension of soil” (SOURCE-3), and “vehicle” (SOURCE-  
532 1) on the lower-middle of the graph with no association with the variable “METEO”. This  
533 clearly shows the important role of industry in relation to air pollution in the two  
534 examined industrial urban areas, especially as this is perceived by the population. The  
535 response categories “yes” (DN-2) and “no” (DN-1) for perceived air pollution changes  
536 between day and night are close to the origin and are non-significant.

537

538 For the “LOCAL” supplementary variable, the lower part of the graph and on the middle  
539 and left of the F1 axis corresponds to the areas in Vitoria showing that the people  
540 perceived an influence of weather changes on the quantity of particles/dust  
541 (corresponding to METEO-1). The upper part of the graph on the middle and right part  
542 of the F1 axis shows that in Dunkirk, there is no perceived association between the  
543 meteorological conditions and air pollution (corresponding to METEO-2). This result  
544 may be related to the fact that people who live close to industries are already accustomed  
545 to pollution and they do not feel the influence of weather changes on the perceived air  
546 pollution. Furthermore, as Figure 1 indicates, in Dunkirk industrial pollution sources are  
547 more interspersed within the urban area, while in Vitoria they are more at the boundaries  
548 of the city (especially northwest, but also partly southeast) and therefore the  
549 meteorological conditions – such as wind direction and wind speed – may have a more  
550 concrete influence on the perceived air pollution.

551

552 Regarding the categories “Source” associated with “Local”, the results in Figure 5 suggest  
553 that, for Vitoria, the locations far from the main industrial areas, like Cariacica (LOCAL-  
554 V7) and Vitoria-centre (LOCAL-V5), were more associated with the construction  
555 work/building source (SOURCE-4) and slightly with the vehicular source (SOURCE-1)  
556 of air pollution. It should be noted that in these areas, and especially Cariacica, high  
557 levels of particulate pollution were measured by the air quality monitoring stations (Table  
558 3) and according to Santos et al., (2017) the main source of particulate matter in Cariacica  
559 is construction work. Currently, construction work in Vitoria is developing rapidly in  
560 terms of housing construction and paving streets and roads, while the number of vehicles  
561 is also increasing: these sources can contribute to increasing air pollution and  
562 dust/particles that cause annoyance, especially since these locations are further away from  
563 industrial sources. In Dunkirk, the locations close to the main industrial areas, St. Pol Sur  
564 Mer (LOCAL-D6), Grande Synthe (LOCAL-D7) and Petite-Synthe (LOCAL-D8) were  
565 found to be associated with the “industry” source (SOURCE-2), while the “construction  
566 work/building” and “vehicular” sources are not significant, as are the “industrial” sources  
567 which are located next to residential areas and visible from the main beaches. St. Pol Sur  
568 Mer is also the location where the highest levels of particulate pollution were measured  
569 (Table 2) and also very close to the industrial sources.

570

571 The above results may also partly be explained by the size of the population in Vitoria,  
572 which is larger than in Dunkirk, and the fact that public transport in Dunkirk is well  
573 developed; therefore, the number of vehicles circulating in Dunkirk is not as high as in  
574 Vitoria. According to Rotko et al. (2002) and Amundsen et al. (2008) heavy traffic is  
575 related to annoyance caused by air pollution, so this result can explain why people  
576 exposed to heavy traffic in Vitoria perceived vehicular sources more significant than in  
577 Dunkirk, especially in areas which are not as influenced by industrial sources. Also, as  
578 noted above, currently the construction sector in Vitoria is developing rapidly both in  
579 terms of housing construction and paving streets and roads, which can generate dust that  
580 may cause annoyance. As suggested by Nikolopoulou et al. (2011), air quality is often  
581 considered to be poor at construction sites, which are burdened by higher PM  
582 concentrations.

583

584 Table 9 shows the coordinates and the test values for the “LOCAL” supplementary  
585 categories. Regarding the test values, there is a strong association (not contribution) with  
586 the variable that contributes to the F2 axis. The positive test values for the F2 axis are the  
587 Dunkirk locations in the upper quadrants of Figure 6, indicating the respondents which  
588 perceived urban air pollution from industries sources. The negative test values for the F2  
589 axis are the Vitoria locations in the lower quadrants, which indicating respondents that  
590 perceived urban air pollution from construction works and vehicular sources.

591

## 592 **5. Conclusions**

593

594 The purpose of this work was to apply the multiple correspondence analysis (MCA)  
595 technique to explore relationships between variables that can influence peoples’  
596 behaviour concerning annoyance caused by air pollution. Data were collected using a  
597 survey on air pollution, environmental issues and quality of life. The MCA technique was  
598 applied as a differential tooling to interpret factors by structural properties and significant,  
599 graphical relationships of proximity and opposition between points.

600

601 The results showed a progressive correspondence between levels of annoyance and other  
602 active variables in the “air pollution” factor group: as the levels of annoyance increased,  
603 the levels of the other qualitative variables (importance of air quality, perceived exposure  
604 to industrial risk, assessment of air quality, perceived air pollution) also increased. It is  
605 possible to conclude that people who reported feeling annoyed by air pollution also  
606 thought that air quality was very important, were very concerned about exposure to  
607 industrial risks, assessed often air quality as horrible and frequently perceived air  
608 pollution by dust/odour/visibility. It is important to emphasize that this result cannot be  
609 considered as a “battery effect”, since these questions were not applied in the sequence in  
610 which the results were analysed. In addition, the summary results of PM<sub>10</sub> concentration  
611 measurements in the two regions showed values above the guidelines established by the  
612 World Health Organization for long and short term exposure, which can be an indicator  
613 of attention to the possibility of occurrence of health problems, quality of life problems,  
614 and complaints about perceived annoyance caused by air pollution. According to the  
615 correspondence graph, people who live in areas close to industries, for example in Petite-  
616 Synthe and Grande Synthe in Dunkirk and Enseada do Suá and Jardim Camburi in  
617 Vitoria, have reported being very annoyed by air pollution. As showed by Machado et al.  
618 (2018), the location and the proximity to industrial sources of air pollution play an  
619 important role to explain peoples’ behaviour.

620

621 This study has also explored the association between respondents' perceptions and  
622 demographic characteristics. The gender and age variables were associated with  
623 perceived annoyance in MRV, while in MRD there was a much lower correspondence.  
624 In general, women were more annoyed than men, while people older than 55 years  
625 reported feeling more annoyed than people in other age ranges. For MRV, the study  
626 showed that women are more annoyed than men and that there is a positive relationship  
627 between age and the parameters level of annoyance, importance of air quality, perceived  
628 exposure to industrial risk, assessment of air quality and perceived air pollution by  
629 dust/odour/visibility.

630

631 Kohlhuber et al. (2006) have shown that socio-economic variables are associated with the  
632 perception of local air quality, suggesting that these variables may be important  
633 determinants of perceived air quality. However, in our study, the relationship between  
634 different forms of occupation remains controversial. It was found that retired and  
635 unemployed people showed high levels of annoyance in MRV, while in MRD students  
636 and unemployed showed low or no level of annoyance. It was observed that people  
637 educated to the university level were more concerned about annoyance caused by air  
638 pollution than those with lower educational levels in MRV. The importance of  
639 socioeconomic factors in the context of air pollution research has been emphasized  
640 because they represent underlying aspects that affect susceptibility, exposure, or disease  
641 diagnosis and treatment (Bell et al., 2005). Therefore, there is a need for careful choice  
642 and interpretation of socioeconomic factors depending on the location, as this can be  
643 partly influenced by social/cultural differences or/and by different weather conditions.

644

645 Significant association was observed between perceived health risks related to high level  
646 of annoyance caused by air pollution, importance of air quality, perceived exposure to  
647 industrial risk, assessment of air quality and perceived air pollution by  
648 dust/odour/visibility. Perceived occurrence of health problems related to annoyance  
649 caused by air pollution was found to be associated with gender (female), age (older), level  
650 of education (university level) and the type of occupation (retired), though it varied by  
651 the study location. The difference between the two sites could be explained by the  
652 difference in the age, occupation and education levels of the residents. There were more  
653 people older, employed and with university level in MRD compared to MRV, while in  
654 MRV there are more young people, students and with primary level of education as  
655 compared to MRD. The main health effects related to air pollution reported by  
656 respondents were lung/respiratory, allergies and eye irritation, which are common  
657 symptoms for a number of urban air pollutants (WHO, 2005). There is also a confirmed  
658 association between occurrence of allergies and high levels of annoyance.

