International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 18, No. 6, p. 51-64, 2021

INNSPUB

RESEARCH PAPER OPEN ACCESS

Biomonitoring of heavy metals by lichen *Xanthoria parietina* in Bejaia area (East Algeria)

Amina Belguidoum, Takia Lograda, Badreddine Bedjaoui, Messaoud Ramdani*

Laboratory for Valorization of Natural Biological Resources, SNV Faculty, Ferhat Abbas University Setif-1. El Bez, Setif 19000, Algeria

Key words: Biomonitoring, Bioaccumulation, heavy metals, *Xanthoria parietina*, Bejaia, Algeria.

http://dx.doi.org/10.12692/ijb/18.6.51-64 Article published on June 6, 2021

Abstract

The metallic air pollution in the Bejaia region (northern Algeria) were examined, using the lichen *Xanthoria parietina* as a bio-monitoring organism. The biological material from 42 stations were sampled and analyzed by flame atomic absorption spectrophotometry (AASF). In order to determine the relationship between the potential sources of contaminants in the study area and the degree of deposition of metals in air, five heavy metals (Cd, Cu, Pb, Mn, and Ag) were analyzed. The results show that the metal contents recorded in the various sampled stations are fluctuating and lead to the following decreasing series: Pb> Mn> Cu> Ag> Cd. The air quality in the town of Amizour is considerably poor compared to the rest of the studied stations. The Pb and Mn levels are very high in all stations with an average of (134.62 ± 148.53 mg/kg and 290.88 ± 175.13 mg/kg) respectively. The highest concentrations of heavy metals were observed around the municipalities of Bejaia, Akbou and Tichy. The current situation suggests an obvious need to mitigate atmospheric pollution by MTE and to control the emissions of toxic metals, in particular Pb from industrial sources and road traffic in large cities.

* **Corresponding Author:** Messaoud Ramdani ✉ ramdanimessaoud@yahoo.com

Introduction

The environmental contamination by toxic chemicals from human activities is a serious public health problem worldwide (Gu, 2018; Kittner *et al.*, 2018; Weinmayr *et al.*, 2018; Kresovich *et al.*, 2019). These chemical compounds are widely distributed in the environment, mainly due to emissions from industrial activities, mining, domestic, and agricultural activities, but above all by intensive automobile traffic (Lodenius *et al.*, 2010; Pandey *et al.*, 2014; Gonzalez-Castanedo *et al.*, 2014; Parzych *et al.*, 2016; Chen *et al.*, 2016). Therefore, the use of bio indicators in diagnostic studies of these dangerous elements in the long term is very advantageous, since the cost is low and can be used on a large scale with high efficiency (Stamenkovic *et al.*, 2013; Antonucci *et al.*, 2016; Belguidoum *et al.*, 2020).

Lichens have a high capacity for absorption and accumulation of atmospheric pollutants, in particular heavy metals, because of their biological characteristics, which allow the absorption of many contaminants directly from the atmosphere by the surface of the thallus (Conti *et al.*, 2011; Augusto *et al.*, 2015; Loppi and Paoli, 2015; Bargagli, 2016; Will-Wolf *et al.*, 2017). These characteristics of lichens, combined with their extraordinary ability to grow in large geographic areas, allow them to be classified as a reliable biomonitor and ideal for assessing air pollution (Garty, 2001; Antonucci *et al.*, 2016).

Frequently, the lichens are used in bio-monitoring studies of metallic air pollutants (Bermejo-Orduna *et al.*, 2014, Nascimbene *et al.*, 2014, Agnan *et al.*, 2015). In many studies, lichens are of great help in determining of heavy metals concentrations released by traffic and accumulated by thalli (Douibi *et al.*, 2015; Gauslaa *et al.*, 2016; Adjiri *et al.*, 2018; Demkova *et al.*, 2017, 2019).

The *Xanthoria parietina* species has a large contact surface with atmospheric pollutants (surface / volume). It is very resistant to air pollution, so it is able to bioaccumulate large amounts of heavy metals in polluted areas (Cuny *et al.*, 2004; Demiray *et al.*, 2012; Adjiri *et al.*, 2018; Parviainen *et al.*, 2019; Vitali *et al.*, 2019).

Generally, atmospheric metal contamination attracts greater attention in urban areas than in rural areas that are less affected by human activities (Wan *et al.*, 2016). The wilaya of Bejaia is located north of the country on the Mediterranean coast. It is an Algerian province served by an important road network and has an airport and a port (port of international trade and hydrocarbons), which occupies an important place in the country by its volume of activity (Belkhiri and Djemili, 2016).

The objective of this study is to assess the amount of heavy metals accumulated in the thalli of the lichen *Xanthoria parietina*, in order to estimate the air quality in the various municipalities of the province of Bejaia.

