Impact of atmospheric pollution on asthma and bronchitis based on lichen biomonitoring using IAP, IHI and GIS in Algiers Bay (Algeria)

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Abstract We investigated the association between air pollution and asthma and bronchitis hospital admissions in Algiers city (Algeria). In addition, we used geographic information systems (GIS) and statistical methods to evaluate their correlation with the atmospheric pollution estimated by the lichen biomonitoring method of the index of atmospheric purity (IAP), the index of human impact (IHI) and environmental parameters. Thus, we georeferenced 976 local patients (including 771 patients with asthma and 205 patients with bronchitis). Then, we compared the patients to the spatial distribution of IAP in thirty-five areas (communities). The results revealed a significant difference in the mean spatial variation in the diseases among those areas. In fact, maps and generalized linear models (GLMs) revealed a significant negative correlation between IAP and

diseases. Therefore, redundancy analysis (RDA) and Monte Carlo tests described a significant effect of IAP, urbanization and the number of roads on the distribution of diseases. We hope our findings contribute to enriching the literature on health research with a low-cost method of monitoring outdoor air pollution.

Keywords Index atmospheric purity (IAP) · Lichens · Asthma · Pollution

Introduction

Air pollution has expanded considerably, especially affecting people with respiratory illnesses. The topic of the health impacts of air pollution has been the subject of debate in many scientific studies.

Some studies suspect that urban pollution can affect respiratory diseases such as COVID-19 (Comunian et al., 2020; Suhaimi et al., 2020) as well as bronchitis, sarcoidosis (Kampa & Castanas, 2008; Nhunga et al., 2018)), asthma, allergies and rhinitis (Just et al., 2007; Martin & Maystre, 1988). In addition, some studies have revealed that asthma is worse in children than in adults (Hehua et al., 2017; Khreis et al., 2018).

Therefore, several quantitative methods using lichen diversity have been described to monitor air pollution: the index of atmospheric purity (IAP) (LeBlanc & De Sloover, 1970), the index of poleotolerance (IP) (Trass, 1973), the index of air quality (IQA) (Kirschbaum

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& Wirth, 1997), the lichen biodiversity index (IBL) (Abas & Awang, 2017; Nimis, 1999), lichen-air quality index (LiAQI) (Boonpeng et al., 2018) and the lichen diversity value (LDV) (Asta et al., 2002).

As a passive biomonitoring method using lichen, the IAP has been adopted more often than the other cited indices (Conti & Cecchetti, 2001; Falla et al., 2000; Käffer et al., 2011).

Studies based on IAP have been frequently applied in many countries (Herzig et al., 2020) worldwide, including Switzerland, Argentina (Estrabou et al., 2011), Austria (Zechmeister & Hohenwallner, 2006), Korea (Jayalalac et al., 2015), France (Gombert et al., 2006), Spain (Blasco et al., 2008), Brazil (Käffer et al., 2011), Italy (Kricke & Loppi, 2002; Loppi & Nascimbene, 1998) and India (Das et al., 2013).

Despite these studies, none investigated the association between asthma or bronchitis distribution and IAP levels.

Algiers is exposed to intense atmospheric pollution, and some studies have revealed that the atmosphere of Algiers city is severely polluted (Boughedaoui et al., 2004; Kerbach et al., 1998).

Thus, an expansive network of air pollution monitoring in the city Sama-Safia was set up in 2002 but abandoned in early 2009.

To monitor this air pollution with easy- and low-cost methods, the fluctuations in this pollution can be spatiotemporally assessed. We chose the IAP index, and we explored its accuracy by assessing its correlation with asthma and bronchitis.

We investigated whether there is a significant link between air pollution, as established by the API, and the distribution of respiratory diseases. This study aims to use maps of atmospheric pollution in a geographic information system (GIS) and statistical analysis to describe the impact of air pollution on the prevalence of different categories of respiratory diseases in Algiers Bay.

