Article

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; Gerdol 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 a bioindicator. 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 (of site) = Total Air Quality Score for each tree in the study site/ Number of trees in the study site

The equation (2), to calculate the AQI of area:

AQI (area) = Total Air Quality Score for study sites/ 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).
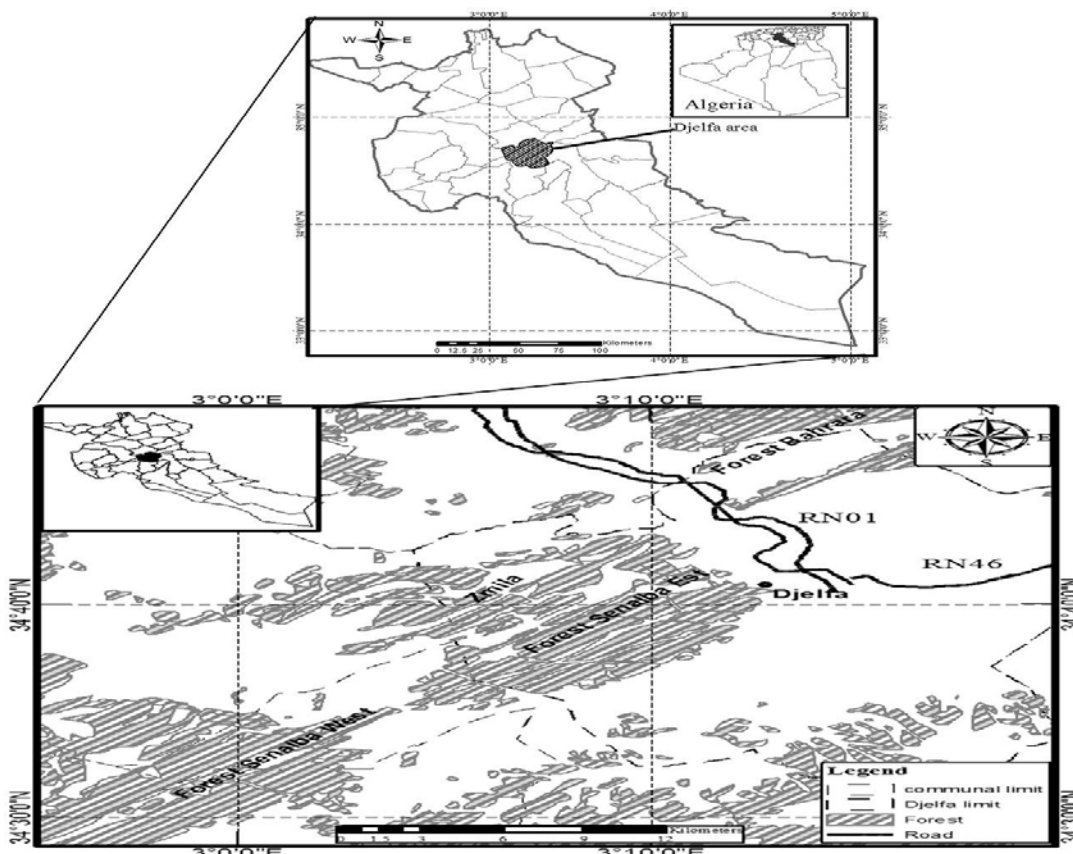

Fig. 1 The location of the study area in Djelfa, Algeria.

Table 1 The air quality index (AQI) scale of Kirschbaum and Wirth.

	The air quality index(AQI)					
	0	0 to 12.5	12.5 to 25	25 to 37.5	37.5 to 50	>50
Atmospheric pollution	Extremely high	Very high	High	Medium	Low	Very low

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.