659

660 The MCA results for the active variable "CAUSE" showed that people perceived that  
661 weather conditions and seasonal changes could affect air pollution. This perception was  
662 more evident in MRV, where heavy industries are at the boundaries of the city and their  
663 effect is more influenced by the prevailing meteorological conditions, such as the wind  
664 speed and especially wind direction. In MRD, people identified industrial sources as an  
665 important cause of air pollution and did not perceive that air pollution annoyance changes  
666 with changes in weather/meteorological conditions. Furthermore, in MRV, the influence  
667 of construction works and vehicular sources on the perception of air pollution was  
668 evident. Considering the geographic location of these two regions, the weather conditions



669 could influence the perceived annoyance caused by air pollution in different ways, and  
670 therefore the geographic location can justify these differences.

671

672 In both regions, the results from PM<sub>10</sub> concentration measurements show that the  
673 perceived annoyance does not only depend on this variable. This conclusion may help to  
674 better understand if the answers of the respondents are linked to other variables, such as  
675 the source of pollution and the meteorology. It is also important to note that there are  
676 differences in air pollution perceptions in the two study areas, which indicates that  
677 perceptions in general may depend on an area's overall setting and availability of  
678 industries, pollution sources or daily activities.

679

680 The results of this study have shown that Multiple Correspondence Analysis is a very  
681 useful tool in providing insight on environmental issues affecting the quality of life, such  
682 as the factors affecting the levels of air pollution annoyance of populations living in urban  
683 areas. This is a very useful tool to derive and synthesize important information from  
684 citizen surveys which can, in turn, complement air quality measurements, in order to  
685 define the best mix of actions to address air quality issues, for instance, national or  
686 regional emission reduction policies in order to meet the air quality objectives in  
687 background locations, as well as to decide on more site-specific and short-term measures  
688 to address air pollution. Such combination of measures is often necessary for the  
689 protection of the public health and the improvement of the quality of life of citizens.

690

## 691 **6. Declarations**

692

693 The ethics committee approved this study was from the University Federal of Espírito  
694 Santo with the 142.581 committee's reference number. This manuscript does not contain  
695 any individual /specific person's data.

696

697 The datasets used and/or analysed during the current study are available from the  
698 corresponding author on reasonable request.

699

700 The authors declare that they have no competing interests.

701

702 This study is part of the results from the research developed in the PhD thesis of the first  
703 author (MM) under the supervision of the authors JS and VR who made the necessary  
704 corrections. All authors declare to have contributed equally by reading and improving the  
705 analyses and the text.

706

707 These authors are indebted to CentraleSupélec and Université Paris-Sud for their financial  
708 supports. This research was also partially supported by the iCODE Institute, research  
709 project of the IDEX Paris-Saclay, and by the Hadamard Mathematics LabEx (LMH)  
710 through the grant number ANR-11-LABX-0056-LMH in the Programme des  
711 Investissements d'Avenir.

712

713 The authors would like to acknowledge the support of two Brazilian research funding  
714 agencies: FAPES (The Research Funding Agency in the State of Espírito Santo) and  
715 CAPES (The Federal Funding Agency for the Development of Higher Education). They  
716 would also like to acknowledge COFECUB, Irénée Zwarterook and a research group  
717 studying industrial risk and the urban environment in the TVES laboratory, Université du

718 Littoral Côte d’Opale in France. Finally, we thank Vinicius de Martin (UFES’ phd  
719 student) for helping with graphical design.

720

## 721 **7. References**

722

723 Albuquerque, T. T. de A.; Andrade, M. de F.; Ynoue, R. Y. Characterization of  
724 atmospheric aerosols in the city of São Paulo, Brazil: comparisons between polluted and  
725 unpolluted periods. *Environ. Monit. Assess.* 2012, 184, 969–984, doi:10.1007/s10661-  
726 011-2013-y.

727 ADEME (2002). Classification et critères d’implantation des stations de surveillance de  
728 la qualité de l’air. Retrieved on 28 July 2013 from:  
729 [http://www.oramip.org/pdf/ademe\\_typologies.pdf](http://www.oramip.org/pdf/ademe_typologies.pdf)

730 Amundsen, A. H.; Klæboe, R.; Fyhri, A. Annoyance from vehicular air pollution:  
731 Exposure–response relationships for Norway. *Atmos. Environ.* 2008, 42, 7679–7688,  
732 doi:10.1016/j.atmosenv.2008.05.026.

733 Andreão, W. L., Trindade, B. T., Nascimento, A. P., Reis Júnior, N. C., Andrade, M. D.  
734 F., & Albuquerque, T. T. D. A. (2019). Influence of Meteorology on Fine Particles  
735 Concentration in Vitória Metropolitan Region During Wintertime. *Revista Brasileira de*  
736 *Meteorologia*, 34(4), 459-470.

737 Atari, D. O.; Luginaah, I. N.; Fung, K. The Relationship between Odour Annoyance  
738 Scores and Modelled Ambient Air Pollution in Sarnia, “Chemical Valley”, Ontario. *Int.*  
739 *J. Environ. Res. Public Health* 2009, 6, 2655–2675, doi:10.3390/ijerph6102655.

740 Atmo Nord-Pas-de-Calais (2009). Bilan 2008 des poussières sédimentables sur le  
741 Dunkerquois. Rapport d’études 01 – 2009- LC. Available at: <http://www.atmo-npdc.fr>

742 Barnett, V. *Sample survey: principles and methods*; 3rd ed.; Wiley: Chichester, 2002;  
743 ISBN 9780470685907.

744 Bell, M.L.; O’Neill, M.S.; Cifuentes, L.A.; Braga, A.L.F.; Green, C.; Nweke, A.; Rogat,  
745 J.; Sibold, K. Challenges and recommendations for the study of socioeconomic factors  
746 and air pollution health effects. *Environ. Sci. Policy* 2005, 8, 525–533

747 Benzécri, J.P. (1969) Statistical analysis as a tool to make patterns emerge from data. In  
748 S. Watanabe (ed.), *Methodologies of pattern recognition*. New York: Academic press.

749 Benzécri, J.P. (1973) *L’Analyse des Données. Vol. 2: L’Analyse des Correspondances*.  
750 Paris: Dunod.

751 Benzécri, J.P. (1992) *Correspondence analysis handbook*. New York: Dekker.

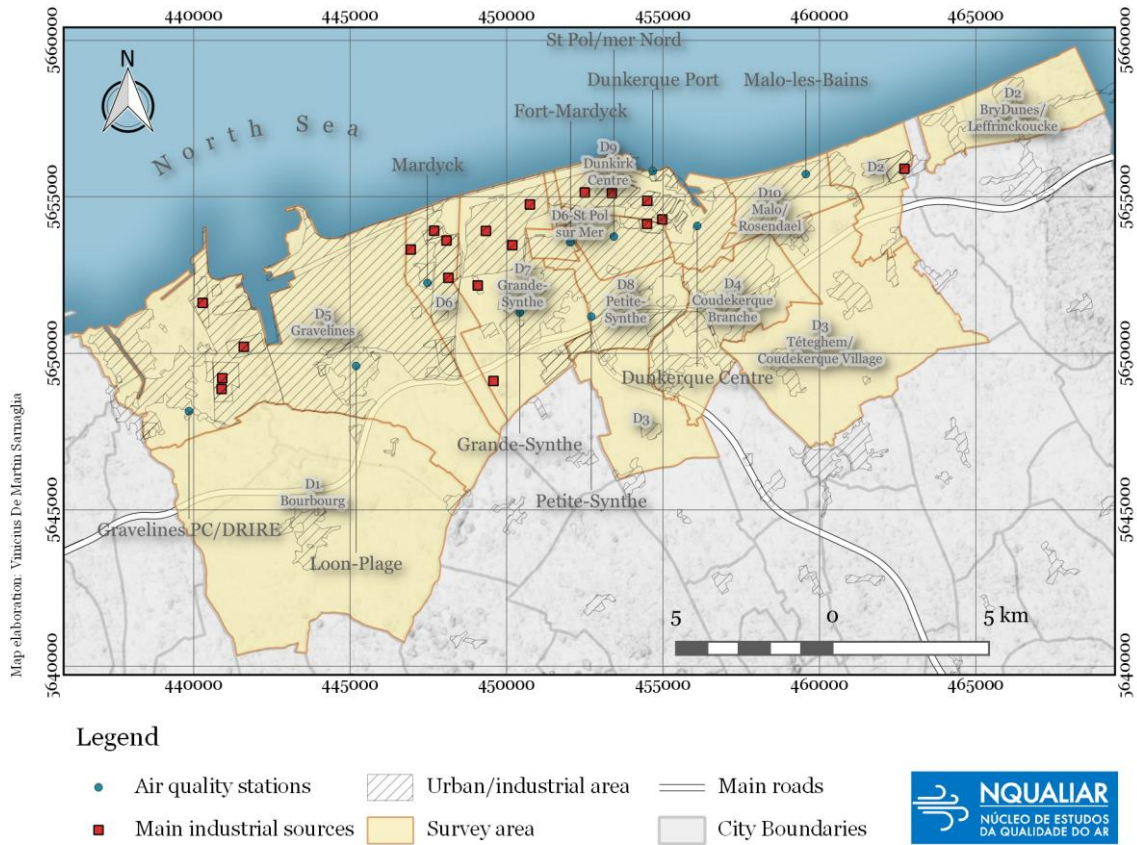
752 Berglund, B.; Berglund, U.; Lindvall, T. Measurement and control of annoyance. In  
753 *Environmental annoyance: characterization, measurement and control*; Koelga, H. S.,  
754 Ed.; Elsevier Sci B.V.: Amsterdam, 1987; Vol. 15, pp. 29–43.