The second objective is to determine the degree of precision of the IAP and IHI indices and the environmental variables used to evaluate the air quality in this area.

Materials and methods

Study area

Algiers, the capital of Algeria, is located southwest of the Mediterranean (Fig. 1). It covers an area

of 200 km² and is populated by at least 2,809,396 inhabitants according to the National Statistical Office.

The topography of the region is rugged and plays a role in the distribution of pollution. The city is divided into two parts: the eastern side and city centre, which has an altitude varying from 0 to 200 m representing the continuity of the Metija Plain, and the western side, which is at a higher altitude, between 0 and 400 m, represented by the Bouzaréah massif.

Some urban forests are present on the western side and around the study area. Our study area mainly involves the centre of the Algiers metropolis. It is bounded between the longitudes 2°58' and 3°12' east and the latitudes 36°43' and 36°49' north. Its climate is characterized by an annual average precipitation of 590 mm, ranging from 700 mm in wet years to 500 mm in dry years; a minimum annual average temperature of 10 °C; and a maximum temperature of 30 °C. The prevailing winds are north and northeast.

Algiers is located in the bioclimatic sub-humid phase in the warm winter.

Many roads and highways with heavy motor vehicle traffic run throughout the city, supporting a fleet that has almost doubled from approximately 566,000 vehicles in 1997 to 1,103,017 vehicles in 2007 National Office of Statistics. In Algiers Bay, there is a very dense urban area as well as many industrial areas located on both sides of the city, contributing to its pollution (Boughedaoui et al., 2004; Ghennam, 2011, 2017; Rahali, 2003).

Data and variables

For the evaluation of the air quality, we used the IAP (LeBlanc & De Sloover, 1970). We applied this method to a systematic survey carried out at 111 stations in 1110 olive (*Olea europaea*) tree areas, where we observed 35 lichen species (Ghennam & Abdoun, 2017). The formula of IAP is

$$IAP = \frac{1}{10} \sum_{i=1}^n Q_i \times r_i$$

where n = number of species, Q_i = ecological index of each species (Q for a species is determined by adding together the number of its companion

Fig. 1 Study area

species present at all investigated sites and then dividing this total by the number of sites) and r_i = cover of species (Gombert et al., 2006).

In this study, the calculated IAP values of each municipality corresponded to the average IAP for all stations inside their administrative borders. Then, we collected all respiratory illness data from the main Algerian hospital, Mustapha Pacha University Hospital, in the centre of the study area. We obtained all data for patients with asthma (benign, moderate and severe) and those with chronic bronchitis (with or without emphysema) that were hospitalized between 2006 and 2016 (Table 1).

Hence, we included only the patients who resided in Algiers, georeferenced them according to their addresses, and then added them into the pollution-monitoring database.

Then, we superposed the various variables and carried out statistical analyses.

For the environmental variables, the GIS database contained all the data on the index of air purity (IAP) until 2016. It also included information about land use, the index of human impact (IHI) proposed by Gombert et al. (2004) and all environmental variables. We calculated the values with the mean of the data recorded for every station within the administrative boundaries of each municipality.

To characterize these environmental variables, we used the averages of the environmental variables and explored disease data recorded at the community level (Table 1).

The number of roads 'Nb. Rt', highways 'Aut', vegetation cover 'VC', urbanization 'Urb', altitude 'ALT' and distance from road 'D. Rt' represented the environmental data (Ghennam & Abdoun, 2017).