Species	Family
Anaptychia ciliaris (L.)	Physciaceae
Caloplaca holocarpa (Hoffm)	Teloschistaceae
Hypogymnia physode (L.)	Parmeliaceae
Lecanora mughicola Nyl.	Lecanoraceae
Pertusaria sp.	Pertusariaceae
Xanthoria parietina (L.)	Teloschistaceae

(a)   (b)

(c)   (d)

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.

	Atmospheric pollution		
	37.5 to 50 Low (AQI : 38-40)	25 to 37.5 Medium (AQI : 25-37)	12.5 to 25 High (AQI : 20-24)
Downtown	0	7.94%	7.94%
Sen Elba East forest	9.52%	28.57%	0
Sen Elba West forest	9.52%	15.87%	0
Bahrara forest	7. 94%	12.70%	0
Total	26.98%	65.08%	7.94%

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).

	The analysis of variance, LSD test, variable AQI; Homogenous Groups, alpha = .05000 Error: Between MS = 20.459, df = 59.000			
	Location	AQI–Mean	1	2
1	Downtown (D)	24.56667		****
2	Sen Elba East forest (SE)	34.19861	****	
4	Bahrara forest (B)	36.08974	****	
3	Sen Elba West forest (SW)	36.56250	****	

Table 5 Correlation between altitude and the Air Quality Index (AQI).

The correlation are significant at p <.05000 N=63				
	Means	Std. Dev.	AQI	Altitude
The Air Quality Index (AQI)	33.660	6.02746	1.000000	0.431541
Altitude	1279.635	95.76539	0.431541	1.000000

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).
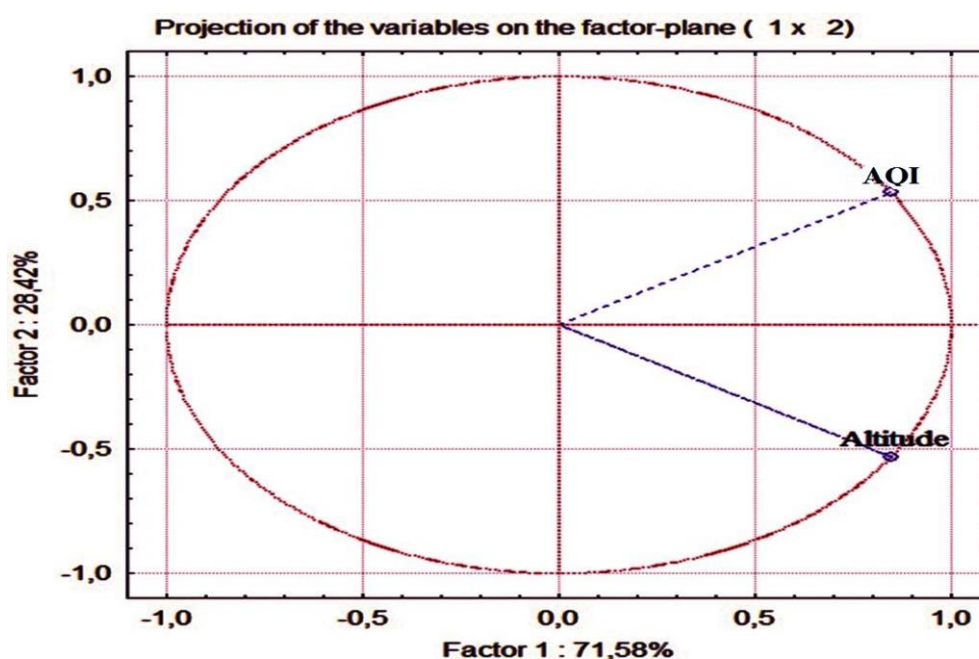

Fig. 3 The principal component analysis (PCA) (The variables Altitude and AQI).

