Chapter 7

Air Pollution Mapping with Bio-Indicators in Urban Areas

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Additional information is available at the end of the chapter

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Abstract

Our study consists of the assessment and the mapping of the atmospheric pollution, which concerns the region of Tiaret city, by using the lichens as bioindicators. In our zone, we did a survey on 25 domains by using Kirschbaum and Wirth 1997 method. This method has enabled to define five classes according to the calculated air quality index (AQI). The dominant class was the one that contained a high pollution degree, which is reflected through the spatial distribution of the lichen species. The achieved map allows us to better visualize the pollution state.

Keywords: air pollution, mapping, lichens, bioindicators, Tiaret, Algeria

1. Introduction

The atmospheric pollution still constitutes a major problem worldwide, especially in the densely populated areas and near industrial sites [1]. More than 2 million people die annually around the world as a result of diseases caused by the air pollution and up to 1.3 million of this figure are inhabitants of the urban areas in developed countries [2]. According to the same source, 1.1 million of these deaths could be avoided if the regulatory limits and norms for air quality were complied with. Facing such a worrisome situation, detection and assessment of atmospheric pollution constitute an important environmental management goal in order to maintain acceptable air quality levels. Several methods exist to monitor compliance with air quality standards and one of them is biomonitoring where responses of living organisms to air quality [3] and environmental pollution in general are recorded [4]. This method can provide qualitative and/or quantitative information about the levels of atmospheric pollution [3]. Biomonitoring demonstrates the concept of risk of pollution and provides a complementary tool for the assessment of the pollution's environmental impact [5, 6]. The use of biomonitoring can also help raise awareness among the public about the importance of the issue of environmental pollution [5, 6]. From the biomonitoring standpoint, four concepts at different levels of biological organization can be defined as follows [7]: biomarker, biointegrator, bioaccumulator and bioindicator. Lichens are the well-known bioindicators and constitute an ideal means for the air quality assessment. Among the lichen bioindicator methods, the approach of Kirschbaum and Wirth [8] is based on the differences in the lichen's sensitivities toward pollution.

Algeria like other countries in the world is facing a serious air pollution problem. In the case of the City of Tiaret, statistics given by the Algerian National Department of Health indicates that 32 new asthma cases are recorded there every month [9]. Many of the asthma cases are likely due to air quality problems and pollution. Impact of the air pollution on public health in Algeria is often overlooked. Hence health officials have to raise public awareness to cope with the problem. At the same time, assessment and monitoring of atmospheric pollution must be improved. It is against this background, that the purpose of the current study is to assess the atmospheric pollution in the region of Tiaret by the examination and census of the lichen flora. Very little work has been done on the subject of biomonitoring using lichens in Algeria. Therefore, this study is aimed at mapping the classes of lichen species in the context of their sensitivity to different levels of pollution. Specific objectives of the study include:

- to identify the lichen species present in the region of Tiaret, Algeria at the agglomeration level;
- to investigate the use of the chosen bioindicator species in the assessment of air pollution in the Tiaret geographical area;
- to estimate the atmospheric pollution according to the Kirschbaum-Wirth method using the collected lichen data; and
- to develop an air quality map of the region of Tiaret using the collected lichen data and estimates.

2. Materials and methods

2.1. The study zone

The study was conducted in the city of Tiaret, which is located in the northwest of Algeria between the mountainous Tell chain in the north and the mountainous Atlas chain in the south at an altitude of 980 m on average. The climate is Mediterranean and semi-arid with a mean annual rainfall of 400 mm/year. The prevailing winds are from the west and northwest, their average speeds range from 3 to 4 m/s. The population of Tiaret is quadrupled during the period from 1966 to 1998, with the actual numbers increasing from 37,990 to 167,000 inhabitants. As a result, the City of Tiaret has a population density of 136.10 inhabitant/km^2. The rate of population growth reached 3.66% per annum between 1977 and 1987, and this was accelerated to 4.11% in 1998 (NOS 1998). The predicted 2015 population of Tiaret is estimated to reach 213,551 inhabitants, and the population growth rate is likely to level off at 2% per annum [10].

Urbanization of the Tiaret city took place in two very different periods, which has resulted in two major and distinct areas in the city. Overall the structure of the city consists of concentric blocks of housing and commercial infrastructure that ultimately converge towards the old urban network of Tiaret City centre. The municipality of Tiaret administers a road network of 200 km, which carries high volume of permanent traffic. Parts of this road infrastructure have deteriorated in recent years. The city has established three types of housing environment zones, which in turn define the type of public roads. This is an indirect outcome of the fact that the network of Tiaret is not organized according to a spatial and functional hierarchy, i.e. it cannot be divided into main boulevards, secondary boulevards, primary public road, secondary public road, etc.

2.1.1. The automobile fleet of Tiaret city

Automobile traffic will have a strong influence on air quality. In December 2008, the automobile fleet of Tiaret city consisted mainly of old vehicle models that do not contain catalysts for removal of exhaust pollutants [11]. More recently, the automobile fleet of the municipality of Tiaret consisted of 31,178 vehicles and up to 75% of them were aged at 20 years or older. Out of this number, there are 1925 cabs, 19,756 gasoline-powered vehicles and 11,422 diesel vehicles. At present, the number of vehicles is almost four times that of 2006 when the total vehicle count stood at 8015 (registration vehicles cards branch of Tiaret, 2010: personal communication). These factors increase the possibilities of the emission of pollutants [12]. This conclusion is further supported by the departments of environment and public health. The road transport has been shown to contribute up to 30% towards the particulate pollution which is of public health significance by causing respiratory disorders in the City of Tiaret. Our work targeted the part of the City of Tiaret to assess the atmospheric pollution. **Figure 1** indicates various sites of research used in our study.