Table 1 Summarized description of data collected (respiratory diseases and environmental variables) [N: effective, Se: error mean, IAP: index atmospheric purity, RD: road number, VC: vegetation cover, URB: urbanization, ALT: altitude, X: latitude, Y: longitude. * Source: University Hospital Mustapha Bacha, Algiers, Algeria (2006–2016). ** Source: Ghennam and Abdoun 2017]

Communities	Code	*Respiratory diseases Log(N)			**Environmental parameters							**Spatial data	
		Asthma		Bronchitis	IAP	IHI	RD	VC	URB	ALT	X (m)	Y (m)	
		Mean ± se	Mean ± se	Mean ± se									
BACHEDJERAH	BD	0.564 ± 0.108	0.739 ± 0.04	0.389 ± 0.088	0	24	3	1	6	2	511,331	4,065,344	
CASBAH	CSB	0.389 ± 0.088	0.389 ± 0.088	0	0	24	4	2	6	1	505,765	4,071,753	
SIDI M'HAMED	SDM	1.421 ± 0.167	1.531 ± 0.26	1.255 ± 0.176	1.563	25	5	2	6	2	504,290	4,068,077	
BAB EL OUED	BAO	0.36 ± 0.059	0.301	0.477	3.457	21	4	3	6	1	504,158	4,072,164	
HUSSEIN DEY	HCD	0.556 ± 0.114	0.724 ± 0.122	0.389 ± 0.088	3.714	20	4	2	6	2	508,081	4,067,075	
DAR EL BAÏDA	DRB	0.46 ± 0.087	0.46 ± 0.087	0	4.178	14	2	4	3	1	521,827	4,065,842	
EL MAGHARIA	MGR	0	0	0	4.2	20	2	3	5	1	508,955	4,065,061	
EL HARRACH	HAR	0.376 ± 0.075	0.401 ± 0.1	0.301	4.46	23	3	3	5	1	511,531	4,065,147	
BORDJ EL KIFFAN	BEK	0.464 ± 0.062	0.54 ± 0.062	0.389 ± 0.088	4.468	20	2	3	5	1	524,073	4,070,436	
ALGER CENTRE	AC	1.81 ± 0.183	1.907 ± 0.316	1.666 ± 0.033	4.693	22	4	3	6	2	504,692	4,070,492	
MOHAMMADIA	MMD	0.434 ± 0.133	0.699	0.301	4.787	22	2	3	4	1	516,000	4,066,763	
BIRKHADEM	BK	0.772 ± 0.135	0.773 ± 0.244	0.772 ± 0.073	5.058	22	1	3	5	2	502,552	4,064,117	
BOLOGHINE IBNOU ZIRI	BOL	0.301 ±	0.301	0.301	5.068	16	2	3	4	6	502,725	4,072,716	
RAÏS HAMIDOU	RH	0.389 ± 0.088	0.477	0.301	5.068	28	3	2	4	1	499,723	4,074,540	
BAB EZZOUAR	BAZ	0.646 ± 0.091	0.753 ± 0.151	0.54 ± 0.062	5.798	22	3	2	6	1	516,198	4,065,733	
BIR MOURAD RAÏS	BMR	0.376 ± 0.075	0.452 ± 0.151	0.301	6.404	24	4	1	5	4	505,151	4,066,170	
EL BIAR	ELB	0.5 ± 0.199	0.699	0.301	6.44	24	3	2	5	3	504,685	4,070,480	
KOUBA	KOB	0.728 ± 0.148	0.773 ± 0.244	0.661 ± 0.184	7.012	24	2	3	5	3	507,703	4,066,585	
OUED KORICHE	SOR	0.301 ±	0.301	0	7.62	21	3	2	5	3	503,859	4,072,424	
BORDJ EL BAHRI	BEB	0.301	0.301	0.301	7.711	24	3	2	6	1	523,350	4,073,116	
DÉLY BRAHIM	DLB	0.54 ± 0.101	0.69 ± 0.088	0.389 ± 0.088	7.881	16	2	4	3	3	500,090	4,069,773	
OULED FAYET	OF	0.477 ±	0.477	0	8.634	5	1	4	2	2	495,735	4,066,676	
MOHAMED BELOUIZDAD	BEL	0.767 ± 0.216	0.919 ± 0.327	0.54 ± 0.239	8.840	20	2	5	4	2	506,093	4,068,021	
EL MARSÀ	MRS	0	0	0	9.25	24	2	4	5	1	523,350	4,073,116	
EL MOURADIA	MOR	0.651 ± 0.147	0.651 ± 0.267	0.651 ± 0.048	9.493	32	1	4	4	4	504,273	4,068,084	
EL ACHOUR	ELA	1.342	1.342	0	9.496	9	2	4	3	2	500,354	4,067,097	
EL MADANIA	EMD	1.031 ± 0.181	1.155 ± 0.3	0.845	10.044	18	2	2	5	3	505,660	4,067,169	
DRARIA	DRA	0	0	0	13.3	22	2	3	3	6	502,219	4,064,576	
BOUZARÉAH	BOZ	0.376 ± 0.075	0.401 ± 0.1	0.301	14.482	13	2	3	5	5	499,338	4,072,461	