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).
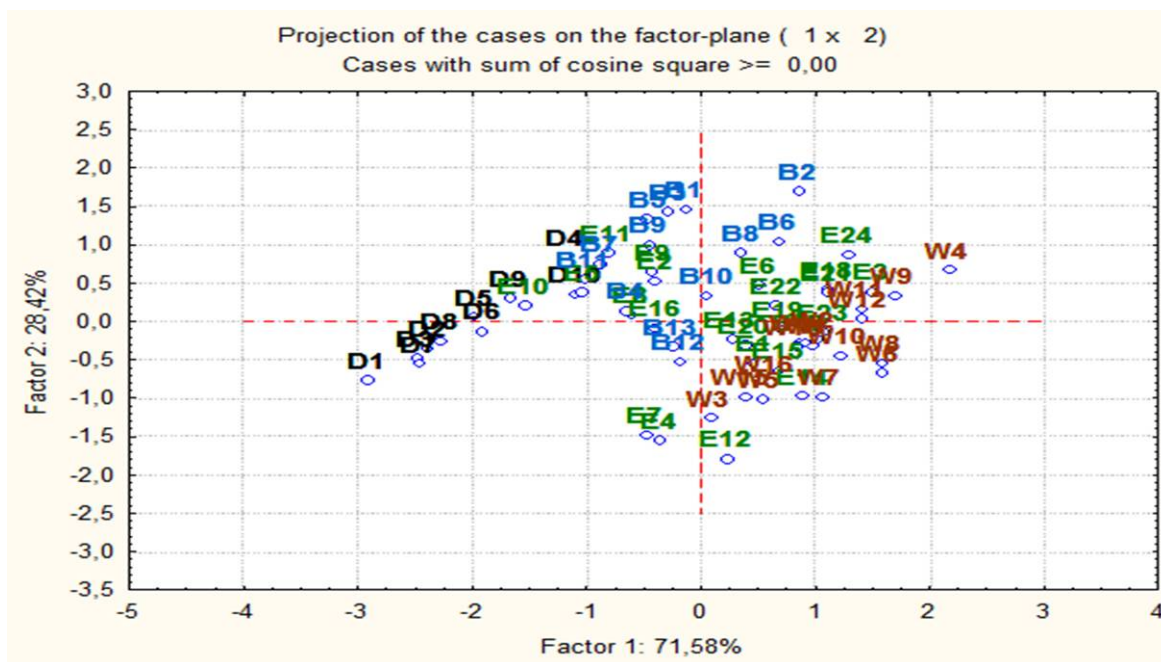
Fig. 4 First and second factors of a principal component analysis (PCA) based on the Air Quality Index (AQI) and the altitude.
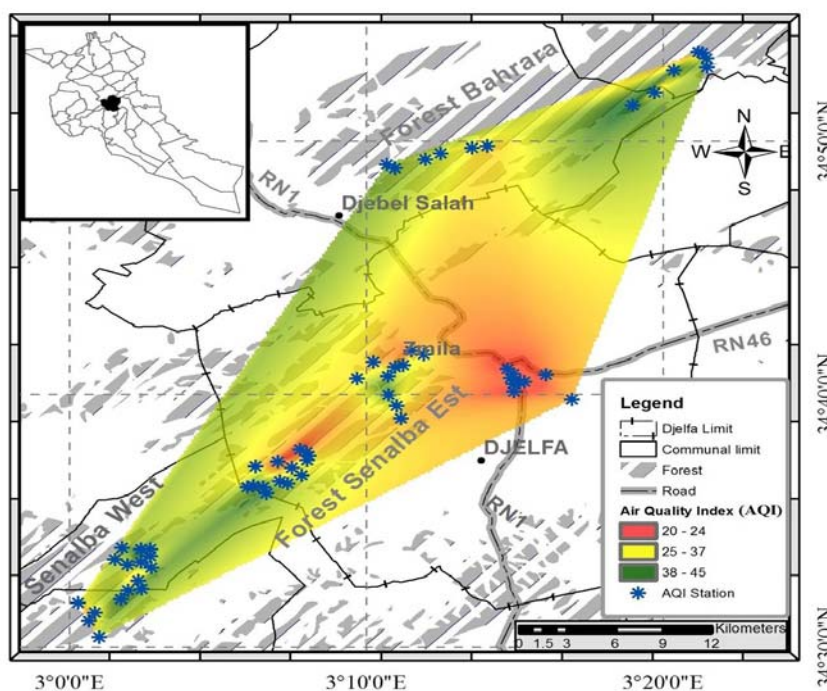

Fig. 5 The air quality map using the interpolation.