2.1.2. Typology of the monitoring stations of the air quality

Information for the classification and selection of sites for air quality monitoring stations were extracted from reference [13]. The urban monitoring stations were selected so that the data collected at these sites would allow the project team to evaluate the average population exposure level to atmospheric pollution in urban areas of Tiaret (**Figure 1**). Pollution levels detected by these stations should be representative of the average levels of the urban agglomerative pollution. The most important geographical locations for the monitoring stations should be in areas with the highest population densities (e.g. Badr city, Louz city, Rousseau city). Pollution in these urban areas will originate from surface and the mixed or combined sources include the following:

- residential, tertiary, commercial and institutional sources,
- road traffic sources,

- agriculture, forestry and
- others (including the natural sectors)

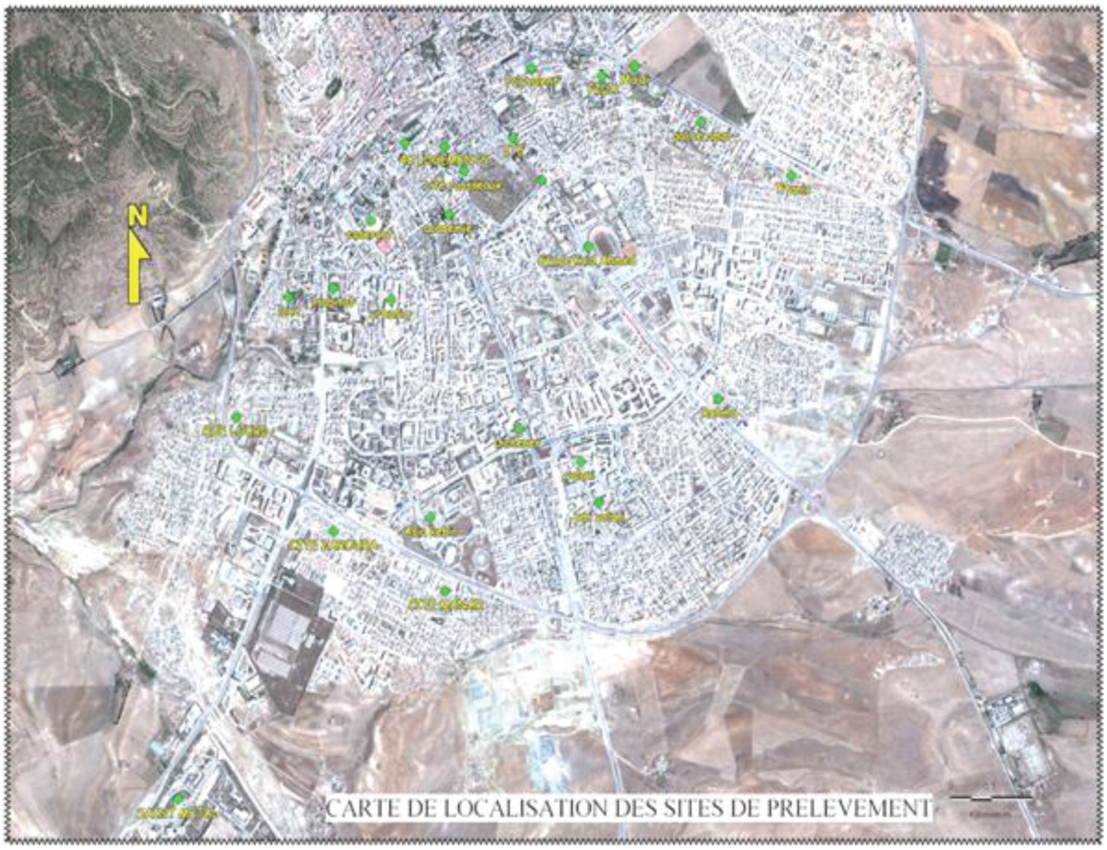

Figure 1. Localization of the research sites in the area of study (region of the city of Tiaret).

Traffic monitoring stations: The objective of these stations is to supply information on the concentration of pollution measured in representative zones of a road infrastructure. These stations can be installed at any type of the studied zone whether it is in a space of a rural or urban domination (Rahma, Volani, La Gare). The category of the issuer which the influence must be dominant on the station is the road transport.

Industrial monitoring stations: The objective of these stations is to supply information on the concentrations of moderate pollution that originate from a combination of several pollution sources and where the pollution accumulation tends to be highest in the vicinity of the industrial source of pollution (SN metal). Dominant sources of pollution will include the following: industry and waste treatment, production, transmission and distribution of energy and others.

National and rural stations: Exposure supervision of the ecosystems and the population in rural areas to the atmospheric pollution can be connected to the said cross-border pollutions (Titanic) using these types of sampling sites.

2.1.3. Distribution of the population

The study of population distribution is very important for the interpretation of the examined phenomena and the outcomes of these phenomena. At the same time, it is significant in determining the population properties and its spatial distribution, as well as the use describing the said population. For the Tiaret Municipality, the spatial units where the population figures were collected were divided up into three spatial frames:

- County town agglomeration
- Secondary agglomeration (Karman, Ain Mesbah, Senia)
- The scattered zone

As stated above, the population of the municipality of Tiaret has experienced a high population growth rate with the majority being located in the municipality's urban areas. This puts pressure on the life system, especially the housing and the socio-educational equipment, the economy and also the employment opportunities.

2.2. Study design and experimental approach

This work was done over 5 months (from January to May, 2012); the big sections were achieved on different sites during this study. Field work consisted of the sampling site selection, selection of the tree species which carry the lichens, sample collection of said lichens and the exact GPS coordinates of all sampling sites. Once the sample collection was complete, samples were returned to the plant ecology laboratory at the Faculty of Natural and Life Sciences at Ibn Khaldoun University in Tiaret. The samples lichen species were then identified in the same facility using relevant catalogues, the key determination and selected chemical indicators such as K—reactivity with potassium hydroxide and CI—reactivity with bleach. The atmospheric pollution map was constructed using the resources of the URBATIA in Tiaret, Algeria.