Table 1 (continued)

Communities	Code	*Respiratory diseases Log(N)			**Environmental parameters							**Spatial data	
		Total	Asthma		Bronchitis	IAP	IHI	RD	VC	URB	ALT	X (m)	Y (m)
			Mean ± se	Mean ± se									
CHÉRAGA	CRG	0.36 ± 0.059	0.389 ± 0.088	0.301	14.482	13	2	4	3	5	496,142	4,070,526	
	OSM	0	0	0	16,22	6	2	4	1	1	514,184	4,064,325	
BEN AKNOUN	BAK	0.477	0.477	0	16,2828	22	3	3	4	5	501,098	4,069,322	
BENI MESSOUS	BMS	0	0	0	17.15	14.75	2	3	3	6	496,693	4,071,573	
HYDRA	HDR	0.659 ± 0.119	0.619 ± 0.159	0.778	26.1128	11	1	5	2	5	503,288	4,067,829	
	EHM	0	0	0	27.93	5.5	1	5	1	6	495,374	4,073,758	

Analysis methods

We used cartography and GIS to carry out thematic analyses with Geo-concept software version 7.3 (GeoConcept S. A. Bagneux France), where we developed maps of IAP by municipality calculating the average of the IAP of the samples located in the territory of each municipality. Then, we represented the different diseases in histogram form for each community. For the statistical tests, we used the Shapiro–Wilk normality test to examine the compatibility of an empirical normal distribution and to be able to apply the means comparison test of several groups with the Kruskal–Wallis test (Taeger & Kuhnt, 2014). The generalized linear model (GLM) and AIC criteria were used to identify the environmental effect on respiratory diseases, and IAP modelling of the different asthma and bronchitis cases was performed using a generalized linear model (Dunn & Smyth, 2018; Harrell & Frank, 2015). To study the relationship and the influence of air pollution and environmental parameters on respiratory diseases, we used redundancy analysis (RDA), which was completed by a Monte Carlo permutation test (Borcard et al., 2018).

Results and discussion

Spatial variation in illnesses

Over the period from 2006 to 2016, the total number patients with respiratory diseases were 976, including 771 with asthma (265 cases were benign, 465 were moderate and 41 were severe) and 205 with bronchitis (124 with emphysema and 81 without emphysema). The Shapiro–Wilk normality test revealed that the distribution of diseases (log N) did not follow the normal law (p value < 0.05). The results of the Kruskal–Wallis test showed that the difference was significant between the averages recorded for each disease (p value < 0.05).

According to Fig. 2 (Table 1), we observed that the communities recording a high number of asthma cases were SDM, EMD and BEL. The communities BD, HCD, MMD, BK, ELB, BAZ, HDR, KOB and DLB recorded an average number of cases. For chronic bronchitis, the recorded peaks occurred in the

communities of SDM and AC, and the average values occurred in the communes HDR, EMD, MOR, BEL, KOB and BK. Low values characterized the

remaining communities. The mean test comparison showed a wide spatial variability in respiratory illness that was statistically significant (p value < 0.05).