Materials and methods

Study area

The study area covers an area of 3268 km². It is distinguished by a mountainous relief with a steep gradient, at relatively high altitudes and very marked slopes (80% of the territory have a slope greater than 25%). The wilaya of Bejaia is a coastal and mountainous province; it covers an area of 3268 km². The region's climate is Mediterranean, with mild and rainy winters in the coastal strip but cold and snowy on the mountains. Average annual precipitation can expect 1100 mm. The precipitation regime there is generally favorable for the development of vegetation. The average annual temperatures range from 16.7°C to 18.6°C.

Sample Collection

The foliaceous lichen *Xanthoria parietina*, widespread in the studied areas and widely used in similar studies. Samples were collected in 42 locations spread throughout Bejaia province (North of Algeria) (Fig. 1).

Each sampled site consists of a maximum area of 100 m², located near roads, as much as possible, with heavy traffic and secondary roads. The samples were collected avoiding the use of tools or containers likely to contaminate them. After collection, the samples were transported to the laboratory for analysis. The lichen samples were dehydrated at 40°C for 48h, cleaned to remove all types of traces of foreign matter (dust, leaves, soil, wood chips) and then ground with an agate mortar.

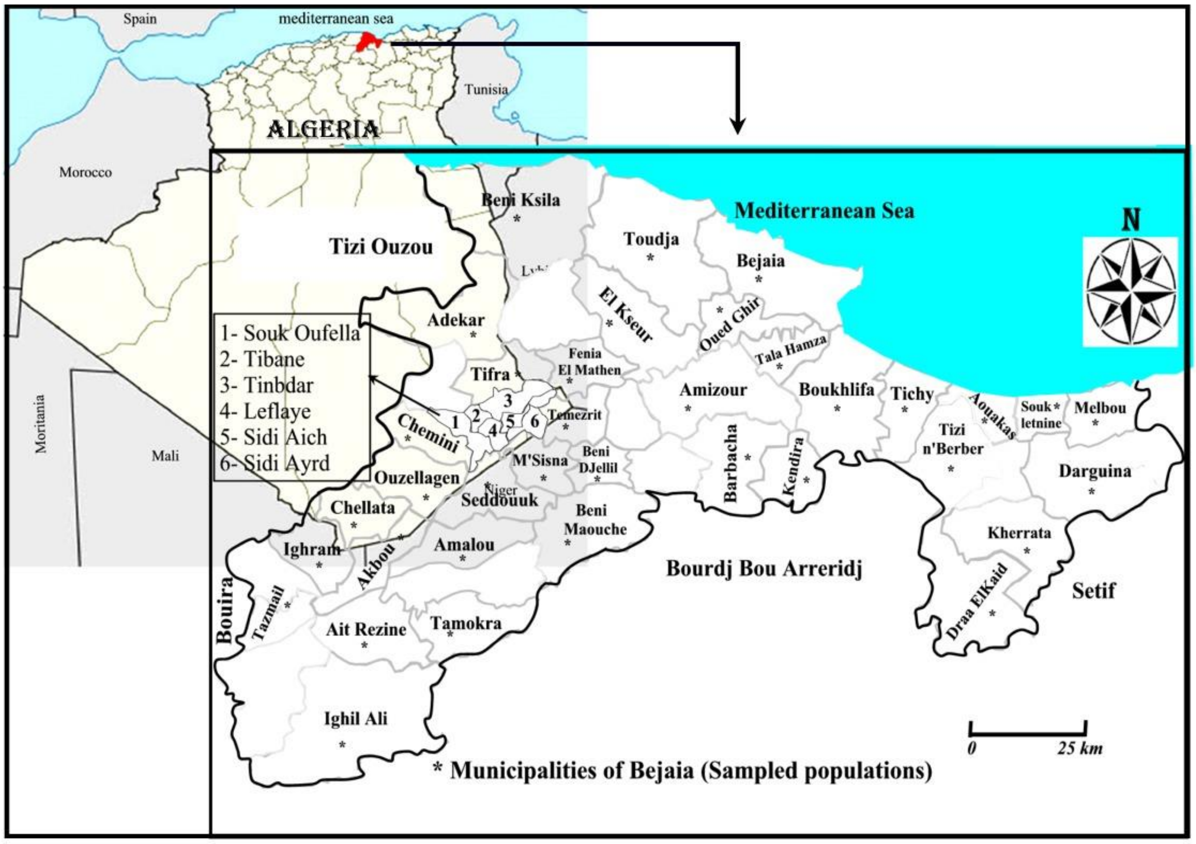

Fig. 1. Sampled populations of *Xanthoria parietina*.

Samples treatment

Lichen samples were digested in the laboratory in aseptic conditions, using a mixture of $HNO_3/HF/H_2O$ in Teflon containers (Hébrard-Labit and Meffray 2004; Adjiri *et al.* 2018).