To estimate the overall air quality in the urban areas of Tiaret, we adopted the method of Kirschbaum and Wirth [8]. Unless otherwise stated, the Kirschbaum and Wirth method and experimental approach are designated as the method in further text and all the information are from reference [8]. The method is relatively simple and cost-effective to use, and it is ideal for experimental air quality data collection in the municipality of Tiaret. Several stages must be carried out in the application of the method for the measurement and mapping of air pollution/air quality. First, determination of different study zones must be carried out. Second, the tree species, which have lichen symbionts, must be selected. Third, sample collection of lichen and their quantitative and qualitative analyses must be performed, while the final stage involves the mapping of the lichens distribution and the relation to air quality.

It is recommended that the study zones are defined using a 1 km domain, but this spacing can be increased or decreased depending on the given study area. Each domain should contain six judiciously selected trees, and these should be evenly distributed throughout in each domain. Selection of trees carrying lichens should adhere to the following criteria: all sampled trees must be isolated and subjected to the same environmental conditions such as luminosity, humidity and exposure to the wind. The bark characteristics and the development of the lichens/lichen cover vary among various trees species. Therefore, it is advisable to perform lichen sampling on only trees belonging to a single species, if possible. Alternatively, lichens from one kind of bark in terms of its natural acidity and structure should be sampled. The tree(s) age should be recorded as the tree's average diameter or as the range between the minimum and maximum tree diameters, if more than one tree is joined together and sampled. For our study, the minimum circumference of the sampled tree was equal to 70 cm, and the lichen cover is allowed time to be developed as rate of lichen cover development is slow.

The trees that should be considered first as the best lichen carriers are the ash tree, the poplar and the lime tree. Oak, the sycamore maple and fruit trees, namely the apple tree, the walnut, the cherry tree, are also good lichen carriers. Willows and birches or plane trees are not good candidates as their bark is too acidic and detaches easily and the potential for lichen cover development is very limited, and these trees do not allow for monitoring air quality and pollution. For the current study, the sampled trees had the highest lichen cover and were the most representative of the vegetation in the particular domain. The sampled trees also had comparable characteristics among the different sampling sites. Sampling of oblique trees and those where surface wounds or the friction of the cattle were detected were also excluded from the sampling.

Two types of lichen analyses were performed. The qualitative sampling consisted of establishment of the identity of the lichen species. The qualitative lichen analysis was conducted by examining the species distribution over the most colonized trunk surface area equal to 20 × 10 cm. Quantitative evaluation is done through the measurement of the frequency of the tree colonization by a given lichen species. For this, a 10-compartment grid of 10 × 10 cm per grid was used to evaluate the colonization frequency of each lichen species identified. The samples were examined between 100 and 150 cm above the ground level to avoid the influence of animal excrement and artificial fertilizers on the results of the lichen analysis. Frequency of a given lichen species was recorded manually as the number of compartments that a given lichen species was detected in. The maximal frequency of a particular lichen species on a given tree was 10. This procedure is repeated for all the species present inside the grid and the given domain. The results of the quantitative analyses were recorded using indices. Every sample is the object of an index and the lichen frequencies measured were the object of such indices for a given domain.

On-site collection of lichen was done in one of two ways. The detached lichens (many of the terricolous lichens) were collected manually. The non-detached lichen species, i.e. all the fruticose lichens and most of the foliose lichens, were removed using a knife of a hammer, together with a small piece of the substratum the lichens were attached to. Care was taken not to damage the lichens attached to bark of trees. After sample collection, the lichen samples were placed in plastic bags, which are appropriate for the short-term storage and transport of lichen samples. The sampling location, the substrate and date were recorded on-site. In the laboratory, the fresh material was spread on a bench and allowed air-dry. Then the lichens can be without other precaution placed in the herbarium in a special envelope. Fruticose lichens take up a lot of space and they break easily. Thus, they must be placed in the herbarium when they are still wet and elastic, and only moderate pressure should be applied. In the samples of herbarium, the labels contained the following information: the place, the field if necessary the substrate (facilitate the determination), the date of collection and the name of the sample collector [8].

Lichen/sample coding was performed to avoid data confounding. For example, *Xanthoria parietina* E1, the domain LOUZ S16. Samples taken in the City of Tiaret were coded, in order to facilitate the data interpretation and avoid any confusion in it. Fifty species were identified and collected at the city of Tiaret and were coded accordingly to prevent confusion and problem in data interpretation. The actual sample coding of the lichen species is indicated with two columns, one for the species name, and the other for their codes. Samples made in the city of Tiaret were grouped under 25 domains coded with numbers (S1, S2, S3,…) (**Table 1**).

Station	Code	Station	Code
Fida	S1	Asia Kebir	S14
Habitat	S2	Rahma	S15
Academie	S3	Louz	S16
Cite Rousseaux	S4	URBATIA	S17
Ite	S5	PMI Volani	S18
Rue De Frigo	S6	40 Logments	S19
Boulice Amare	S7	SN metal	S20
Volani	S8	Voie d'evitement	S21
Terrain Boumediene	S9	Cite Zaarora	S22
Stade Kaid Ahmed	S10	Cite Manare	S23
Titanic	S11	La Gare	S24
Maidi	S12	Polyvalent	S25
Cite Badr	S13		

Table 1. The coding of the studied domain.