- 755 Blanes-Vidal, V.; Suh, H.; Nadimi, E. S.; Løfstrøm, P.; Ellermann, T.; Andersen, H. V.;  
756 Schwartz, J. Residential exposure to outdoor air pollution from livestock operations and  
757 perceived annoyance among citizens. *Environ. Int.* 2012, 40, 44–50.
- 758 Boyouk, N., Léon, J. F., Delbarre, H., Augustin, P., & Fourmentin, M. (2011). Impact of  
759 sea breeze on vertical structure of aerosol optical properties in Dunkerque,  
760 France. *Atmospheric research*, 101(4), 902-910.
- 761 Braga A.L.F.; Saldiva, P.H.N.; Pereira, L.A.A.; Menezes, J.J.C.; Conceição, G.M.S.; Lin,  
762 C.L.; Zanobetti, A.; Shwartz, J.; Dockery, D.W. (2001). Health effects or air pollution  
763 exposure on children and adolescents in São Paulo, Brasil. *Pediatr. Pulmonol.*, 31, 106-  
764 113, 2001.
- 765 Calvo-Mendieta, I.; Flaquart, H.; Frere, S.; Gonthier, F.; Hellequin, A. P.; Blanc, A. Le  
766 Perception du risque industriel par les populations du Dunkerquois, Rapport  
767 intermédiaire.; Dunkerque, 2008.
- 768 Castanho, A. D. A., & Artaxo, P. (2001). Wintertime and summertime São Paulo aerosol  
769 source apportionment study. *Atmospheric Environment*, 35, 4889–4902.
- 770 Cochran, W. G. *Sampling techniques - A Wiley publication in applied statistics*; 3rd ed.;  
771 Wiley: New York, 1977; ISBN 047116240X.
- 772 Crivisqui, E. (1995). The correspondence analysis as instrument to analyse the profile of  
773 the worker in the tomato crop in the Goiás state, Brazil. Programme de Recherche et  
774 D'Enseignement en Statistique Appliquée. PRESTA, Belgique: Université Libre de  
775 Bruxelles.
- 776 Egondi T.; Kyobutungi C.; Ng N.; Muindi K.; Oti S.; Vijver S. V. De; Ettarh R.; Rocklov  
777 J.(2013) Comunity perceptions of air pollution and related health risks in Nairobi Slums.  
778 *Int. J. Environ. Res. Public Health*, 10, 4851-4868.
- 779 Farfel, M.R., Orlova, A.O., Lees, P.S.J., Rohde, C., Ashley, P.J., Julian Chisolm, J., 2005.  
780 A study of urban housing demolition as a source of lead in ambient dust on sidewalks,  
781 streets, and alleys. *Environ. Res.* 99, 204–213. doi:10.1016/j.envres.2004.10.005
- 782 Fischer G.W., Morgan M.G., Fischhoff B., Nair I, and Lave L.B. (1991), “What risk are  
783 people concerned about?”, *Risk Analysis*, 11, 303-314.
- 784 Garçon G., Dagher Z., Zerimech F., Ledoux F., Courcot D., Aboukais A., Puskaric E.,  
785 Shirali P. (2006) Dunkerque city air pollution particulate matter-induced cytotoxicity,  
786 oxidative stress and inflammation in human epithelial lung cells (L132) in culture.  
787 *Toxicology in Vitro*, 20, 519-528.
- 788 Grenacre, M. J. (1984) *Theory and Applications of correspondence analysis*. New York:  
789 Academic press.
- 790 Greenacre, M. & Blasius, J. (2006). *Multiple correspondence analysis and related*  
791 *methods*. Chapman & Hall/CRC Press, London.

- 792 Greenacre, M. (2007). *Correspondence Analysis in Practice*, Second Edition. London:  
793 Chapman & Hall/CRC.
- 794 Gustafson E. (1998). Gender differences in Risk perception: theoretical and  
795 methodological Perspectives, *Risk Analysis*, 18(6), 805-811.
- 796 Hellequin, A. P.; Zwarterook, I. Mauvais air: vivre au quotidien près d’usines polluantes  
797 et dangereuse. In *IIeme colloque international UMR 5600-ENTPE “Le risque industriel:  
798 une question de sciences humaines”*; Lyon, 2010.
- 799 IBGE Sensus 2010; Instituto Brasileiro de Geografia e Estatística: Brasilia, 2010.
- 800 (IJSN) INSTITUTO JONES DOS SANTOS NEVES –. Regional Profile 2009: Região  
801 Metropolitana da Grande Vitória. Disponível em: <http://www.ijsn.es.gov.br>. Acesso em  
802 09 de junho de 2015.
- 803 Jacquemin B., Sunyer J., Forsberg B., Gotschi T., Oglesby L., Ackermann-Liebrich U.,  
804 De Marco R., Heinrich J., Jarvis D., Toren K., Kunzli N. 2007. Annoyance due to air  
805 pollution in Europe. *International Journal of Epidemiology*, 36, 809–820.
- 806 Kohlhuber, M.; Mielck, A.; Weiland, S.K.; Bolte, G. (2006). Social inequality in  
807 perceived environmental exposures in relation to housing conditions in Germany.  
808 *Environ. Res.*, 101, 246–255.
- 809 Kim M., Yi O., Kim H. (2012). The role differences in individual and community  
810 attributes in perceived air quality. *Science of the Total Environment*, 425, 20-26.
- 811 Klæboe, R., Kolbenstvedt, M., Clench-Aas, J., Bartonova, A. (2000). Oslo traffic study  
812 part 1: an integrated approach to assess the combined effects of noise and air pollution on  
813 annoyance. *Atmospheric Environment*, 34, 4727-4736.
- 814 Lebart L, Morineau A, Warwick K. (1984). *Multivariate descriptive statistical analysis*.  
815 Chichester, UK: Wiley.
- 816 Lercher, P., Schmitzberger, R., Kofler, W. (1995). Perceived traffic air pollution,  
817 associated behavior and health in an alpine area. *Science of the Total Environment* 169  
818 (1–3), 71–74.
- 819 Le Roux, B. and Rouanet, H. (2004). *Geometric Data Analysis, From Correspondence  
820 Analysis to Structured Data Analysis*. Dordrecht. Kluwer Academic Publishers.
- 821 Le Roux, B. et Rouanet, H. (2010). *Multiple Correspondence Analysis*, SAGE, Series:  
822 *Quantitative Applications in the Social Sciences*, CA:Thousand Oaks Paris.
- 823 Les ateliers. Atelier international de maîtrise d’œuvre urbaine. Dunkerque, une  
824 agglomération maritime transfrontalière actrice d’un développement métropolitain.  
825 *Cahier de session - 2ème edition*. Du 3 au 17 juillet 2010.
- 826 Lindvall, T., Radford, E.P., 1973. Measurement of annoyance due to exposure to  
827 environmental factors. *Environ. Res.* 6, 1–36. doi:10.1016/0013-9351(73)90014-5.

