Lichens as bioindicators of air pollution: Results from North Africa region

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Abstract
The atmospheric pollution is an international phenomenon which threatens the human life around the world. Contrary to North America and Europe, which have observatories of the atmospheric pollution, some other regions such as Africa are dispossess of this kind of institutions, things that pushed the scientists in the environment and air quality to use other methods which are simple and inexpensive, the most used is the biomonitoring and particularly with lichens. The aim of this study is to assess the air pollution using lichens as bioindicators and to create the air quality map using an interpolation method that based on the values of air quality index (AQI) in North Africa. The study was carried out in 63 sites distributed into three zones. The results show that 65.08% of sites have a medium rate of pollution, 26.98% of sites have a low rate, and only 7.94% present a high rate of pollution. The statistical analyses show that, the abiotic factors (the altitude values and the dominant wind) are positively correlated with the air quality values. The air quality map obtained allows us to detect the areas with a high level of atmospheric pollution in the region. We hope through this work to encourage the governmental agencies to become more involved with lichenological studies.

Keywords air quality; bio-monitors; lichens; interpolation; North Africa.

1 Introduction
Human made atmospheric pollution has been a peril since the headway of science and innovation. Worldwide industrialization and human lifestyles has put an effect on environment matter of genuine concern, particularly today that the outcomes of human intervention are as of now obvious. Despite the way that environment is
extremely significant for persons and different organisms existing, it is also imperiled due to human activities. Air and water admit any sort of toxins created by the most part from industries, domestic or traffic sources. Air quality can be observed by estimating the particulate contaminants directly in the air or in deposits, by models describing the distribution of contaminants, or by utilizing bioindicators. The terms bioindicator and biomonitor are utilized to refer to an organism, or a portion of it, that records the incident of contaminants based on explicit symptoms, responses, morphological changes or concentrations. The use of lichens as atmospheric pollution biomonitors is well known (Boamponsem et al., 2017; Conti and Cecchetti, 2001; Kularatne and De Freitas, 2013; Marié et al., 2016; Saxena and Sonwani, 2020; Will-Wolf et al., 2017). Lichens present several advantages since their sample collections are not expensive and can be used at several sites so that a comparative data can be achieved. Moreover, lichens are perennial and can accumulate elements originating from natural and anthropogenic sources over long periods of time. Their high degree of trace element accumulation enables the determination of several elements with high precision and accuracy (Maizi et al., 2012; Pollard et al., 2015; Saiki et al., 2007). Therefore, a few papers have been published on biomonitoring using lichens as bioindicators in different geographic territories (De La Cruz et al., 2020; Deruelle, 1984; Hawksworth and Rose, 1970; Gerdlol et al., 2005; Koch et al., 2018; Naeth and Wilkinson, 2008; Pirintsos et al., 1993; Root et al., 2015; Ventura et al., 2019; Zambrano et al., 1999). However, in Algeria studies on the utilization of lichens as biomonitors are rare and environmental pollution is a regularly developing concern and problem.

Despite their great demographic growth, their geographical situation – between Tellien Atlas and Saharan Atlas, where the forest represents more than 30%- and their Mediterranean climate, the Djelfa region - situated in 300km South of the capital of Algeria (Algiers)- has a very clearly problem of atmospheric pollution. The objective of this study was an assessment of air quality in the urban area of Djelfa and its surroundings using the epiphytic lichens as biomonitors. For this purpose, this study tries to calculate the air quality index (AQI) and to create the AQI map with interpolation of data.

2 Study area and Methodology

2.1 Study site

The study region included four areas (Fig. 1), the downtown of Djelfa, Sen Elba East forest (6 km West of downtown), the Sen Elba West forest (24 km South West of the downtown) and Bahrara forest (20 km North-East of downtown).

The study region comprises 63 sites consisting of 378 trees of the dominate specie are randomly selected. The distance between two sites is one (01) km and between two selected trees is 75 m to 90 m. The location of each tree is recorded using GPS.