2.2.1. *Identification of the lichens*

Cuts of the thallus from all collected lichens were identified in the laboratory after examination with a binocular magnifying glass and a microscope. The following determinants were used: the form and the colour of the thallus and fructification, the presence of verrucosis whorl scar (isidium), floury mass (solarium) and other structures. In order to determine the crustose lichens, the use of the microscope is essential [8]. In certain cases, it is enough to bring a good magnifying glass with a magnification of 10× and test for reactivity with potassium hydroxide and little bleach. We note K+ when the potassium hydroxide (KOH at 20%) reacts (otherwise: K-) and C+ (C is for C1, the chlorine), when the bleach reacts (otherwise: C-).We put a quite small drop. At the same time, if the colouring seems fuzzy or not clear, it is absorbed onto a white tissue, making it easier to distinguish the obtained colour. During sampling, a small knife is useful to lift or remove fragments but it is necessary to avoid damaging the trees and the rare or unique lichen species were not sampled in line with previously reported studies [14]. Taking these limitations into accounts, all the lichen species that were observed in the field were counted and recorded. Thus, the method guidelines were considered limiting and were modified to the conditions in the Tiaret geographical area.

Assessment scale of the air quality classes and map construction: The value of the air quality indices (referred to as AQI in further text) was represented by colours. And for this purpose, the values were grouped into classes. Each class has its own colour. **Figure 2** shows the pollution degree according to the assessment scale of the air quality as outlined in the method [8]. To construct the pollution map, once the identified species and the AQI were calculated for every domain, we have established a pollution degree scale for the different studied domains according to different colours.

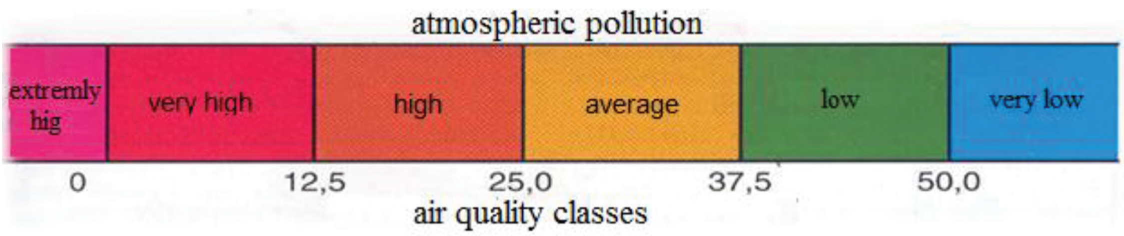

Figure 2. Assessment scale of the air quality classes (by Kirschbaum and Wirth method, 1997).

At URBATIA, all the collected data were exploited to construct a map of atmospheric pollution in the southern region of the city of Tiaret. Using the MapInfo®7.8 software, a map was constructed using the Kriging method interpolation and the vertical mapper™ between the concentration points in elements of the software and for the domain location. Setting of the map was done using AUTOCAD software. By applying the GPS data collected, the geographic coordinates (x, y) were obtained, and the z coordinates are represented by the AQI.

3. Results and discussion

The focus of our work was the assessment and construction of an atmospheric pollution map of the Tiaret city by using lichen bioindicators. We now use the AQI values to show different results that were calculated in each studied domain by the method [8], to allow us to classify the zones according to the atmospheric pollution degree. Then we will clearly indicate the space distribution of the listed lichen species. Then we will introduce the atmospheric pollution map achieved for this region. Finally, a comparison will be made with other previous research.

3.1. Results of the indices of the air quality (AQI)

In order to calculate the indices we have followed this way: Calculating the average frequency of each lichen species existing on the six studied trees and then the average frequency of each species will be added up and the total amount represents the index of the air quality.

3.1.1. Example of calculation of the AQI in a domain

For illustrative purposes only, we show an example of the AQI for one of the studied domain (see **Table 2** for details), but it should be noted that the index is calculated as a whole for each of the 25 studied domains.

Station	**Academy Latitude: 35° 21'54.08" N Longitude: 1° 19' 09.81" E Altitude: 1006 m**						
	Trees						
Species of lichens	1	2	3	4	5	6	Average frequency of the species
E1	0	10	10	8	0	10	6.33
E5	0	0	0	10	0	0	1.66
E11	10	1	0	9	10	0	5.00
E12	0	9	10	0	0	0	3.16
E16	0	0	0	0	7	0	1.16
E21	10	0	0	0	0	0	1.66
E23	0	0	0	0	10	0	1.66
E43	0	0	0	0	10	0	1.66
E61	0	0	0	1	0	0	0.16
Index of air quality: AQI (sum of frequencies)							22.5

Table 2. An example of calculation of the AQI in the domain ACADEMIE.

3.1.2. AQI results at all studied domains

For all the 25 domains, the total of the frequencies give the value of the AQI by which the pollution degree was assessed and this is done according to different classes (see **Table 3** for details). Results in **Table 3** demonstrate in a global way the air quality of each studied domain. If the value of the AQI is low, then the pollution is high and the status of air quality is critical or worst from the environmental management point of view, if AQI reaches the extreme value of 0. On the other hand, a high value of the AQI indicates a good air quality. According to the **Table 3**, the lowest pollution degree was recorded at the domain RAHMA (AQI = 0), where the pollution is extremely high. In this domain, an illegal rubbish container was identified and could be the source of the air quality problems. Some domains showed low air quality indices, impacted by a limited existing number of lichen species with a low covering rate, e.g. Cite Badr, La Gare, Cite Manare and SN metal. Domains of Badr and La Gare are overcrowded urban areas and busy road traffic junctions. On the other hand, domains of Cite Manare and SN metal contain high levels of industrial activity. These facts provide an explanation for the calculated AQI

An average AQI was recorded at the domain Kaid Ahmed stadium and Titanic, which are opened domains with low degree of building and population coverage. On the other hand, the domain LOUZ indicates a low pollution degree (AQI = 38.5). This domain is situated close to the north region of the city and distant from the sources of emissions and the industrial units and road traffic, the fact that it is situated in a secluded area towards the city centre. From 25 studied domains, five pollution classes were highlighted. From **Figure 3**, it is clear that 68% of the total number (17 domains) of the studied domains exhibited a high pollution degree and 16% or four domains were very highly polluted. Only 8% (two domains) of the total domains sampled show an average pollution degree. While for the two pollution classes: the extremely high class (4%), the lower class (4%), they represent the lowest number of domains, and it is one domain for each.