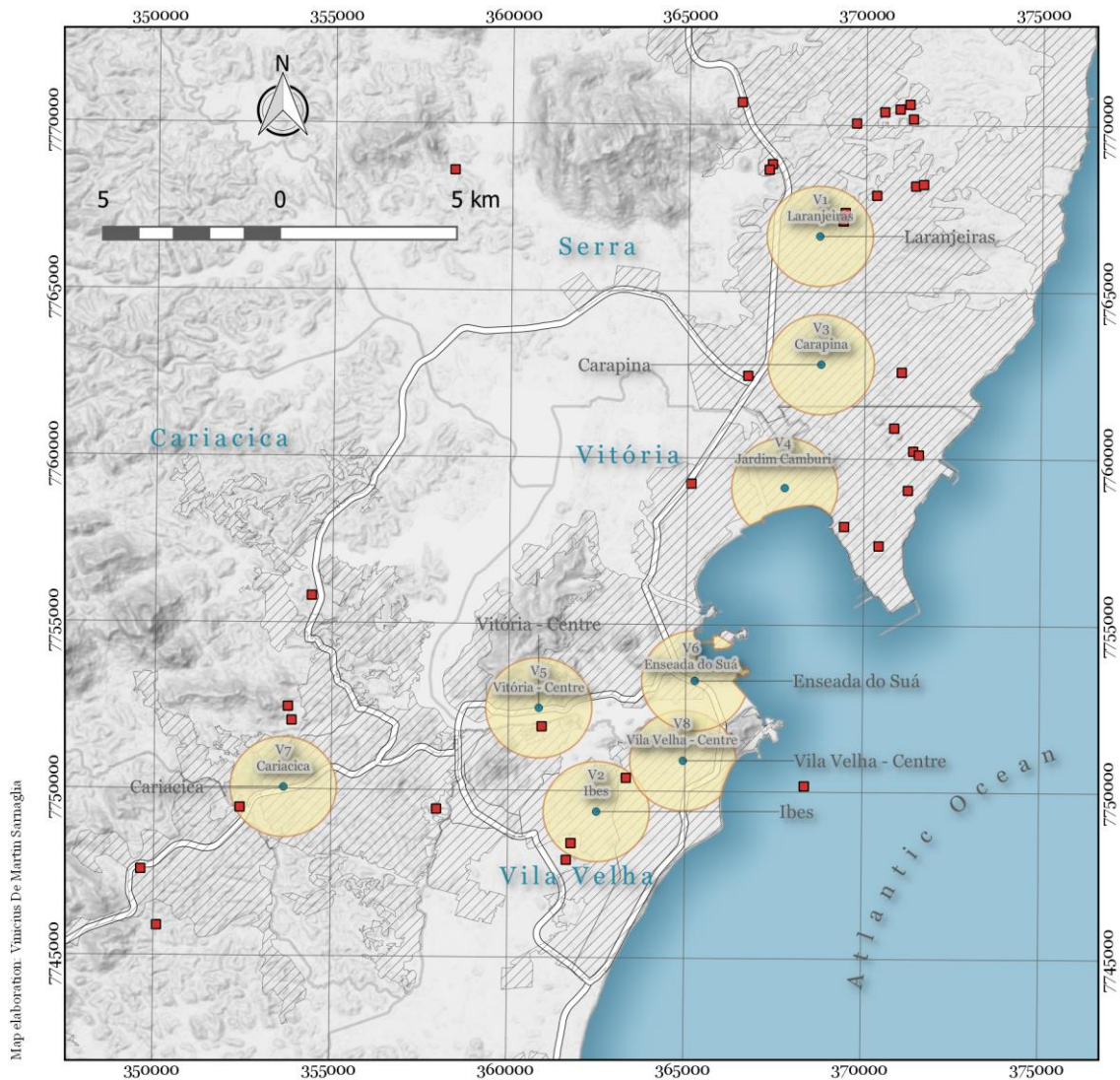
- 828 Llop S., Ballester F., Estarlich M., Esplugues A., Fernández-Patier R., Ramón R., Marco  
829 A., Aguirre A., Sunyer J., Iñiguez C., on behalf of INMA-Valencia cohort. Ambient air  
830 pollution and annoyance responses from pregnant women. *Atmospheric Environment*,  
831 42, 2982-2992, 2008.
- 832 Machado, M., Santos, J. M., Reisen, V. A., Reis Jr, N. C., Mavroidis, I., & Lima, A. T.  
833 (2018). A new methodology to derive settleable particulate matter guidelines to assist  
834 policy-makers on reducing public nuisance. *Atmospheric Environment*, 182, 242-251.
- 835 Machado, M.; Reisen, V. A.; Santos, J. M.; Reis, N. C.; Frère S.; Bondon P.; Ispány M.;  
836 Cotta H. H.A. Use of multivariate time series techniques to estimate the impact of  
837 particulate matter on the perceived annoyance. *Atmos. Environ.* 2019, 117080.  
838 DOI: 10.1016/j.atmosenv.2019.117080.
- 839 Nascimento A.P.; Santos, J. M.; Mill J.G.; Souza J.B.; Reis, N. C.; Reisen, V. A. (2017).  
840 Association between the concentration of fine particles in the atmosphere and acute  
841 respiratory diseases in children. *Revista de Saúde Pública*, 51, 3. Epub January 12, 2017.
- 842 Nikolopoulou M., Kleissl J., Linden P.F., Lykoudis S. (2011). Pedestrians' perception of  
843 environmental stimuli through field surveys: Focus on particulate pollution. *Science of  
844 the Total Environment*, 409(13), 2493-202.
- 845 Oglesby, L.; Künzli, N.; Monn, C.; Schindler, C.; Ackermann-Liebrich, U.; Leuenberger,  
846 P. Validity of annoyance scores for estimation of long-term air pollution exposure in  
847 epidemiologic studies: the Swiss Study on Air Pollution and Lung Diseases in Adults  
848 (SAPALDIA). *Am. J. Epidemiol.* 2000, 152, 75–83,  
849 doi:10.1080/10473289.2000.10464156.
- 850 Orru, H.; Idavain, J.; Pindus, M.; Orru, K.; Kesanurm, K.; Lang, A.; Tomasova, J.  
851 Residents' Self-Reported Health Effects and Annoyance in Relation to Air Pollution  
852 Exposure in an Industrial Area in Eastern-Estonia. *Int. J. Environ. Res. Public Health*  
853 2018, 15, 252, doi:10.3390/ijerph15020252.
- 854 Orru, K.; Nordin, S.; Harzia, H.; Orru, H. The role of perceived air pollution and health  
855 risk perception in health symptoms and disease: a population-based study combined with  
856 modelled levels of PM10. *Int. Arch. Occup. Environ. Health* 2018b, 91, 581–589,  
857 doi:10.1007/s00420-018-1303-x.
- 858 Passchier-Vermeer, Willy, and Wim F. Passchier. "Noise exposure and public  
859 health." *Environmental health perspectives* 108.suppl 1 (2000): 123-131.
- 860 Pope C.A. III, (1991). Respiratory hospital admissions associated with PM10 pollution  
861 in Utah, Salt Lake and Cache valleys. *Arch. Environ. Health*, 46, 90-97.
- 862 PPA (2002). Plan de protection de l'atmosphère de l'agglomération Dunkerquoise.  
863 Retrieved on 20 April 2013 2013 from: [http://www.nord-pas-de-calais.developpement-  
864 durable.gouv.fr/IMG/pdf/ppa-dunkerque.pdf](http://www.nord-pas-de-calais.developpement-durable.gouv.fr/IMG/pdf/ppa-dunkerque.pdf)
- 865 Rotko T., Oglesby L., Kunzli N., Carrer P., Nieuwenhuijsen M.J., Jantunen M. (2002).  
866 Determinants of perceived air pollution annoyance and association between annoyance