2.2 Data collection

The method of assessment of air quality is to utilize a counting technique for the frequency of lichen growth in 10 squares, where the frequency is the number of squares which comprise the lichen (Geebelen and Hoffmann, 2001; Sommerfeldt and John, 2001; VDI, 1995, 2005; Wolfgang et al., 2013). The air quality score for one site is the average for the total air quality score of all the trees in the specific site. The air quality score of area is the average for the total air quality score for all sites in area study. The air quality score obtained will be assessed to determine the level of pollution in the areas where the lichens are growing. The air quality score for each study site was calculated according to equation (1) and for each study area was calculated according to equation (2) (Samsudin et al., 2012).

The equation (1), to calculate the AQI of site:

\[
AQI \text{ (of site)} = \frac{\text{Total Air Quality Score for each tree in the study site}}{\text{Number of trees in the study site}}
\]
The equation (2), to calculate the AQI of area:

\[ AQI \text{ (area)} = \frac{\text{Total Air Quality Score for study sites}}{\text{Number of study sites}} \]

The study data was accumulated during 2015 to 2016. We use the collected data of AQI to classify the prospected sites according to the scale of air quality index of Kirschbaum and Wirth (1997) (Table 1).

![Fig. 1 The location of the study area in Djelfa, Algeria.](image)

<table>
<thead>
<tr>
<th>Atmospheric pollution</th>
<th>0 to 12.5</th>
<th>12.5 to 25</th>
<th>25 to 37.5</th>
<th>37.5 to 50</th>
<th>&gt;50</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQI (scale)</td>
<td>Extremely high</td>
<td>Very high</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
</tr>
</tbody>
</table>

We used the analysis of variance (ANOVA) and principal component analysis (PCA) to identify the homogeneous study areas (compared to the AQI), and so as to comprehend the impact of abiotic variables (Altitude) on lichen diversity and frequency. It should be noted that all statistical analyses were made with Statistica 8. The geographical data was interpolated and mapped using the software ArcGIS 10.3.
3 Results and Discussion
The most frequent lichen species are indicated in Table 2 and Fig. 2. The results showed that 65.08% of sites had a medium rate of pollution, 26.98% of sites had a low rate, and only 7.94% presented a high rate of pollution according to a Kirschbaum and Wirth scale (Table 1, Table 3).

Table 2  Most frequented lichen species in the sampling grid.

<table>
<thead>
<tr>
<th>Species</th>
<th>Family</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaptychia ciliaris (L.)</td>
<td>Physciaceae</td>
</tr>
<tr>
<td>Caloplaca holocarpa (Hoffm)</td>
<td>Teloschistaceae</td>
</tr>
<tr>
<td>Hypogymnia physode (L.)</td>
<td>Parmeliaceae</td>
</tr>
<tr>
<td>Lecanora mughicola Nyl.</td>
<td>Lecanoraceae</td>
</tr>
<tr>
<td>Pertusaria sp.</td>
<td>Pertusariaceae</td>
</tr>
<tr>
<td>Xanthoria parietina (L.)</td>
<td>Teloschistaceae</td>
</tr>
</tbody>
</table>

Fig. 2 The most abundant lichens species in the study area: (a) Xanthoria parietina (L.) (b) Hypogymnia physode (L.) (c) Pertusaria sp. (d) Anaptychia ciliaris (L.).
Table 3 Classification of study sites by the AQI values using (Kirschbaum and Wirth) scale.

<table>
<thead>
<tr>
<th>Atmospheric pollution</th>
<th>Downtown (D)</th>
<th>Sen Elba East forest (SE)</th>
<th>Bahrara forest (B)</th>
<th>Sen Elba West forest (SW)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (AQI: 38-40)</td>
<td>0</td>
<td>9.52%</td>
<td>9.52%</td>
<td>7.94%</td>
<td>26.98%</td>
</tr>
<tr>
<td>Medium (AQI: 25-37)</td>
<td>7.94%</td>
<td>28.57%</td>
<td>15.87%</td>
<td>12.70%</td>
<td>65.08%</td>
</tr>
<tr>
<td>High (AQI: 20-24)</td>
<td>7.94%</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7.94%</td>
</tr>
</tbody>
</table>

The sites had a low pollution (AQI between 38 and 40) situated in Bahrara forest with a rate equal to 7.94% of all sites, and in Sen Elba forests (East and West) with a rate of 9.52% for every area. We respectively recorded a rate equal to 28.57%, 12.70%, 15.87% and 7.94% in Sen Elba East forest, Bahrara forest, Sen Elba West forest and in downtown. These all sites have a medium pollution (AQI varied from 25 to 37). In the West and South-West of the downtown (Sen Elba East and Sen Elba West), the values of AQI varied from 25 to 40 (medium to low pollution), this was related to the remoteness of large agglomerations, to the low intensity of the traffic road and the distance between this area and the national roads (RN°1 and RN°46).