A solution of our samples is prepared using the ground solid materials to which 10 ml of 40% hydrofluoric acid (HF) and 3 ml of 70% perchloric acid ($HClO_4$) were added. Evaporation takes place on a hotplate at 160°C. After a quasi-total evaporation, 1 ml of 65% nitric acid (HNO_3) and 10 ml of distilled water were added. The samples are then left for 30 min at 4°C in the refrigerator. The dissolution of the residue is performed by placing the samples on a hotplate at 60°C for 1h. The resulting mixture is transferred to a 100 ml flask for filtration, adjusting the volume with distilled water.

Analytical methods for MTE concentration measurements in lichens

The concentrations of the following elements Pb, Mn, Ag, Cu and Cd, were determined by Atomic Absorption Spectro-photometry with Flame (AASF). There are no established standards of trace elements concentration in lichens (Hébrard-Labit and Meffray, 2004). To interpret the results of each element studied we used as a standard reference, the values of the European Commission BCR information CRM-482 (Table 1).

Statistical analysis

Data were subjected to Principal Components Analysis (PCA) to examine the relationship among the trace elements and the bioaccumulation by lichens, and the relation between the presence of these elements and the pollution. Cluster analysis

(UPGMA) was carried out on the original variables and on the Manhattan Distance Matrix to look for hierarchical associations among the elements and the locations. Statistical analyzes were performed using the software STATISTICA 10.

Results

The concentrations of the elements (Ag, Cd, Cu, Mn and Pb) accumulated in the thalli of *Xanthoria parietina* from 42 municipalities in the Provence of Bejaia were analyzed using flame atomic absorption spectrophotometry (SAAF) (Table 2). The concentrations of MTE accumulated by *X. parietina* are variable and exceed standard values.

The accumulation of Pb in the thalli of *X. parietina* is very high in all stations studied, with an average of 291 ± 175 mg/kg, far exceeding the certified standard, in particular in the town of Akbou. This high rate in this commune is probably due to the proximity of a large vehicle market and to the dust emissions emitted by four aggregate quarries, south of the city of Akbou, which persistently contribute to the atmospheric pollution.

Table 1. Certified values of trace elements (mg/kg) using AASF.

MTE	Symbols	Certified values	uncertainty
Lead	Pb	40.9	1.4
Manganese	Mn	33	0.5
Copper	Cu	7.03	0.19
Cadmium	Cd	0.56	0.02
Silver	Ag	2.9*	--

* Minimum value observed (Daillant, 2003).

The concentrations of Mn and Cu in *X. parietina* thalli, with an average of 252.19 ± 134.30 mg/kg for Mn and 134.62 ± 148.53 mg/kg for Cu, reveal values exceeding the certified standards. The thalli collected from the Amizour station have the highest rates with 735 mg / kg and 894 mg / kg for Mn and Cu, respectively. Whereas Tamokra and M'Sisna stations have the lowest rates of these elements.

Cadmium contents are low and very close, but still exceeding the certified standard in all stations. The highest concentration of Cd was recorded in the municipality of Bejaia (8.21 mg/kg).

This contamination is largely explained by automobile traffic and anthropogenic activities, which represent an important source of Cadmium and lead in this urban environment.

A strong accumulation of Ag should be noted in the thalli of *X. parietina* with an average of 8.03 ± 5.94 mg/kg. The highest rate is observed in the commune of Ighram (33.35 mg/kg), near sites devoted to arboriculture, especially olive and fig trees. Statistical analysis of the results shows that the HTAs are separated into two groups. The group with a high concentration in the thalli is formed by the elements Mn and Pb. The second group gathers the elements (Cu, Ag and Cd) (Fig. 2). This analysis allowed us to classify these elements according to the following relation: Pb> Mn> Cu> Ag> Cd.

The element Pb has high concentrations in X. parietina thalli with an average of 290.88 ± 175.13 mg/kg, while the Cd is the least abundant in the thalli (3.06 ± 2, 22 mg/kg). The Pb shows the greatest variation in the samples, followed by the Mn (252.19 ± 134.30 mg/kg). The levels of variation in Ag and Cd concentration are relatively small (Fig. 3).

The three-dimensional spatial projection of the stations, based on the first three axes from the PCA, shows a grouping of the point cloud with the individualization of certain populations, So five populations are isolated, Amizour, Bedjaia, Tichy, Akbou and Ighrem (Fig. 4).

Table 2. Accumulation of MTE in *X. parietina* thalli (mg/kg).