- 867 scores and air pollution (PM<sub>2.5</sub>, NO<sub>2</sub>) concentrations in the European EXPOLIS study.  
868 *Atmospheric Environment*, 36, 4593–4602.
- 869 Salvador, N., Reis, N. C., Santos, J. M., de Almeida Albuquerque, T. T., Lorigato, A. G.,  
870 Delbarre, H., ... & Moreira, D. M. (2016). Evaluation of weather research and forecasting  
871 model parameterizations under sea-breeze conditions in a North Sea coastal  
872 environment. *Journal of Meteorological Research*, 30(6), 998-1018
- 873 Santos, J. M.; Reis Jr, N. C.; Galvão, E. S.; Silveira, A.; Goulart, E. V.; Lima, A. T.; Reis,  
874 N. C.; Galvão, E. S.; Silveira, A.; Goulart, E. V.; Lima, A. T. Source apportionment of  
875 settleable particles in a mining-impacted urban and industrialized region in Brazil.  
876 *Environ. Sci. Pollut. Res.* 2017, doi:10.1007/s11356-017-9677-y.
- 877 Souza, J. B.; Reisen, V. A.; Franco, G. C.; Ispány, M.; Bondon, P.; Santos, J. M.  
878 Generalized additive models with principal component analysis: an application to time  
879 series of respiratory disease and air pollution data. *J. R. Stat. Soc. Ser. C (Applied Stat.*  
880 *2018*, 67, 453–480, doi:10.1111/rssc.12239.s
- 881 Stenlund, T.; Lidén, E.; Andersson, K.; Garvill, J.; Nordin, S. Annoyance and health  
882 symptoms and their influencing factors: A population-based air pollution intervention  
883 study. *Public Health* 2009, 123, 339–345, doi:10.1016/j.puhe.2008.12.021.
- 884 Schwartz, J. (1991). Particulate air pollution and daily mortality in Detroit.  
885 *Environmental Research*, 56(2), 204-213.
- 886 Vallack, H.; Shillito, D. Suggested guidelines for deposited ambient dust. *Atmos.*  
887 *Environ.* 1998, 32, 2737–2744, doi:10.1016/S1352-2310(98)00037-5.
- 888 WHO (2005). WHO air quality guidelines global update 2005. Report on a WHO  
889 Working Group. Bonn, Germany, 18-20 October 2005. Retrieved on 28 July 2014 from:  
890 <http://www.euro.who.int/Document/E87950.pdf>.
- 891 WHO (2014). Burden of disease from the joint effects of Household and Ambient Air  
892 Pollution for 2012. WHO: Geneva. Retrieved on 28 July 2014 from:  
893 [http://www.who.int/phe/health\\_topics/outdoorair/databases/FINAL\\_HAP\\_AAP\\_BoD\\_2](http://www.who.int/phe/health_topics/outdoorair/databases/FINAL_HAP_AAP_BoD_24March2014.pdf?ua=1)  
894 [4March2014.pdf?ua=1](http://www.who.int/phe/health_topics/outdoorair/databases/FINAL_HAP_AAP_BoD_24March2014.pdf?ua=1)



**Figure 1.** Sub-regions of interest and the main emission sources in Dunkirk.





Map elaboration: Vinícius De Martin Sarzagaglia

**Legend**

- Air quality stations
- Main industrial sources
- Survey area
- ▨ Urban/industrial area
- == Main roads
- City boundaries

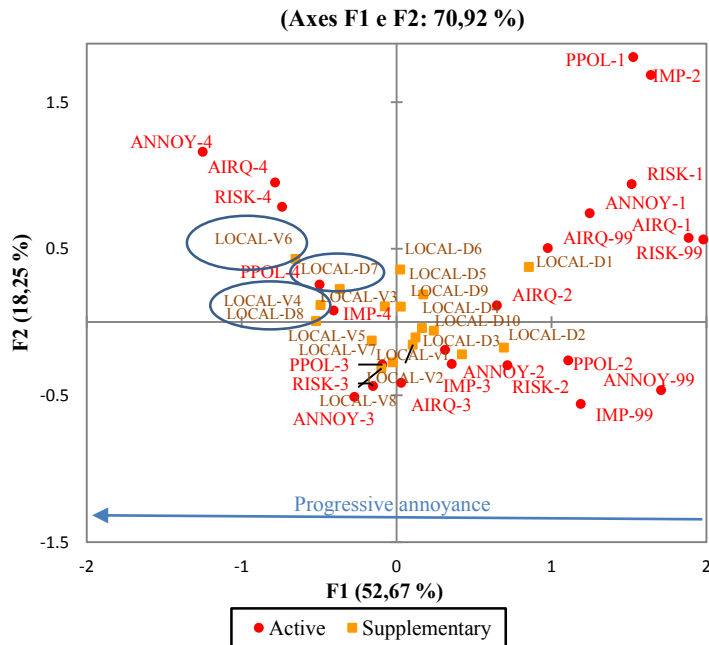


WGS84 Datum - UTM Projection - Zone 24S

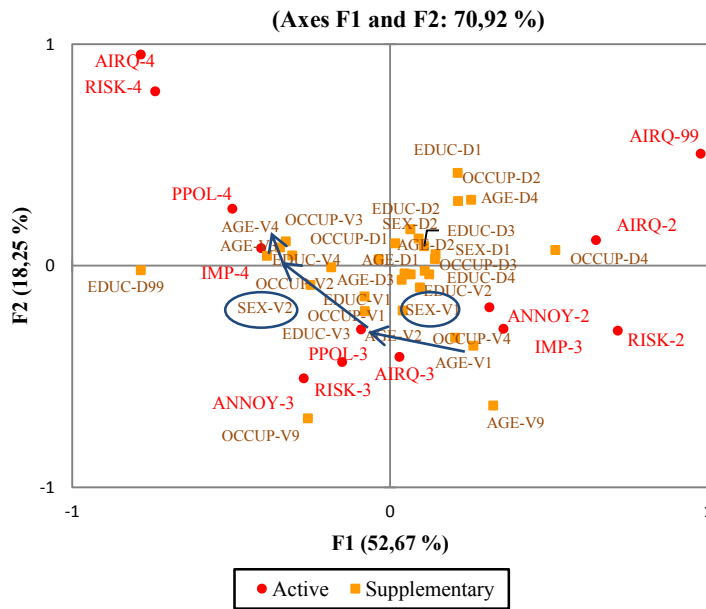
Data source: main roads (IJSN, 2012), city boundaries (IJSN, 2018), urban/industrial area (IJSN, 2010), relief basemap (Aster GDEM/SRTM apud MapSurfer.NET, 2020), main industrial sources (IEMA, 2019).

**Figure 2.** Sub-regions of interest (survey area) and the main emission sources in Vitória.

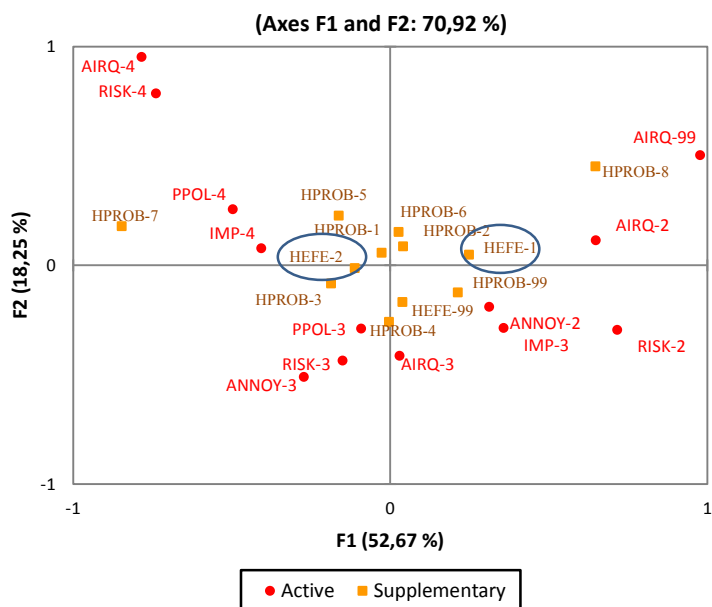




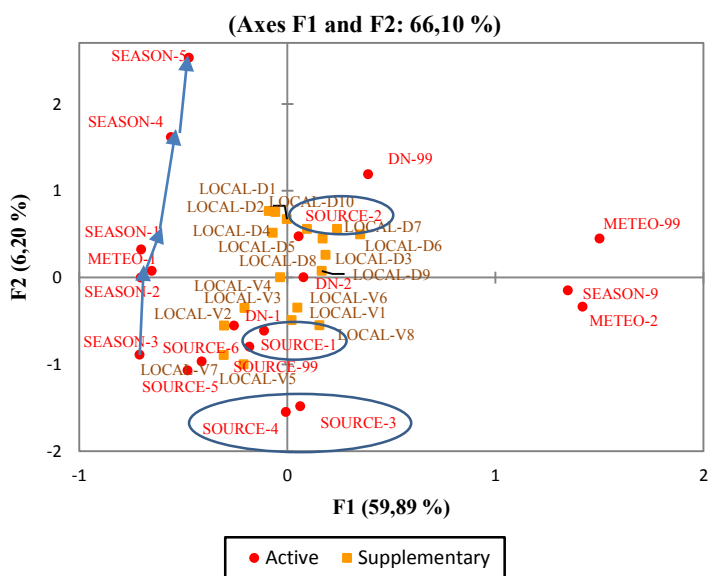
**Figure 3.** MCA results for the “air pollution” group of active variables and the “housing location” group of supplementary variables.