Station	Code	AQI	Pollution degree	Type of station
Fida	S1	22.3	High	Urban station
Habitat	S2	20.67	High	Traffic station
Académie	S3	22.5	High	Traffic station
Cite Rousseau	S4	17.67	High	Urban station
Ite	S5	13.83	High	Traffic station
Rue De Frigo	S6	24.83	High	Traffic station
Boulice Amar	S7	23.83	High	Traffic station
Volani	S8	25	High	Traffic station
Terrain Boumedienne	S9	23	High	Urban station
Stade Kaid Ahmed	S10	30	Average	Traffic station
Titanic	S11	33.83	Average	National rural station
Maidi	S12	24.33	High	Urban station
Cite Badr	S13	12.16	High	Urban station
Assia Kebire	S14	18	High	Traffic station
Rahma	S15	0	Extremely high	Traffic station
Louz	S16	38.5	Low	Urban station
URBATIA	S17	18.1	High	Urban station
PMI Volani	S18	19.8	High	Urban station
40 Logements	S19	24.6	High	Traffic station
SN metal	S20	9	Very high	Industrial station
Rue Lourd	S21	23.4	High	National rural station
Cite Zaarora	S22	24.7	High	Industrial station
Cité Manare	S23	8.2	Very high	National rural station
La Gare	S24	11.6	Very high	Traffic station
Polyvalent	S25	19.5	High	Urban station

Table 3. The values of the AQI of the studied zone.

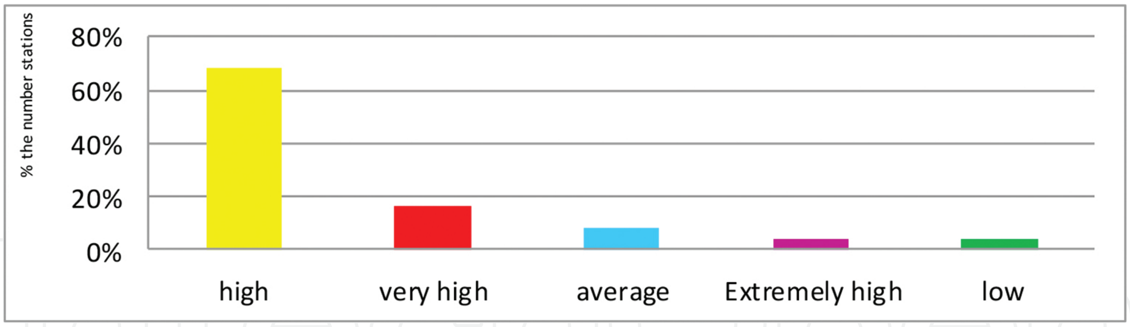

Figure 3. Evolution of the domain numbers according to the pollution classes.

Most of studied domains had an AQI that varies between 12.5 and 25, which corresponds closely to a high pollution degree [8]. In this area, we find different types of domains especially urban and traffic, it reflects an important population density and a significant road infrastructures.

3.2. Results of the pollution classes obtained on each type of domain

From **Figure 4**, we notice that, regardless of the domain's typology, the high and very high two classes are present. In an urban and traffic domain, the high class is mostly present (7/10 and 8/10, respectively). It is also presented in the national industrial and rural domain in a rate of one class per domain. About the high class, we notice it with a low rate (only one domain of each type). A class with an average pollution degree is indicated of each national traffic and rural domain. Though at the domain of urban type, slightly polluted class appears simultaneously, and a class of an extremely high pollution degree.

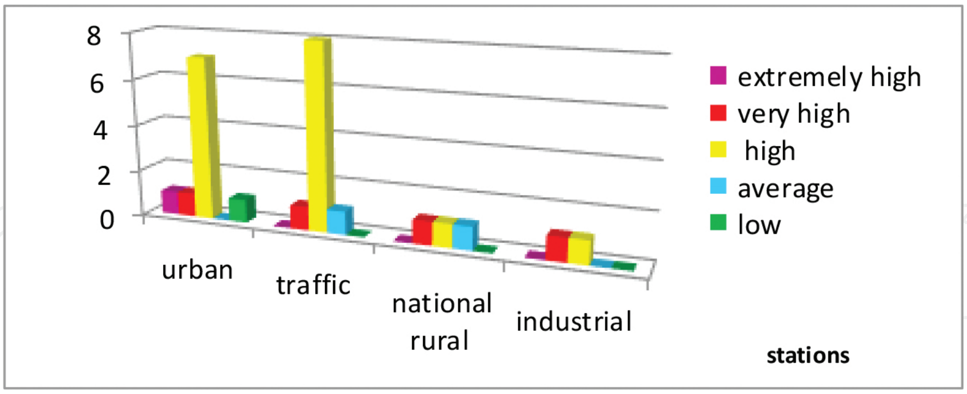

Figure 4. Pollution classes according to the typology of the studied domains.

3.2.1. Average results of AQI according to the studied stations

An average AQI is calculated by averaging the calculated AQI at the different domains of the same typology. From **Figure 4**, we note that the average AQI of all types of domains varies from 21.51 to 19.03, which corresponds to a high pollution degree. Even if these different domains are in the same class (high), we notice that the urban type shows the highest AQI average (21.51) then the industrial type shows the lowest AQI of 20.33 and 19.59, respectively.

3.3. Spatial distribution of the lichen species

In our study zone, we have observed and identified 50 lichen species, which permitted us to conduct an overall evaluation of the pollution degree in the studied domains. In **Table 4**, the families of lichen species in all domains and the species number in all the families are summarized. Different lichen species are also identified according to the Thallus type, name foliaceous, crustacean, and basidiolichen, and the results are presented in **Figure 5**.