Stations	Cd	Cu	Pb	Mn	Ag	Stations	Cd	Cu	Pb	Mn	Ag
Bejaia	8.21	232	597	591	9.36	Tizi n'Berber	4.01	99	115	189	6,69
Akbou	7.76	81	752	444	6.25	Boudjelil	1.96	81	219	342	5,59
Amizour	5.32	894	576	735	3.15	Tamokra	0.50	48	98	125	6,37
Adekar	5.98	351	365	234	21.25	Tibane	0.40	54	81	138	12,2
Sedouk	5.43	69	253	258	5.86	Ighil Ali	2.75	196	611	275	15,6
Kherrata	4.15	108	419	282	7.25	Toudja	4.50	202	464	358	12,4
Timezrit	3.69	87	287	378	6.36	Thala Hamza	0.60	48	115	234	7,26
Chemini	5.35	345	345	199	24.19	Chellata	1.95	52	139	155	4,93
Ousellaguen	3.27	78	458	255	3.96	Souk Oufella	6.96	235	98	190	2,77
Aokas	2.89	66	502	228	9.78	Tifra	0.50	73	117	182	3,37
El Kseur	2.75	99	303	195	6.37	Sidi Ayob	2.31	77	169	185	5,59
Sidi Aich	6.25	126	425	270	7.56	Boukhalifa	1.68	122	143	168	6,63
Darguina	2.70	87	258	177	6.36	M'Sisna	0.21	45	164	145	5,79
Souk El Tenine	6.54	69	526	252	5.39	Malbou	1.50	110	266	209	8,99
Tazmalt	2.20	60	235	243	6.99	Ben Ksala	0.30	85	151	127	7,14
Barbacha	4.53	75	398	195	7.14	Tinebdar	2.16	105	203	170	3,58
Tichy	3.05	99	629	648	12.18	Amalou	0.50	57	168	149	5,79
Drâa El Kaid	2.50	51	293	183	3.46	Kendira	0.50	98	183	157	3,47
Oued Ghir	2.75	126	267	228	6.37	Leflaye	0.60	77	140	177	6,13
Ait Rizine	4.52	60	237	318	5.89	El Mathen	0.40	84	134	163	3,99
Ighrem	3.64	441	190	243	33.35	Beni Maouche	0.90	102	124	198	4,67
Moyenne							3,1	134,6	291	252	8.03
SD							2,2	148,5	175	134	5.94
RSD							72,7	110,3	60,2	53,3	74
Min.							0,2	45	81	125	2.8
Max.							8,2	894	752	735	33.4
Valeur Standard							0.6	7.1	40.9	33	2.9

These populations represent the most polluted sites in the Bejaia region. The concentrations of MTE found in the thalli of the Amizour population are high, in particular for Cu and Mn. These high rates are probably due in large part to significant agricultural activities of the region, especially tree crops (olive and fig), to industrial activities and uncontrolled local mining activities (the Amizour mine at Cu, Pb and Zn), and the excessive increase in frequent and severe road traffic in the region. In contrast, the Tamokra population thalli accumulate low MTE concentrations, with the lowest Mn concentration compared to the different stations studied (125 mg/kg).

The use of the UPGMA shows the heterogeneity of the accumulation of metals in the 42 populations of *X. parietina* and confirms the separation of the sites studied into two very distinct groups (Fig. 5).

The first group is represented by the Amizour station with the highest accumulation of MTE in the thalli, especially for Cu and Mn. This station has a high degree of pollution. While the second group splits into two branches. The Bejaia, Tichy and Akbou stations represent the first branch, with a very high accumulation of Pb, between 597 and 752 mg/kg. The remaining sites form the second branch, which seems to be the least polluted. However, their accumulation rates are much higher than standard values.

Generally the concentrations of Pb, Mn and Cu are high in the stations studied, which shows a strong impact of the sources of air pollution, especially in the stations which are crossed by the national roads with heavy traffic such as Amizour and Bejaia. The lowest rates of MTE concentrations were observed in the commune of Tamokra, it is a station with low population density, without industrial activity and low road traffic.