**Figure 4.** MCA results for the “air pollution” group of active variables and the “sociodemographic” group of supplementary variables.



**Figure 5.** MCA results for the “air pollution” group of active variables and the “health problems” group of supplementary variables



**Figure 6.** MCA results for the “cause” group of active variables and the “local” group of supplementary variables

**Table 1.** Descriptive statistics of PM<sub>10</sub> concentrations ( $\mu\text{g}/\text{m}^3$ ) at the Dunkirk monitoring stations in 2008

| Stations         | Minimum | Maximum | Percentile 90% | Percentile 95% | Mean  | Std. deviation |
|------------------|---------|---------|----------------|----------------|-------|----------------|
| Dunkerque Centre | 6.47    | 84.87   | 31.76          | 34.98          | 21.51 | 8.95           |
| Malo-les-Bains   | 6.04    | 63.20   | 27.66          | 31.44          | 19.10 | 8.03           |
| Fort-Mardyck     | 6.62    | 158.81  | 50.68          | 56.56          | 31.59 | 16.89          |
| StPol/merNord    | 5.65    | 143.08  | 54.32          | 64.40          | 34.19 | 17.02          |
| Petite-Synthe    | 7.29    | 80.25   | 31.43          | 36.48          | 21.44 | 9.70           |
| Grande-Synthe    | 8.17    | 114.25  | 46.60          | 57.49          | 27.69 | 16.71          |
| Mardyck          | 5.87    | 101.14  | 47.41          | 61.16          | 25.39 | 16.99          |

**Table 2.** Descriptive statistics of PM<sub>10</sub> concentrations ( $\mu\text{g}/\text{m}^3$ ) at the Vitoria monitoring stations

| Stations        | Minimum | Maximum | Percentile 90% | Percentile 95% | Mean  | Std. deviation |
|-----------------|---------|---------|----------------|----------------|-------|----------------|
| Laranjeiras     | 8.29    | 85.58   | 50.58          | 57.08          | 33.60 | 12.60          |
| Carapina        | 2.88    | 84.76   | 31.01          | 35.41          | 21.51 | 7.86           |
| Jardim Camburi  | 7.75    | 76.66   | 29.12          | 32.38          | 21.44 | 7.17           |
| Enseada do Suá  | 9.70    | 71.28   | 41.14          | 46.13          | 29.44 | 8.77           |
| Vitória Centro  | 11.13   | 83.12   | 41.45          | 47.45          | 29.26 | 9.31           |
| Vila Velha-Ibes | 6.41    | 76.75   | 46.87          | 52.29          | 31.22 | 12.09          |
| Cariacica       | 11.16   | 115.20  | 73.04          | 85.01          | 46.67 | 19.4           |

**Table 3.** The questions from the two surveys and the factor groups for the variables represented by these questions

| Questions  | Variable                          | Factor groups     |
|--|-----------------------------------|-------------------|
| Do you feel annoyed by air pollution?            | Annoyance                         | Air pollution     |
| Is air quality important to you?                 | Importance or air quality         |                   |
| How do you feel regarding industrial risk        | Industrial risk perception        |                   |
| How do you rate air quality in your              | Assessment of air quality         |                   |
| How often do you perceive air pollution due      | Air pollution perception          |                   |
| Where do you live?                               | Dunkirk-locals<br>Vitoria- locals | Local             |
| What is your gender?                             | Gender                            | Socio-demographic |
| Who old are you?                                 | Age                               |                   |
| What is your occupation?                         | Occupation                        |                   |
| What is your level of education?                 | Level of education                |                   |
| Do you or someone in your household have         | Health problems                   | Health            |
| What are the main health problems caused by      | Health effects                    | Cause             |
| What is the main source of settled dust in your  | Source                            |                   |
| Do you think that air pollution/settled          | Meteorological conditions         |                   |
| If yes, in which season is air pollution/settled | Season                            |                   |
| Do you think air pollution is worst during the   | Day/ Night                        |                   |

**Table 4.** MCA results of the active variables grouped under the “Air pollution” factor group

| Active variables           | Categories     | Code       | Freq. (%) |         | Coordinates |         | Contributions |         | Squared cosines |         |
|----------------------------|----------------|------------|-----------|---------|-------------|---------|---------------|---------|-----------------|---------|
|                            |                |            |           |         | Axis F1     | Axis F2 | Axis F1       | Axis F2 | Axis F1         | Axis F2 |
| Annoyance                  | Not annoyed    | ANNOY 1    | 167       | (16,16) | 1.248       | 0.743   | 0.132         | 0.058   | 0.300           | 0.106   |
|                            | Slightly ann.  | ANNOY 2    | 265       | (25,65) | 0.313       | -0.190  | 0.013         | 0.006   | 0.034           | 0.012   |
|                            | Very Annoyed   | ANNOY 3    | 458       | (44,33) | -0.271      | -0.510  | 0.017         | 0.075   | 0.059           | 0.207   |
|                            | Extremely ann. | ANNOY 4    | 139       | (13,45) | -1.251      | 1.162   | 0.111         | 0.119   | 0.243           | 0.210   |
|                            | NK             | ANNOY 9/99 | 4         | (0,38)  | 1.709       | -0.463  | 0.006         | 0.001   | 0.011           | 0.001   |
| Importance of air quality  | Not important  | IMP 1      | 11        | (1,06)  | 2.390       | 2.932   | 0.032         | 0.060   | 0.062           | 0.093   |
|                            | Slightly imp.  | IMP 2      | 28        | (2,7)   | 1.643       | 1.684   | 0.038         | 0.050   | 0.075           | 0.079   |
|                            | Very important | IMP 3      | 423       | (40,94) | 0.358       | -0.286  | 0.028         | 0.022   | 0.089           | 0.057   |
|                            | Extremely imp. | IMP 4      | 566       | (54,79) | -0.406      | 0.078   | 0.047         | 0.002   | 0.199           | 0.007   |
|                            | NK             | IMP 9/99   | 5         | (0,48)  | 1.189       | -0.558  | 0.004         | 0.001   | 0.007           | 0.002   |
| Industrial risk perception | Not exposed    | RISK 1     | 76        | (7,3)   | 1.518       | 0.941   | 0.089         | 0.042   | 0.183           | 0.070   |
|                            | Slightly exp.  | RISK 2     | 186       | (18,0)  | 0.716       | -0.295  | 0.049         | 0.010   | 0.113           | 0.019   |
|                            | Very exposed   | RISK 3     | 508       | (49,17) | -0.150      | -0.436  | 0.006         | 0.061   | 0.022           | 0.184   |
|                            | Extremely exp. | RISK 4     | 255       | (24,68) | -0.738      | 0.785   | 0.071         | 0.099   | 0.179           | 0.202   |
|                            | NK             | RISK 9/99  | 8         | (0,77)  | 1.980       | 0.564   | 0.016         | 0.002   | 0.031           | 0.002   |
| Assessment of air quality  | Excellent      | AIRQ 1     | 10        | (0,96)  | 1.886       | 0.575   | 0.018         | 0.002   | 0.035           | 0.003   |
|                            | Good           | AIRQ 2     | 178       | (17,23) | 0.649       | 0.114   | 0.038         | 0.001   | 0.088           | 0.003   |
|                            | Bad            | AIRQ 3     | 601       | (58,18) | 0.030       | -0.414  | 0.000         | 0.065   | 0.001           | 0.238   |
|                            | Horrible       | AIRQ 4     | 222       | (21,49) | -0.783      | 0.952   | 0.069         | 0.127   | 0.168           | 0.248   |
|                            | NK             | AIRQ 9/99  | 22        | (2,1)   | 0.978       | 0.504   | 0.011         | 0.004   | 0.021           | 0.006   |
| Air pollution perception   | Never          | PPOL 1     | 20        | (1,9)   | 1.529       | 1.808   | 0.024         | 0.041   | 0.046           | 0.065   |
|                            | Sometimes      | PPOL 2     | 146       | (14,13) | 1.110       | -0.261  | 0.091         | 0.006   | 0.203           | 0.011   |
|                            | Often          | PPOL 3     | 474       | (45,88) | -0.091      | -0.289  | 0.002         | 0.025   | 0.007           | 0.071   |
|                            | Always         | PPOL 4     | 375       | (36,3)  | -0.495      | 0.256   | 0.047         | 0.016   | 0.140           | 0.037   |
|                            | NR             | PPOL 9     | 3         | (0,29)  | 0.512       | -1.801  | 0.000         | 0.006   | 0.001           | 0.009   |
|                            | NK             | PPOL99     | 15        | (1,45)  | 2.324       | 3.219   | 0.041         | 0.098   | 0.080           | 0.153   |