The high level of pollution was recorded only in the downtown with a proportion equal to 7.94% of all sites and this, because of the volume of daily traffic (at least 6000 vehicles/day), the population density and the commercial activity. In the East of the downtown, the AQI values indicated a high pollution in the neighboring sites of the two national roads (RN°1 and RN°46); then the pollution was medium to low in the area where farthest to roads (Afsaneh et al., 2018; Murat and Ebru, 2016; Sett and Kundu, 2016; Ouali Alami et al., 2014; Shukla et al., 2014; Vuković et al., 2014; Biswas et al., 2012).

In order to show the homogenous group of area according the AQI values, we used the analysis of variance, the results (Table 4) proved there was a significant difference between groups, and the downtown area was most polluted compared with other areas of study.

We noticed that the altitude values were positively correlated with the AQI values of the area (Table 5).

Table 4 Identification of homogenous groups using the analysis of variance (LSD test).

<table>
<thead>
<tr>
<th>Location</th>
<th>AQI–Mean</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downtown (D)</td>
<td>24.56667</td>
<td></td>
<td>****</td>
</tr>
<tr>
<td>Sen Elba East forest (SE)</td>
<td>34.19861</td>
<td>****</td>
<td></td>
</tr>
<tr>
<td>Bahrara forest (B)</td>
<td>36.08974</td>
<td>****</td>
<td></td>
</tr>
<tr>
<td>Sen Elba West forest (SW)</td>
<td>36.56250</td>
<td>****</td>
<td></td>
</tr>
</tbody>
</table>
Table 5 Correlation between altitude and the Air Quality Index (AQI).

<table>
<thead>
<tr>
<th></th>
<th>Means</th>
<th>Std. Dev.</th>
<th>AQI</th>
<th>Altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Air Quality Index (AQI)</td>
<td>33.660</td>
<td>6.02746</td>
<td>1.000000</td>
<td>0.431541</td>
</tr>
<tr>
<td>Altitude</td>
<td>1279.635</td>
<td>95.76539</td>
<td>0.431541</td>
<td>1.000000</td>
</tr>
</tbody>
</table>

The correlation are significant at p < .05000 N=63

We used the principal component analysis (PCA) to identify the homogeneous study sites (compared to the AQI), and so as to comprehend the impact of abiotic variables (Altitude) on lichen frequency (Fig. 3, Fig. 4).

Fig. 3 The principal component analysis (PCA) (The variables Altitude and AQI).

We obtained the AQI map of Djelfa region (Fig. 5) by interpolation of AQI values using geographical data. The results showed that the sites located in West were less polluted than East because the direction of the dominant wind was West and Northwest in winter and Southwest in summer, and there were also a differences in altitudes between the Sen Elba forest (West and East) (from 1300 m to 1450 m) and the altitudes in the downtown and the Bahrara forest (from 1080 m to 1300 m).
4 Conclusions
The aim of this research is the assessment and the mapping of the atmospheric pollution in the region of Djelfa by using lichen as bioindicators. We calculated AQI values in the 63 sites consisting of 378 trees, the results show that 65.08% of sites have a medium rate of pollution, 26.98% of sites have a low rate, and only 7.94% present a high rate of pollution according to a Kirschbaum and Wirth scale, the high level of pollution is
recorded only in the downtown, and this, because of the volume of daily traffic (at least 6000 vehicles/day), the population density and the commercial activity. We noticed that the altitude values are positively correlated with the AQI values of the area, and the dominant wind represent another factor have an effect on the AQI values. The AQI map obtained allows us to detect the areas with a high level of atmospheric pollution in the Djelfa region. As a final point, there is a need for governmental environmental agencies to become more involved with lichenological studies. Obviously there is a need to fund projects that maximal beneficial information is obtained and a much more extensive database on lichens for used in different areas of science.

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