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.

Acknowledgement

References

Afsaneh M., Nabiollah M., Faramarz M, Alireza RV. 2018. Assessment of heavy metal contamination in urban dusts and road dusts of Tehran. Proceedings of the International Academy of Ecology and Environmental Sciences, 8(2): 124-138

Biswas S, Jha S, Singh R. 2012. A fuzzy mathematics approach in measuring air pollution from motor vehicles. Computational Ecology and Software, 2(3): 160-168

Boamponsem LK, De Freitas CR, Williams D. 2017. Source apportionment of air pollutants in the Greater Auckland Region of New Zealand using receptor models and elemental levels in the lichen, *Parmotrema reticulatum*. Atmospheric Pollution Research, 8(1): 101-113

Conti ME, Cecchetti G. 2001. Biological monitoring: lichens as bioindicators of air pollution assessment—a review. Environmental Pollution, 114(3): 471-492

De La cruz ARH, Ayuque RFO, De la cruz RWH, et al. 2020. Air quality biomonitoring of trace elements in the metropolitan area of Huancayo, Peru using transplanted *Tillandsia capillaris* as a biomonitor. Anais Da Academia Brasileira De Ciencias, 92: 312-320

Deruelle S. 1984. L'utilisation des lichens pour la détection et l'estimation de la pollution par le plomb. Bull Ecology, 15: 1-6

Geebelen W, Hoffmann M. 2001. Evaluation of bio-indication methods using epiphytes by correlating with SO2-pollution parameters. Lichenologist, 33(3): 249-260

Gerdol R, Bragazza L, Marchesini R, et al. 2005. Effects of season and low-level air pollution on physiology and element content of lichens from the U.S. pacific North West. Science of the Total Environment, 343: 155-167

Hawksworth DL, Rose F. 1970. Qualitative scale for estimating sulphur dioxide air pollution in England and Wales using epiphytic lichens. Nature, 227: 145-148

Kirschbaum U, Wirth V. 1997. Les lichens bio-indicateurs. In: Les reconnaître, évaluer la qualité de l'air (Eugen Ulmer, eds). Paris, France

Koch NM, Lucheta F, Käffer MI, et al. 2018. Air quality assessment in different urban areas from Rio Grande doSul state, Brazil, using lichen transplants. Anais Da Academia Brasileira De Ciencias, 90(2 Suppl. 1): 2233-2248

Kularatne KIA, De Freitas CR. 2013. Epiphytic lichens as biomonitors of airborne heavy metal pollution. Environmental and Experimental Botany, 88: 24-32

Maizi N, Alioua A, Tahar A. 2012. Jumelage des bio-indicateurs et d'un réseau de surveillance de la qualité de l'air pour la détection de la pollution par le SO$_2$ dans la région d'Annaba (Algérie). Biotechnology, Agronomy, Society and Environment, 16(2): 149-158

Marié DC, Chaparro MAE, Irurzun MA, et al. 2016. Magnetic mapping of air pollution in Tandil city (Argentina) using the lichen *Parmotrema pilosum* as biomonitor. Atmospheric Pollution Research, 7(3): 513-520

Murat O, Ebru SE. 2016. Determination of traffic noise pollution of the city of Tekirdag. Journal of Environmental Protection and Ecology, 17(4): 1276-1284

Naeth MA, Wilkinson SR. 2008. Lichens as biomonitors of air quality around a diamond mine, Northwest Territories, Canada. Journal of Environmental Quality, 3: 1675-1684