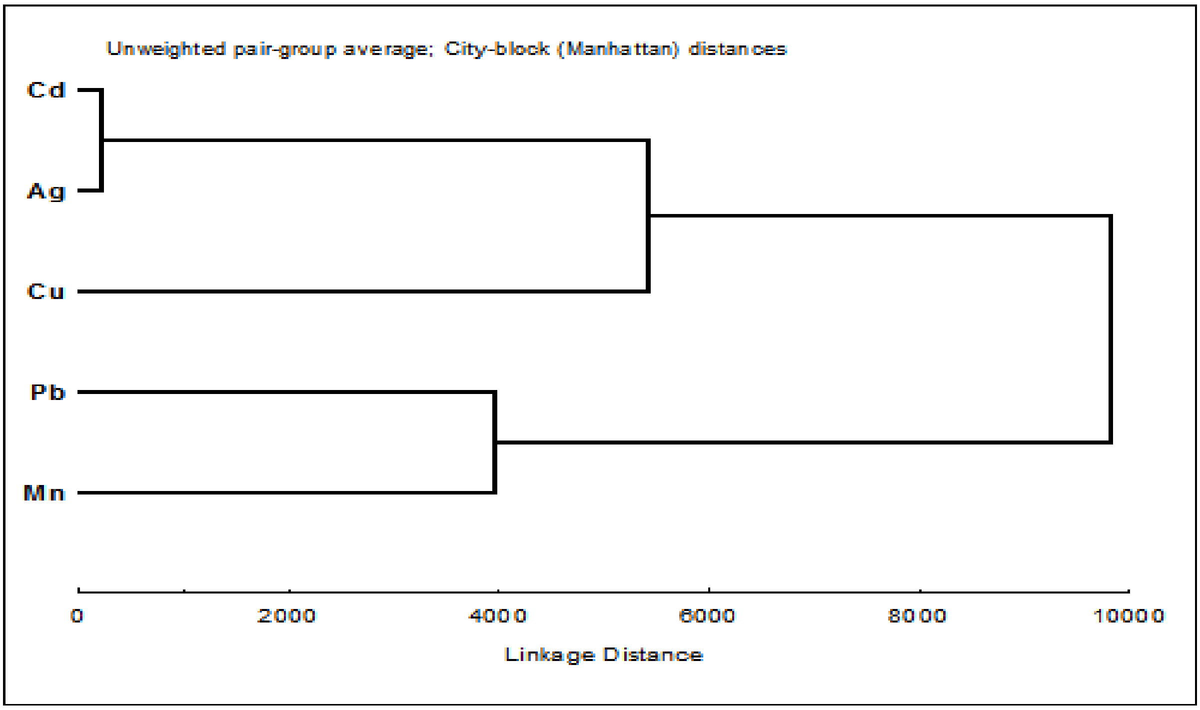

Fig. 2. Relationships among MTE accumulations in *X. parietina* of Bejaia Region.

Discussion

The concentration of MTE accumulated by *Xanthoria parietina* thalli in the wilaya of Bejaia, for the five metals, shows the following decreasing series: Pb> Mn> Cu> Ag> Cd. These results differ from those of the literature, whose Pb is always higher than Mn (Balabanova *et al.*, 2012; Nimis *et al.*, 2000).

The assessment of metal accumulation levels in the municipalities of the province of Bejaia showed extremely high values in the thalli of *X. parietina*.

The Amizour station is the most affected compared to the stations studied. En general, the high concentrations of these elements are closely linked to local uncontrolled mining activities, especially with regard to lead and copper extracted from the Amizour mine. Similar findings were made by some authors, (Boamponsem *et al.*, 2010; Li *et al.*, 2014; Mwaanga *et al.*, 2016; Liu *et al.*, 2016; Demkova *et al.*, 2019). Thus, emissions from road traffic and frequent severe in the region contribute significantly to the increase in these items in the atmosphere (Liu *et al.*, 2016).

The high concentrations of Pb, Cu, and Mn observed can be linked to the vicinity of sampling points in industrial activity zones, including the metallurgical and chemical industries (González-Castanedo *et al.*, 2014; Pollard *et al.*, 2015), and agricultural activities (Pascaud *et al.*, 2014; Nguyen *et al.*, 2016; Ratier *et al.*, 2018).

The highest accumulation of Pb is recorded in thalli of *X. parietina* of Akbou town; this station is located near a large vehicle market; thus, this accumulation is directly or indirectly associated with emissions from diesel fueled vehicles (Liu *et al.*, 2016; Ahmad *et al.*, 2018; Kazimirova *et al.*, 2016; Coufalík *et al.*, 2019). Monaci *et al.*, (2000) in Italy made similar observations. In fact, it is confirmed that the deposit of Pb is mainly related to vehicle emissions (Tokalıoglu and Kartal, 2006; Wang *et al.*, 2019). In addition, the commune of Akbou reveals high levels of Mn, Cd and Cu. These high rates are probably due to the excessive use emissions of explosives for extracting sand, and to the dust which emanates from four quarries of aggregates, on the mount of Piton in the south of the city of Akbou and which contribute in a way persistent to air pollution (Peng *et al.*, 2016; Paoli *et al.*, 2017).