Station in common	AQI 2010 (pollution class)	AQI2013 (pollution class)	Notes
Volani	27.6 (average)	25 (high)	Degradation of air quality
PMI Volani	16.8 (high)	19.8 (high)	Stable air quality
L'Acadimie	20.6 (high)	22.5 (high)	Stable air quality
Cite Rousseaux	37.3 (average)	17.67 (high)	Degradation of air quality
Ite	20.2 (high)	13.83 (high)	Stable air quality
40 Logements	14.5 (high)	24.6 (high)	Stable air quality

Table 4. Comparison of the different AQI at the common domains.

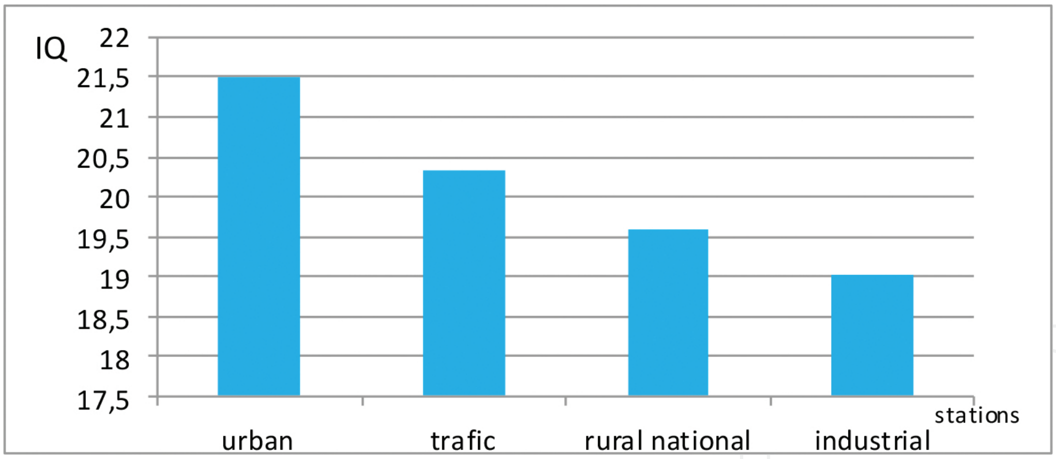

Figure 5. The species number of each thallus type.

Noting that the existence of *Xanthoria polycarpa* indicates a very high pollution, such levels can be inferred for the following domains: SN metal and La Gare. The *Physconia grisea* spp. found at the domains of Academie, Cite Badr and Assia Kebir was indicated as a very resistant species by Fadel et al. [15], which is the case in our study. *Physcia tenella* was found in Titanic domain, and it can be classified as moderately resistant, which reflects the pollution degree found at that station. Some domains like Cite Badr, La Gare, SN metal, Volani, Ite, contain very few lichen species, and thus, their recovery rate was weak. Those domains highly urbanized and

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experience busy road traffic, i.e. the lichen species will represent a high occurrence of diffuse sources of the atmospheric pollution. The overall extent of pollution is increasing. In domains with moderate and high average levels of pollution, a high number of lichen species was observed, i.e. indicating that the ecological conditions there are favourable to the development of the species. This conclusion is demonstrated by the recovery of two different lichen species from the domain of Louz, including the recovery of lichen species that have been shown to be susceptible to atmospheric pollution, namely *Physconia distorta* [16].

3.4. Presentation of the pollution map of the studied zone

After calculating the AQI of each domain, the data were used to produce the pollution map of the study zone, shown in **Figure 6**. Different pollution zones are distinguished by colour coding, which is explained below.