**Table 5.** MCA results of the supplementary variables grouped under the “Local” factor group

| Supplementary Variables | Category                     | Code      | Freq. (%) | Coordinates |         | Test value |         |
|-------------------------|------------------------------|-----------|-----------|-------------|---------|------------|---------|
|                         |                              |           |           | Axis F1     | Axis F2 | Axis F1    | Axis F2 |
| Dunkirk                 | Bourbourg                    | LOCAL-D1  | 24 (2,32) | 0.856       | 0.376   | 4.240      | 1.864   |
|                         | BrayDunes/Leffrinckoucke     | LOCAL-D2  | 33 (3,19) | 0.694       | -0.175  | 4.048      | -1.020  |
|                         | Téteghem/Coudekerque/Village | LOCAL-D3  | 31 (3,00) | 0.124       | -0.105  | 0.702      | -0.592  |
|                         | Coudekerque Branche          | LOCAL-D4  | 82 (7,93) | 0.242       | -0.058  | 2.280      | -0.547  |
|                         | Gravelines                   | LOCAL-D5  | 60 (5,80) | 0.174       | 0.189   | 1.385      | 1.508   |
|                         | St Pol sur Mer               | LOCAL-D6  | 83 (8,03) | 0.024       | 0.359   | 0.228      | 3.406   |
|                         | Grande Synthe                | LOCAL-D7  | 52 (5,03) | -0.365      | 0.224   | -2.699     | 1.660   |
|                         | Petite-Synthe                | LOCAL-D8  | 35 (3,38) | -0.518      | 0.007   | -3.114     | 0.044   |
|                         | Dunkerque                    | LOCAL-D9  | 30 (2,90) | 0.030       | 0.106   | 0.166      | 0.590   |
|                         | Malo/Rosendael               | LOCAL-D10 | 88 (8,51) | 0.166       | -0.041  | 1.629      | -0.403  |
| Vitoria                 | Laranjeiras                  | LOCAL-V1  | 51 (4,93) | 0.424       | -0.219  | 3.102      | -1.606  |
|                         | Ibes                         | LOCAL-V2  | 82 (7,93) | 0.104       | -0.154  | 0.986      | -1.450  |
|                         | Carapina                     | LOCAL-V3  | 37 (3,58) | -0.074      | 0.108   | -0.456     | 0.669   |
|                         | Jardim Camburi               | LOCAL-V4  | 67 (6,48) | -0.489      | 0.116   | -4.138     | 0.980   |
|                         | Centro de Vitoria            | LOCAL-V5  | 51 (4,93) | -0.160      | -0.127  | -1.171     | -0.928  |
|                         | Enseada do Sua’              | LOCAL-V6  | 52 (5,34) | -0.651      | 0.430   | -4.812     | 3.177   |
|                         | Cariacica                    | LOCAL-V7  | 85 (8,22) | -0.023      | -0.274  | -0.220     | -2.639  |
|                         | Centro de Vila Velha         | LOCAL-V8  | 90 (8,71) | -0.096      | -0.315  | -0.958     | -3.130  |

**Table 6.** MCA results of the supplementary variables grouped under the “Sociodemographic” factor group

| City    | Supplementary variables | Category            | Code      | Freq. (%)    | Coordinates |         | Test value |         |
|---------|-------------------------|---------------------|-----------|--------------|-------------|---------|------------|---------|
|         |                         |                     |           |              | Axis F1     | Axis F2 | Axis F1    | Axis F2 |
| Dunkirk | Gender                  | Male                | SEX- D1   | 211 (20.426) | 0.232       | 0.090   | 2.337      | 0.818   |
|         |                         | Female              | SEX-D2    | 307 (29.719) | 0.145       | 0.219   | 1.881      | 2.535   |
|         | Age                     | 16-24               | AGE-D1    | 77 (7.454)   | 0.066       | -0.040  | 0.598      | -0.368  |
|         |                         | 25-34               | AGE-D2    | 83 (8.035)   | 0.017       | 0.100   | 0.162      | 0.947   |
|         |                         | 35-54               | AGE-D3    | 191 (18.490) | 0.046       | -0.036  | 0.699      | -0.547  |
|         |                         | >55                 | AGE-D4    | 167 (16.167) | 0.256       | 0.296   | 3.610      | 4.183   |
|         | Occupation              | Employed            | OCCUP-D1  | 247 (23.911) | -0.035      | 0.028   | -0.635     | 0.502   |
|         |                         | Unemployed          | OCCUP-D2  | 107 (10.358) | 0.215       | 0.290   | 2.344      | 3.164   |
|         |                         | Retired             | OCCUP-D3  | 108 (10.455) | 0.142       | 0.029   | 1.558      | 0.322   |
|         |                         | Student             | OCCUP-D4  | 54 (5.227)   | 0.520       | 0.069   | 3.925      | 0.523   |
|         |                         | NK                  | OCCUP-D99 | 2 (0.194)    | 0.128       | 1.531   | 0.181      | 2.167   |
|         | Education level         | No formal educ.     | EDUC-D1   | 48 (4.647)   | 0.213       | 0.417   | 1.510      | 2.957   |
|         |                         | Primary school      | EDUC-D2   | 92 (8.906)   | 0.064       | 0.164   | 0.641      | 1.643   |
|         |                         | High school         | EDUC-D3   | 213 (20.620) | 0.107       | 0.087   | 1.759      | 1.431   |
|         |                         | University          | EDUC-D4   | 164(15.876)  | 0.123       | -0.041  | 1.723      | -0.568  |
|         |                         | NK                  | EDUC-D99  | 2 (0.194)    | -0.784      | -0.021  | -1.109     | -0.030  |
| Vitoria | Gender                  | Male                | SEX-V1    | 205 (19.845) | 0.153       | -0.180  | 1.517      | -1.597  |
|         |                         | Female              | SEX-V2    | 310 (30.010) | -0.404      | -0.159  | -5.251     | -1.858  |
|         | Age                     | 16-24               | AGE-V1    | 140 (13.553) | 0.263       | -0.362  | 3.344      | -4.608  |
|         |                         | 25-34               | AGE-V2    | 71 (6.873)   | 0.040       | -0.204  | 0.350      | -1.782  |
|         |                         | 35-54               | AGE-V3    | 145 (14.037) | -0.308      | 0.045   | -3.996     | 0.583   |
|         |                         | >55                 | AGE-V4    | 156 (15.102) | -0.346      | 0.082   | -4.683     | 1.106   |
|         |                         | NK                  | AGE-V9    | 3(0.290)     | 0.325       | -0.632  | 0.563      | -1.096  |
|         | Occupation              | Employed            | OCCUP-V1  | 226 (21.878) | -0.080      | -0.140  | -1.362     | -2.378  |
|         |                         | Unemployed          | OCCUP-V2  | 113 (10.939) | -0.184      | -0.008  | -2.077     | -0.089  |
|         |                         | Retired             | OCCUP-V3  | 100 (9.681)  | -0.327      | 0.109   | -3.440     | 1.147   |
|         |                         | Student             | OCCUP-V4  | 72 (6.970)   | 0.205       | -0.326  | 1.804      | -2.870  |
|         |                         | NK                  | OCCUP-V9  | 4 (0.387)    | -0.258      | -0.690  | -0.517     | -1.382  |
|         | Education level         | No formal education | EDUC-V1   | 7 (0.678)    | 0.037       | -0.064  | 0.097      | -0.171  |
|         |                         | Primary school      | EDUC-V2   | 131 (12.682) | 0.109       | -0.025  | 1.335      | -0.307  |
|         |                         | High school         | EDUC-V3   | 238 (23.040) | -0.079      | -0.207  | -1.386     | -3.633  |
|         |                         | University          | EDUC-V4   | 138 (13.359) | -0.387      | 0.043   | -4.883     | 0.546   |