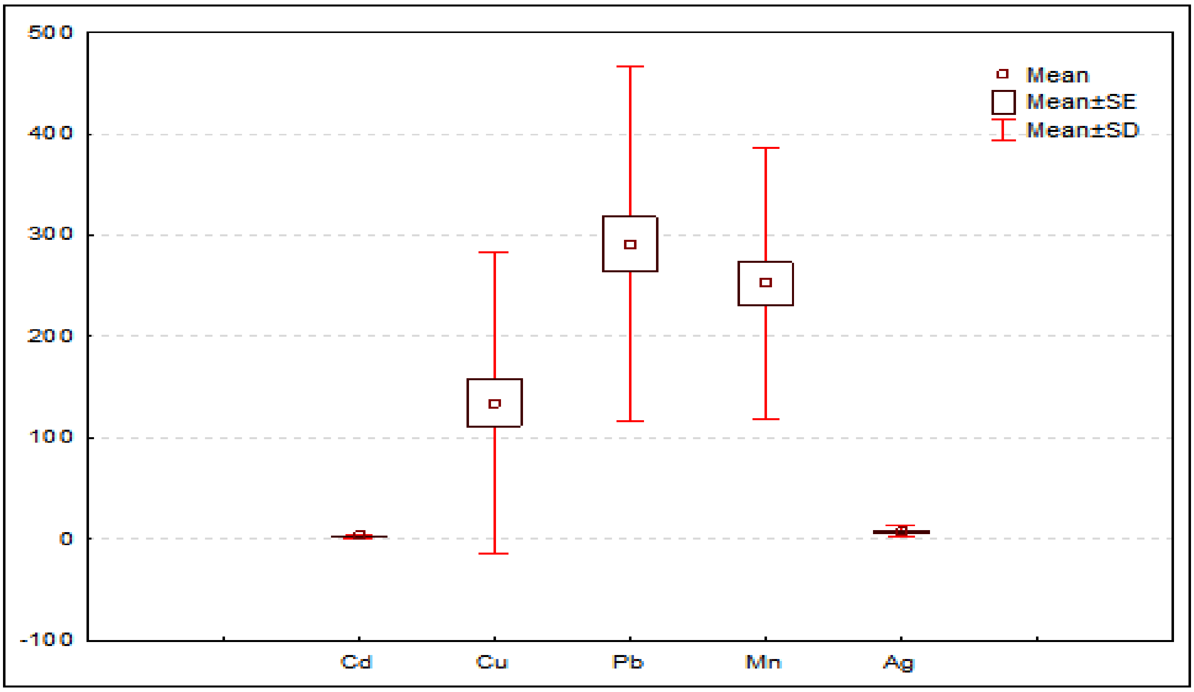

Fig. 3. Variability of MTE concentrations in thallus *X. parietina*.

Extremely high values of Cd and Pb have been observed in the municipality of Bejaia. These high rates are due to automobile traffic and anthropogenic activities, which represent an important source of Cadmium and lead in this urban environment (Alkama *et al.*, 2009; Benaissa *et al.*, 2016; Wan *et al.*, 2016; Lin *et al.*, 2017; Ben Aissa *et al.*, 2018; Hamma and Petrişor, 2018).

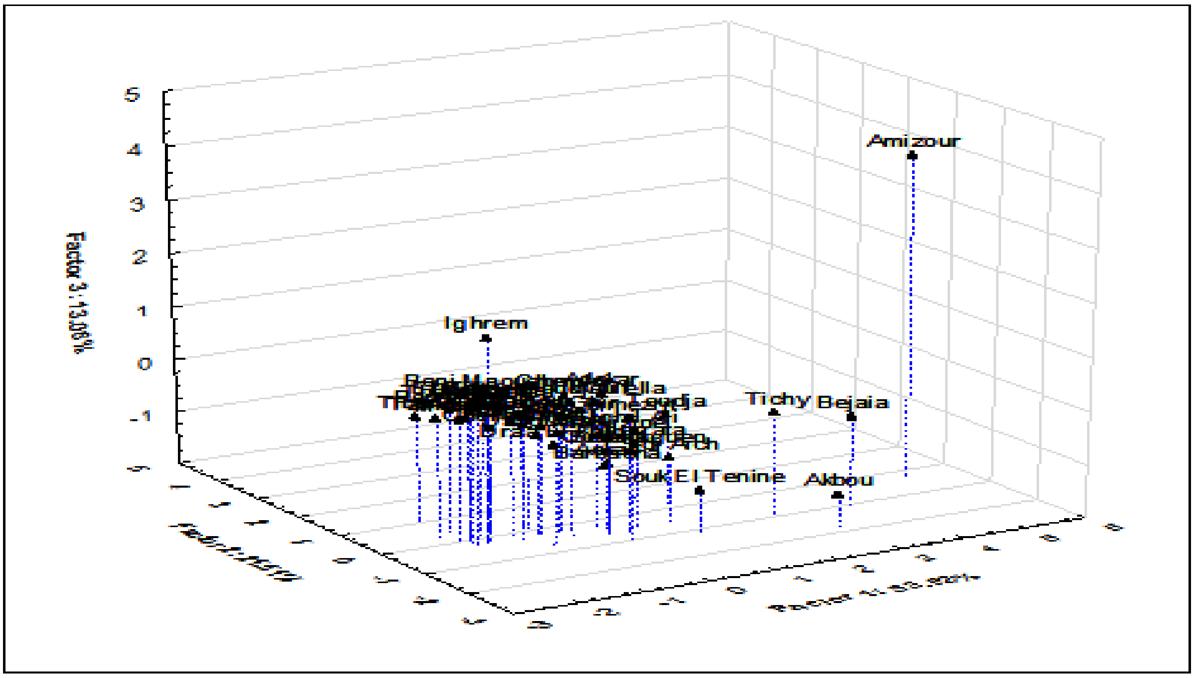

Fig. 4. Spatial projection of the populations, based on the first three axes.