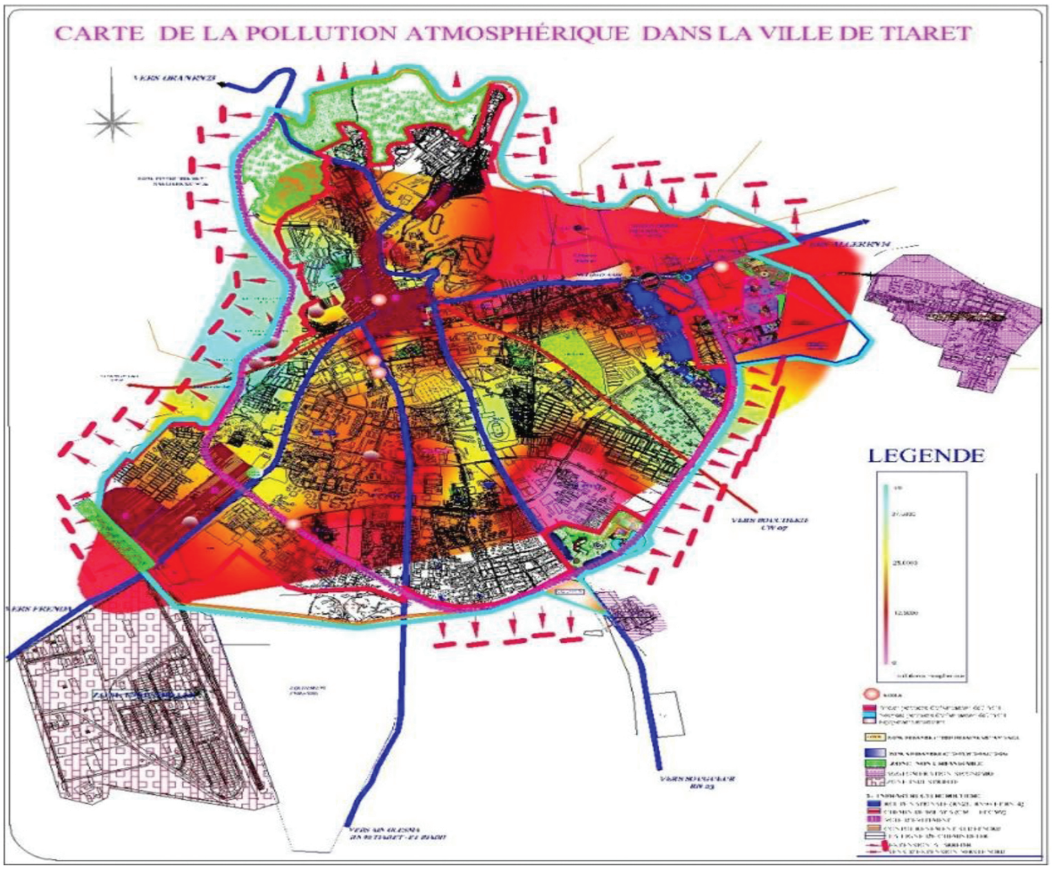

Figure 6. Atmospheric pollution mapping with lichens in Tiaret city.

3.5. Reading of the pollution map

Figure 6 provides a complete picture and evaluation of the atmospheric pollution level in the studied zones. An in-depth analysis of this map results in five pollution classes represented by five gradual colours.

Class 01 refers to an extremely high pollution, indicated on the map by the mauve colour, represented by only one domain Rahma with a pollution degree, AQI = 0 leads us to suggest that the air quality is low in this domain. This is similar to the data on lead pollution from road traffic in the Rahma domain [17]. The apparition of this class can be due to the hazardous waste and to the emanations of exhaust gases issued from the road traffic. Furthermore, this domain is characterized by a relatively steep gradient, which obliges the engine to develop more power and to consume more fuel, thus releasing more pollutants, bringing about a considerable increase in emissions, and a very important area of road traffic. The area also has a high concentration of gas stations with underground fuel storage tanks, which can result in leakage of gasoline and diesel and thus contribute to the atmospheric pollution from filling of reservoirs in gas stations [18].

Class 02 indicates a very high pollution in the domain Badr and La Gare, because of the high population density in these domains, domestic discharges (solvent evaporation), discharges from internal heating (especially in the winter), the road traffic emissions, as well as the important industrial emissions in the domain SN metal and Cite Manare. These findings are similar to those of reference [15], which have demonstrated that the peripheral domains of the urban network are highly polluted and indicated by the results of this study for the SN metal domain. Fadel et al. [15] also reported atmospheric transport of the pollutants from various industrial in the prevailing wind direction. This mechanism could provide an explanation for the pollution levels recorded in this study for the industrial domains, such as SN metal. Therefore, the class 02 sources of atmospheric pollution include those of domestic origin (Cite Badr), those from road traffic (La Gare) and finally those of industrial origin (SN metal). This is in line with findings from previous studies [1, 19, 20].

Class 03: the results of the third class indicate that this zone is affected by a high pollution degree. The affected areas belong to traffic domains (Academie, Volani, Assia Kebir, Habitat, Ite, Rue De Frigo, Boulice Amar, 40 Logements), Urban domains (Polyvalent, Fida, Cite Rousseaux, Terrain Boumediene, URBATIA, PMI Volani, Maidi), a national rural domain (Rue Lourd) and an industrial domain (Cite Zaarora).

These domains are the more representative on the map, and they appear by a yellow colour, which dominate almost the entire map (68%) of the studied zone. They are the busiest and more frequented of the entire city, which favour the pollution to reach a worrying peak. They are also subjected to a strong urbanization and an increase in the number of vehicles, entailing harmful effects on the environment. The last point mainly applies to traffic from old vehicles with a diesel engine and those who use fuels that does not correspond to the regulations of the environmental protection [11]. According to reference [21], the real conditions of the traffic are connected to the urban and rural circle and to the category of the road (highway, express way, medium-sized road, local network), to the function of the road (transit, distribution, residential access), to the mandatory speed limits, to the road's characteristic and to the traffic level (fluid, busy, saturated).

The number of vehicles in the national roads is densely; it is the case of the domain Rue Lourd in our study zone, the fact that the municipality of Tiaret which is conceived as a metropolis of the highland region is often frequented by all kinds of vehicles.

The industrial zone Cite Zaarora is represented at this class (separately from the industrial zone SN metal, which is present in the class 02, corresponding to a very high pollution degree), this is probably due to the fact that Cite Zaarora, even if it is an industrial zone, still being less active than the SN metal zone, which explains its presence in this class.

One of the reasons that explains the high pollution level in some studied domains is the organizational form of the roads; it is applied with a lot of ignorance, the fact that the radial links are not ensured and the main network was not designed to support the current traffic. It brings about bottleneck between the south and the north (the case of the domain Academie, 40 Logements and Ite in our study zone), which means that the city centre, as an obligatory crossing point, is suffocated by the massive number of vehicles. It causes a network disorganization of the traffic, considered as an essential element of the urban planning [22].

At some domains of this class, for example, Cite Rousseau, PMI and Volani, wind is abated by hindrances formed by a high density of infrastructures, which fosters local pollutant accumulation. This is explained by the absence of the wind that contributes to the accumulation of pollutants close to its sources. In fact the buildings typography can disrupt the normal functioning of the wind and its trajectory and modifying the average characteristic and turbulence of the wind blowing [23].

We note at this class level the existence of the equipment (Maid), services (Volani), agricultural activities (Assia Kabir), and a large amount of schools (Polyvalent), where the pollution directly affects the human health.

Class 04 indicates that the pollution is moderate, it is represented by the blue colour at the domains: Stade Kaid Ahmed, Titanic and La Rue Des Freres Kaidi (W11), these sites are open areas, boosting the dispersion of the atmospheric fallout, which are transported by the wind. There is no topographic obstacle to stop them. It contributes to avoid the localized accumulation phenomena of the pollution. In fact, Loubet et al. [24] explained that the most adverse conditions of the atmospheric pollution dispersion meet when the wind speed is low or nil. Antipolis [22] also confirmed that the wind is an essential factor, which explains the dispersion of the pollutant emitted. It intervenes as long by its direction to orientate the pollution plumes than with its speed to dilute and to bring about the pollutant emissions.