Ouali Alami FZ, Elabidi A, Mouhir L, et al. 2014. Utilisation des lichens comme bio-indicateurs de la pollution atmosphérique par le plomb, cadmium et zinc de la région de Rabat-Sale-Zemmour-Zaêr (Maroc). Afrique Science, 10(3): 89-106

Pirintsos SA, Vokou D, Diamantopoulos J, et al. 1993. An assessment of the sampling procedure for estimating air pollution using epiphytic lichens as indicators. Lichenologist, 25(2): 165-173

Pollard AS, Williamson BJ, Taylor M, et al. 2015. Integrating dispersion modelling and lichen sampling to assess harmful heavy metal pollution around the Karabash copper smelter, Russian Federation. Atmospheric Pollution Research, 6(6): 939-945

Root HT, Geiser LH, Jovan S, Neitlich P. 2015. Epiphytic macrolichen indication of air quality and climate in interiorforested mountains of the Pacific Northwest, USA. Ecological Indicators, 53: 95–105

Saiki M, Alves E, Marcelli M. 2007. Analysis of lichen species for atmospheric pollution biomonitoring in the Santo André municipality, São Paulo, Brazil. Journal of Radioanalytical and Nuclear Chemistry, 273(3): 543-547

Samsudin MW, Din L, Zakaria Z, et al. 2012. Measuring air quality using lichen mapping at Universiti Kebangsaan Malaysia (UKM) Campus. Procedia Social and Behavioral Sciences, 59: 635-643

Saxena P, Sonwani S. 2020. Remediation of ozone pollution by ornamental plants in indoor environment. Global Journal of Environmental Science and Management, 6(4): 497-508

Sett R, Kundu M. 2016. Epiphytic lichens: Their usefulness as bio-indicators of air pollution. Donnish Journal of Research in Environmental Studies, 3(3): 17-24

Shukla V, Upreti DK, Bajpai R, et al. 2014. Spatial distribution of metallic content in Himalayan ecosystem monitored using lichens. Water, Air and Soil Pollution, 225: 1859

Sommerfeldt M, John V. 2001. Evaluation of a method for the reassessment of air quality by lichen mapping in the City of Üzmir, Turkey. Turkish Journal of Botany, 25: 45-55

Ventura LMB, Ramos MB, Santos JO, et al. 2019. Monitoring of air quality before the Olympic Games Rio 2016. Anais Da Academia Brasileira De Ciencias, 91(1): e20170984

Verein Deutscher Ingenieure (VDI). 1995. Ermittlung und Beurteilungphytotoxischer Wirkungen von Immissionenmit Flechten. VDI-Richtlinie 3799, Blatt 1. Flechtenkartierung, Düsseldorf, Germany

Verein Deutscher Ingenieure (VDI). 2005. Biological measurement procedures for determining and evaluating the effects of ambient air pollution by means of lichens (bioindication). Mapping the diversity of epiphytic lichens as an indicator of environmental quality. VDI-3957. Part 13. Germany

Vuković G, Aničić Urošević M, Razumenić I, et al. 2014. Air quality in urban parking garages (PM10, major and trace elements, PAHs): Instrumental measurements *vs*. active moss biomonitoring. Atmospheric Environment, 85: 31-40

Will-Wolf S, Jovan S, Amacher MC. 2017. Lichen elemental content bioindicators for air quality in upper Midwest, USA: A model for large-scale monitoring. Ecological Indicators, 78: 253-263

Wolfgang M, Veronika PD, Roman T, et al. 2013. Significant decrease in epiphytic lichen diversity in a remote area in the European Alps. Austria. Basic and Applied Ecology, 14: 396-403

Zambrano A, Nash TH, Gries C. 1999. Physiological effects of the Mexico City atmosphere on lichen transplants on oak. Journal of Environmental Quality, 28: 1548-1555