The same results, high concentrations of Cd and Pb in urban areas, were found by Aghaei and Khademi (2016) in Iran, in France (Dron *et al.*, 2016), in Algeria (Adjiri *et al.*, 2018), in Spain (Parviainen *et al.*, 2019) and in Bosnia and Herzegovina (Ramić *et al.*, 2019).The sea is also considered as a persistent source of MTE emission in the municipality of Bejaia, by the processes of the exchange of these elements by the biogeochemical cycles between the sea and the atmosphere (Bagnato *et al.*, 2013; Zhang *et al.*, 2019).

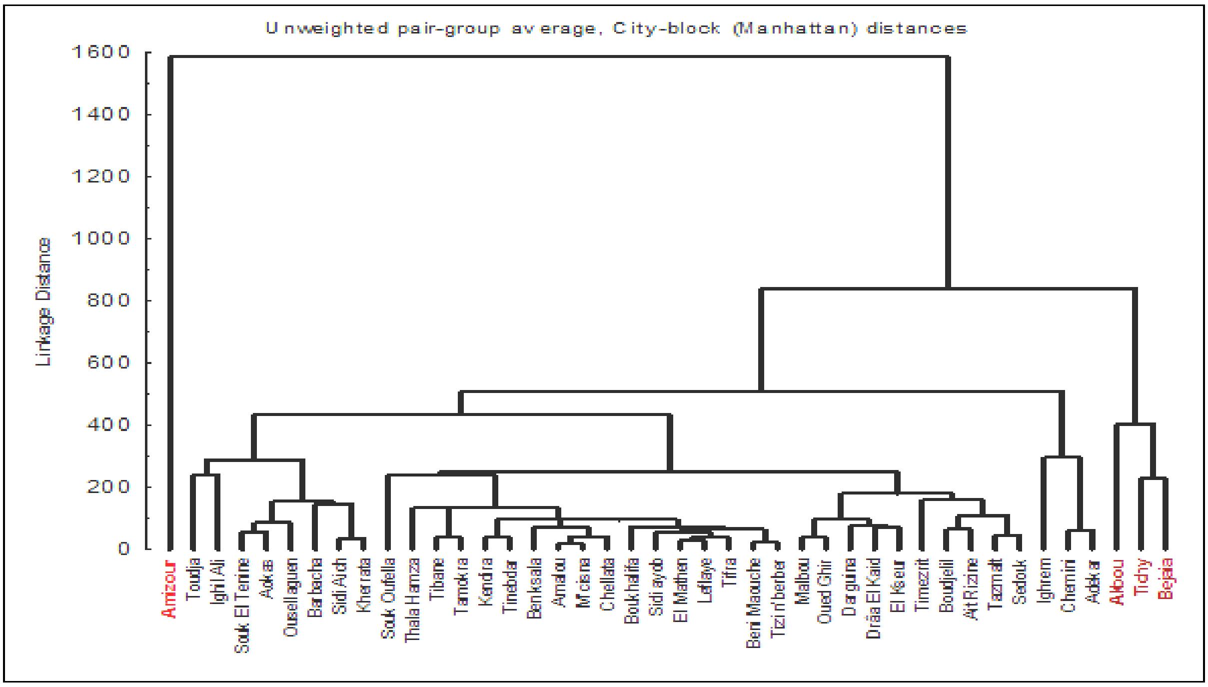

Fig. 5. UPGMA based on the concentration of heavy metals in *X. parietina* thalli.

Repeated ballasting or degassing, which are carried out in violation of regulations near the coast, can also be important sources of Cd, Pb, Mn and Cu in the air (Cram *et al.*, 2006; Piazzolla *et al.*, 2015; Ahmed *et al.*, 2017). A small accumulation of Ag in the sites studied should be noted, with values between (2.77 and 33.35 mg / kg). However, the concentration of Ag in the commune of Ighram was high, due to the intensive use of pesticides, herbicides and fertilizers in arboriculture (Pelletier and Campbell, 2004; Onakpa *et al.*, 2018), and from extraction and processing of mining products (Austruy, 2012), and especially the use of the photographic industry and film development (Daillant, 2003).

Conclusion

The concentrations of five elements (Pb, Cd, Cu, Mn and Ag) were controlled using a lichenic organism *Xanthoria parietina*, collected in 42 municipalities of Bejaia region. MTE analysis revealed significant air pollution in most of the municipalities studied.

The results indicate a good agreement between the concentrations of metals in lichens and the anthropic impacts, which are notably represented by mining, agricultural activities, chemical industries, and the combustion processes linked to vehicle emissions. The results showed that the highest contaminant levels were recorded for Pb, Mn and Cu, and particularly affect the municipalities of Bejaia, Tichy and Akbou. As well as the environmental change in the municipality of Amizour, the closest to the Pb mine.