Class 05 represented on the map by a green colour, which is localized at the domain Louz with a maximal AQI equals to 38.5. In fact, this domain is characterized by a low traffic road, its location is opened and wide, in which case the air is considered as slightly polluted. As we move away from the dense centre of the agglomeration (Louz) as the pollution level decreases. Maatoug et al. [17] have effectively confirmed that the opened sites are less polluted, favouring the dispersion of the atmospheric fallout which is carried by the wind.

Our less polluted domain (Louz) is situated far from the emission sources of the industrial units and the sources of urban emanations; this concept is confirmed by Fadel et al. [15], during their research on the bio assessment of the atmospheric pollution in the city of Skikda.

In this regard, and to support our discussion, it may also be considered necessary that we make a comparison between our research and that of Snouci [25] achieved on some common domains with our study zone (14 common domains) and by using the same methods of the atmospheric pollution assessment.

In order to better illustrate the comparison between the two researches, **Table 4** shows the common domains with their AQI.

According to **Table 4**, we notice that, among the 14 common domains, six of them remained at the some pollution level, five have undergone air quality deterioration, while only three domains have undergone a slight improvement.

Then, about the domains which have shown a similitude of the AQI (Ite, PMI, Volani, Academie, Habitat and Rue Frigo), we note that they have kept the same pollution level in the two researches (high pollution).

The AQI of the domains Volani, Cite Rousseaux, Polyvalent, Assia Kebir and SN metal in our research has been decreased, compared to the calculated pollution level on 2010. We note that the domain Cite Rousseaux has been a subject of an important deterioration of the air quality (AQI decreased from 37.3 in 2010 to 17.7 in 2013), it is due to a heavy urbanization and to the increased rate of the number of vehicles in the city of Tiaret which is increased considerably since 2010. In fact, those domains are situated in the commercial districts of the city of Tiaret. This leads to strong road traffic in those districts by all types of vehicles that continue to increase. The other domain which has been an important cause for of deterioration of the air quality, is the domain SN metal (AQI decreased from 23.4 in 2010 to 9 in 2013) where the industrial emissions have been accumulated during this time, which represent the most important cause of the air quality deterioration.

Our study showed that the AQI of the domains; 40 Logements, Voie D'evitement, Terrain Boumedienne and Stade Kaid Ahmed have increased compared to the study of the year 2010; this is probably due to the elimination of some commercial activities, and to the transfer of certain administrative departments and the closure of some streets in these domains, which lead to a decrease in the road traffic.

In general, we can say that the atmospheric pollution in the region of the city of Tiaret had been in a sharp increase during the last 3 years (2010–2013). In our study, the apparition of a new class that corresponds to an extremely high pollution degree at the domain Rahma can justify such deterioration; due to the household hazardous waste, that are accumulated during a period of time at that domain, and to the population density, also to commercial activities (sale of building materials) and to the road traffic, which is multiplied along this period.

4. Conclusion

Our research focused on the assessment and the mapping of the overall atmospheric pollution in the region of Tiaret by using as bioindicators, lichen species and the total lichen flora. The calculated AQI. values in the 25 domain study zone led to breakdown of the sampling sites into five classes of pollution **(**Kirschbaum and Wirth method, 1997):

- The first class is represented by the traffic domain Rahma with an API = 0 and extremely high pollution degree.
- The second class corresponds to a very high pollution degree shared between automobiles, industrial and urban domain, where the most representative domains are Cite Badr (AQI= 12.16) and SN metal (AQI = 9).
- The third class is the dominant class, and it corresponds to a high pollution degree with an AQI, which varies between 12.5 and 25. This class groups 17 domains of different typologies (urban, traffics, industrial, rural, and national) located in a severely dense agglomeration and we register the existence of two sites that belong to the industrial zone Zaarora and SN metal.
- The fourth class is called the moderate class, and it is represented by two domains: Stade Kaid Ahmed (AQI = 30) and Titanic (AQI = 33.83); scattered in urban agglomerations with a low population density and in the road sector, relatively low.
- The fifth class is the last class, which comprises only one domain (Louz) with a low urbanization, far from all types of emission sources, with an AQI = 38.5, it reflects a low pollution degree.

Afterwards, we have listed and identified 50 lichen species in the 25 domains in our study zone. The census results and the identification have obviously showed that their number and coverage rates are strictly linked to the pollution degree. The lichen distribution and speciation directly correspond to the pollution degree, based on the observation of the ground. We have classified the collected species in the study zone according to their crustose Thallus types (29 species), foliose (20 species) and basidiolichen (one species). Finally, a pollution atmospheric mapping of the part of the city of Tiaret is achieved according to different classes given by the AQI for the localization of the domains on the map.

In fact, the method permits mapping of pollution for vast geographical areas in a relatively short time, because of the epiphyte vegetation that we have noticed. The used approach also provides an indication about the average pollution in the Tiaret area over several years. Moreover, lichens give us an overall pollution picture in the atmosphere of the Tiaret municipality. Among the measures to improve air quality in the study area, we can cite the renewal of the car fleet which permits without doubt, a decrease in the pollutant emissions of the road traffic; and to improve the adjustment of the combustion used in engines, and to use less pollutant fuels. In a perspective of continuity of this study, it would be interesting to achieve the some work in an extended period of time to assess the pollution evolution during the time. It will also be necessary to achieve this study in partnership with other Algerian cities to estimate the average degree of the pollution in Algeria. It allows us to catalogue the Algerian lichen species. In conclusion, we can say that the bio indicators have provided us with very interesting information, which allowed the detection of the air quality degradation before this one affects severely biotopes or human.

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