Fig. 2 Spatial variation in respiratory diseases in Algiers Bay, Algeria (2006–2016) [1–35 classed by IAP 0–28, Table 1]

Relation between IAP and illnesses

The spatial distribution of respiratory illness on the function of IAP spatial distribution (Fig. 3a, Table 1) showed that the respiratory diseases in the most polluted zones were in communities low IAP values, except for the two communities BAK and HDR, which presented high IAP values but had a large number of disease cases.

In addition, we observed three times more hospitalizations for asthma than for bronchitis. On the other hand, we registered the absence of diseases in the communities EHM, BMS, OSM and DRA that had moderate and high levels of pollution. Two other communes, MRS and MGR, showed high and very high levels of pollution.

Regarding the spatial distribution of asthma with IAP (Fig. 3b, Table 1), we observed the predominance of moderate asthma followed by mild asthma. Severe asthma occurred in five communities: RH, BOZ, BAZ, HAR and HDR. Figure 3c (Table 1) illustrates the spatial distribution of bronchitis with or without emphysema in relation to IAP, and bronchitis with or without emphysema occurred in a high number of patients in two communities (AC and SDM).

Analysis with GLM model, RDA and Monte Carlo test

The GLMs (Fig. 4, Table 2) were statistically significant, explaining an analogous negative effect between respiratory diseases and IAP.

Fig. 3 Spatial distribution maps of respiratory diseases and the atmospheric purity index (IAP) in Algiers Bay, Algeria [(a) respiratory illness, b asthma (Mil: mild, Mod: moderate and

Sev: severe), c bronchitis (Brw: without emphysema and Brt: with emphysema)]

Fig. 4 Generalized linear model (GLM) showing the effect of IAP on respiratory diseases

For the RDA analysis, the environmental and IAP parameters explained 87.9% (RDA1=68.33% and RDA2=19.57%) of the total respiratory disease variability (Fig. 5). We distinguished three groups of communities: A and B were positively correlated with IAP, VC and ALT and negatively correlated with IHI, URB and RN as well as with respiratory illnesses. Group C was positively correlated with IHI, URB, RN and respiratory illnesses and negatively correlated with IAP, VC and ALT (Fig. 5).

In addition, mild asthma mainly occurred in three communities, CRG, MMD and BOL, whereas BEB and MRS showed very high IHI values and occur at a low altitude. In addition, the highest number of severe asthma cases characterized community RH. The results of the Monte Carlo permutation test (Table 3) showed that URB, IAP, and RN significantly affected the variability in the distribution of

respiratory diseases. However, ALT, IHI and VC were nonsignificant (p value > 0.05, Table 3).

Discussion

The association between outdoor air pollution and asthma hospitalizations is well established in the scientific literature. Air pollution increases hospitalizations for asthma, according to Cakmak et al. (2012), Ding et al. (2017), Guo et al. (2018), Hebborn and Cakmak (2015) and Pan et al. (2014). However, studies concerning the link between air pollution and asthma hospitalizations are limited in developing countries (Cai et al., 2014).

In Algiers (Algeria), IAP maps showed a very high level of pollution, according to the European level of pollution (Conti & Cecchetti, 2001).

Table 2 Results of the generalized linear model (GLM)

Disease		Asthma				Bronchitis		
		Total	Mild	Moderate	Severe	Total	BRwith	BRwithout
Intercept	Estimate	3.956161	2.78199	3.50878	1.07330	2.67996	2.1045	1.86690
	P value	<2e-16	<2e-16	<2e-16	0.0000622	<2e-16	<2e-16	<2e-16
IAP	Estimate	-0.126929	-0.10811	-0.13770	-0.13638	-0.13586	-0.1225	-0.15807
	P value	85<2e-16	3.26e-13	<2e-16	0.000808	7.93e-14	0.0000000587	0.000000204

Fig. 5 Redundancy analysis (RDA) showing the influence of the environmental parameters of Algiers Wilaya (department) on respiratory diseases

Among the thirty-five areas (communities), only six showed high pollution, and two showed moderate pollution. The most polluted areas of the city were situated in the north-eastern part of Algiers Bay. A low altitude less than 50 m with a high level of IHI and an IAP less than 12.5 characterized these areas.