**Table 7.** MCA results of the supplementary variables grouped under the “Health” factor group

| Supplementary Variables | Category         | Cod.     | Freq. % |        | coordinates |         | Test value |         |
|-------------------------|------------------|----------|---------|--------|-------------|---------|------------|---------|
|                         |                  |          |         |        | Axis F1     | Axis F2 | Axis F1    | Axis F2 |
| Health problem          | No               | HEFE-1   | 304     | 29.429 | 0.249       | 0.048   | 5.175      | 0.999   |
|                         | Yes              | HEFE-2   | 694     | 67.183 | -0.111      | -0.013  | -5.113     | -0.581  |
|                         | NR/NK            | HEFE-99  | 26      | 3.388  | 0.039       | -0.167  | 0.234      | -1.007  |
| Health effects          | Lung/respiratory | HPROB-1  | 454     | 43.950 | -0.027      | 0.057   | -0.759     | 1.630   |
|                         | Cancer           | HPROB-2  | 95      | 9.197  | 0.041       | 0.086   | 0.420      | 0.880   |
|                         | Allergies        | HPROB-3  | 192     | 18.587 | -0.186      | -0.082  | -2.856     | -1.262  |
|                         | Bronchitis       | HPROB-4  | 35      | 3.388  | -0.003      | -0.258  | -0.017     | -1.550  |
|                         | Asthma attacks   | HPROB-5  | 5       | 0.484  | -0.162      | 0.228   | -0.362     | 0.510   |
|                         | Eye irritation   | HPROB-6  | 46      | 4.453  | 0.027       | 0.152   | 0.188      | 1.057   |
|                         | Stress           | HPROB-7  | 5       | 0.484  | -0.846      | 0.179   | -1.895     | 0.402   |
|                         | Others           | HPROB-8  | 11      | 1.065  | 0.648       | 0.453   | 2.159      | 1.510   |
|                         | NK               | HPROB-99 | 190     | 18.393 | 0.214       | -0.123  | 3.267      | -1.880  |

**Table 8.** MCA results of the active variables grouped under the “Cause” factor group

| Active variables | Categories        | Cod.      | Freq. (%) |        | Coordinates |         | Contributions |         | Squared cosines |         |
|------------------|-------------------|-----------|-----------|--------|-------------|---------|---------------|---------|-----------------|---------|
|                  |                   |           |           |        | AxisF1      | Axis F2 | Axis F1       | Axis F2 | Axis F1         | Axis F2 |
| Source           | Vehicle           | SOURCE-1  | 190       | 18.393 | -0.111      | -0.614  | 0.001         | 0.053   | 0.003           | 0.085   |
|                  | Industry          | SOURCE-2  | 688       | 66.602 | 0.054       | 0.474   | 0.001         | 0.115   | 0.006           | 0.448   |
|                  | Soil suspension   | SOURCE-3  | 22        | 2.130  | 0.062       | -1.481  | 0.000         | 0.036   | 0.000           | 0.048   |
|                  | Building          | SOURCE-4  | 85        | 8.228  | -0.006      | -1.551  | 0.000         | 0.152   | 0.000           | 0.216   |
|                  | Sea breeze /wind  | SOURCE-5  | 21        | 2.033  | -0.410      | -0.968  | 0.002         | 0.015   | 0.003           | 0.019   |
|                  | Others            | SOURCE-6  | 12        | 1.162  | -0.479      | -1.071  | 0.001         | 0.010   | 0.003           | 0.013   |
|                  | NK                | SOURCE-99 | 15        | 1.452  | -0.182      | -0.798  | 0.000         | 0.007   | 0.000           | 0.009   |
| Meteo            | Yes               | METEO-1   | 711       | 68.829 | -0.651      | 0.074   | 0.150         | 0.003   | 0.935           | 0.012   |
|                  | No                | METEO-2   | 251       | 24.298 | 1.419       | -0.336  | 0.252         | 0.021   | 0.646           | 0.036   |
|                  | NK                | METEO-99  | 71        | 6.873  | 1.501       | 0.449   | 0.080         | 0.011   | 0.166           | 0.015   |
| Season           | Summer            | SEASON-1  | 392       | 37.948 | -0.702      | 0.323   | 0.096         | 0.030   | 0.301           | 0.064   |
|                  | Autumn            | SEASON-2  | 47        | 4.550  | -0.703      | -0.001  | 0.012         | 0.000   | 0.024           | 0.000   |
|                  | Winter            | SEASON-3  | 189       | 18.296 | -0.709      | -0.888  | 0.047         | 0.111   | 0.112           | 0.177   |
|                  | Spring            | SEASON-4  | 49        | 4.743  | -0.558      | 1.615   | 0.008         | 0.095   | 0.016           | 0.130   |
|                  | Depend industries | SEASON-5  | 6         | 0.581  | -0.472      | 2.529   | 0.001         | 0.029   | 0.001           | 0.037   |
|                  | NK                | SEASON-99 | 350       | 33.882 | 1.349       | -0.151  | 0.318         | 0.006   | 0.933           | 0.012   |
| Day/Night        | Yes               | DN-1      | 427       | 41.336 | -0.255      | -0.556  | 0.014         | 0.098   | 0.046           | 0.218   |
|                  | No                | DN-2      | 407       | 39.400 | 0.078       | 0.003   | 0.001         | 0.000   | 0.004           | 0.000   |
|                  | NK                | DN-99     | 199       | 19.264 | 0.388       | 1.187   | 0.015         | 0.209   | 0.036           | 0.336   |

**Table 9.** MCA results of the supplementary variables grouped under the “Local” factor group

| Supplementary Variables | Category                      | Cod.      | Freq. (%) | Coordinates |         | Test value |         |
|-------------------------|-------------------------------|-----------|-----------|-------------|---------|------------|---------|
|                         |                               |           |           | Axis F1     | Axis F2 | Axis F1    | Axis F2 |
| Dunkirk                 | Bourbourg                     | LOCAL-D1  | 24 (2.32) | -0.057      | 0.752   | -0.284     | 3.723   |
|                         | BrayDunes/Leffrinckoucke      | LOCAL-D2  | 33 (3.19) | -0.001      | 0.673   | -0.007     | 3.925   |
|                         | Téteghem/ Coudekerque Village | LOCAL-D3  | 31 (3.00) | 0.170       | 0.446   | 0.960      | 2.521   |
|                         | Coudekerque Branche           | LOCAL-D4  | 82 (7.93) | -0.087      | 0.763   | -0.825     | 7.198   |
|                         | Gravelines                    | LOCAL-D5  | 60 (5.80) | -0.069      | 0.513   | -0.551     | 4.089   |
|                         | St Pol sur Mer                | LOCAL-D6  | 83 (8.03) | 0.351       | 0.495   | 3.330      | 4.697   |
|                         | Grande Synthe                 | LOCAL-D7  | 52 (5.03) | 0.240       | 0.559   | 1.772      | 4.132   |
|                         | Petite-Synthe                 | LOCAL-D8  | 35 (3.38) | 0.184       | 0.259   | 1.106      | 1.560   |
|                         | Dunkirk centre                | LOCAL-D9  | 30 (2.90) | 0.165       | 0.075   | 0.919      | 0.414   |
|                         | Malo/Rosendael                | LOCAL-D10 | 88 (8.51) | 0.094       | 0.559   | 0.926      | 5.485   |
| Vitoria                 | Laranjeiras                   | LOCAL-V1  | 51 (4.93) | 0.021       | -0.491  | 0.152      | -3.596  |
|                         | Ibes                          | LOCAL-V2  | 82 (7.93) | -0.303      | -0.556  | -2.860     | -5.240  |
|                         | Carapina                      | LOCAL-V3  | 37 (3.58) | -0.205      | -0.352  | -1.268     | -2.177  |
|                         | Jardim Camburi                | LOCAL-V4  | 67 (6.48) | -0.035      | 0.003   | -0.293     | 0.023   |
|                         | Vitoria-centro                | LOCAL-V5  | 51 (4.93) | -0.209      | -1.001  | -1.531     | -7.330  |
|                         | Enseada do Sua                | LOCAL-V6  | 52 (5.34) | 0.049       | -0.347  | 0.360      | -2.564  |
|                         | Cariacica                     | LOCAL-V7  | 85 (8.22) | -0.305      | -0.893  | -2.933     | -8.590  |
|                         | Vila Velha-centro             | LOCAL-V8  | 90 (8.71) | 0.155       | -0.551  | 1.537      | -5.471  |