This result was due to the neighbouring industrial area and traffic (Fig. 1) causing intense pollution (Boughedaoui et al., 2004).

Our study indicated a statistically significant association between air pollution based on the index of

atmospheric purity (IAP) and the spatial distribution of local asthma and bronchitis hospitalization for 2006–2016 in Algiers city.

The statistical test indicates that IAP, urbanization (URB) and road number (RN) significantly explained the variability in the spatial distribution of respiratory disease. These results confirm that an IAP, such as the air pollution index (API), can be used to evaluate the health risks of air pollution in China, the USA and the UK (Li et al., 2015; Shen et al., 2017). However, ALT, IHI and vegetation cover VC did not have a significant effect. Alcock et al. (2017) concluded the same for the nonsignificant association of vegetation and asthma hospitalizations with high air pollution. The community Rais Hamidou (RH) is the only studied community with both a low IAP and a high number of cases of severe asthma; this can be explained by the presence of a cement factory and a quarry.

There were three times more cases of patients being admitted to hospitals with asthma than with bronchitis. This observation can be explained by the fact that some cases of bronchitis can be treated without hospitalization.

Three communities recorded a high number of asthma cases, and nine recorded an average value of cases. These areas were the most polluted areas. The same observation occurred for chronic bronchitis cases, and the recorded peaks occurred in two areas (communities) with the highest level of pollution and situated next to the Algiers port. On the other hand, the community with the lowest level of pollution and far from the urban centre did not record any patient admissions.

These results corroborate an increase in asthma exacerbation and asthma cases due to an increase in air pollution (Just et al., 2006; Kim et al., 2015; Kim et al., 2013; Ozcan & Cubukcu, 2015; Tian et al., 2017; Veremchuk et al., 2018; Zora et al., 2013).

There were some limitations to the present study. First, smoking habits associated with asthma were not included in our database. Second, the study was not extended to smaller hospitals around the study zone.

Conclusion

In conclusion, our results contribute to the scientific literature on the link between air pollution and respiratory diseases using lichen-based methods with

Table 3 Statistical influence of the significant and nonsignificant (grey case) environmental factors on respiratory illnesses according to RDA ($\alpha = 5\%$)

	<i>df</i>	AIC	<i>F</i>	Pr (> <i>F</i>)
URB	1	−43.338	5.9199	0.005
IAP	1	−40.732	3.1329	0.025
RN	1	−40.238	2.6261	0.045
ALT	1	−39.694	2.0774	0.110
IHI	1	−39.767	2.1504	0.115
VC	1	−38.915	1.3052	0.300

significant results and new data in Africa. The study revealed a significant association between air pollution level and asthma or bronchitis hospitalizations. However, the risk of asthma hospitalizations is more probable than that of bronchitis hospitalizations. We found a statistically significant negative correlation between IAP and the spatial distribution of respiratory diseases; in contrast, IAP was positively correlated with urbanization and the number of roads.

The use of IAP in lichenic biomonitoring and its association with the distribution of respiratory diseases, along with the visualization of IAP on GIS, forms a very effective tool in studying the impact of air pollution on the health of populations and is useful for decision-making. Finally, it is important to improve this low-cost method of biomonitoring air quality for public health.

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Authors' contributions Individual contributions to the paper were the following: Ghennam k conceptualization; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software validation; visualization; writing-original draft; writing-review and editing. Attou F data curation; visualization; review and editing; formal analysis. Abdoun F supervision; visualization; project administration; review and editing.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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