Acknowledgement

The source financials for the work are provided by MESRS of Algeria (Project code No. D01N01UN190120200005), and no potential conflicts of interest.

References

Adjiri F, Ramdani M, Lograda T, Chalard P. 2018. Bio monitoring of metal trace elements by epiphytic lichen in the Bordj Bou Arreridj area, east of Algeria. Scholars Academic Journal of Biosciences **6(2),** 199–208. http://dx.doi.org/10.21276/sajb.2018.6.2.12

Aghaei A, Khademi H. 2016. Evaluating and determining of heavy metals in the atmospheric dust by using statistical methods (PCA and CA). Algerian Journal of Environmental Science and Technology **2(3),** 6–16. https://www.asjp.cerist.dz/en/article/19816

Agnan Y, Sejalon-delmas N, Claustres A, Probst A. 2015. Investigation of spatial and temporal metal atmospheric deposition in France through lichen and moss bioaccumulation over one century. Science of the Total Environment **529,** 285–296. https://doi.org/10.1016/j.scitotenv.2015.05.083

Ahmad I, Khan B, Khan S, Khan MT, Schwab AP. 2018. Assessment of lead exposure among automobile technicians in Khyber Pakhtunkhwa, Pakistan. Science of the Total Environment **633,** 293–299. http://dx.doi.org/10.1016/j.scitotenv.2018.03.160

Ahmed MM, Doumenq P, Awaleh MO, Syakti AD, Asia L, Chiron S. 2017. Levels and sources of heavy metals and PAHs in sediment of Djibouti-city (Republic of Djibouti). Marine pollution bulletin **120(1-2),** 340–346. https://doi.org/10.1016/j.marpolbul.2017.05.055

Alkama R, Adjabi S, Idir FA. 2009. Air Pollution in Bejaia City (Algeria): Measurements and Forecasts. Polish Journal of Environmental Studies **18(5),** 769–773. http://www.pjoes.com/Air-Pollution-in-Bejaia-City-Algeria-r-nMeasurements-and-Forecasts,88293,0,2.html

Antonucci A, Vitali M., Avino P, Manigrasso M, Protano C. 2016. Sensitive multiresidue method by HS-SPME/GC-MS for 10 volatile organic compounds in urine matrix: a new tool for bio monitoring studies on children. Analytical and Bioanalytical Chemistry **408,** 5789–5800. http://dx.doi.org/10.1007/s00216-016-9682-x

Augusto S, Pinho P, Santos A, Botelho MJ, Palma-oliveira J, Branquinho C. 2015. Declining trends of PCDD/Fs in lichens over a decade in a Mediterranean area with multiple pollution sources. Science of the Total Environment **508,** 95–100. https://doi.org/10.1016/j.scitotenv.2014.11.065

Austruy A. 2012. Aspects physiologiques et biochimiques de la tolérance à l'arsenic chez les plantes supérieures dans un contexte de phytostabilisation d'une friche industrielle. Sciences agricoles. Université Blaise Pascal - Clermont-Ferrand II, p 300. https://tel.archives-ouvertes.fr/tel-00745701/document

Bagnato E, Sproveri M, Barra M, BItetto M, Bonsignore M, Calabrese S, Stefano VD, Oliveri E, Parello F, Mazzola S. 2013. The sea–air exchange of mercury (Hg) in the marine boundary layer of the Augusta basin (southern Italy): Concentrations and evasion flux. Chemosphere **93(9),** 2024–2032. http://dx.doi.org/10.1016/j.chemosphere.2013.07.025

Balabanova B, Stafilov T, Sajn R, Baceva K. 2012. Characterization of heavy metals in lichen species *Hypogymnia physodes* and *Evernia prunastri* due to bio monitoring of air pollution in the vicinity of copper mine. International Journal of Environmental Research **6(3),** 779–794. http://eprints.ugd.edu.mk/id/eprint/5060

Bargagli R. 2016. Moss and lichen biomonitoring of atmospheric mercury: a review. Science of the Total Environment **572,** 216–231. http://dx.doi.org/10.1016/j.scitotenv.2016.07.202

Belguidoum A, Lograda T, Ramdani M. 2020.

Heavy metals accumulation in Hertiacheirifolia along the highway in Setif region, Algeria. Biodiversitas Journal of Biological Diversity **21(6),** 2786–2793. http://dx.doi.org/10.13057/biodiv/d210655

Belkhiri A, Djemili A. 2016. Le rôle des plates-formes logistique extra-portuaires dans la réduction des couts logistiques des operateurs du commerce extérieur ? Cas de l'entreprise portuaire de Bejaia–Algérie. Lucrările Seminarului Geografic" Dimitrie Cantemir" **43,** 33–44. http://dx.doi.org/10.15551/lsgdc.v43i0.03

Benaissa F, Maesano CN, Alkama R, Annesi-Maesano I. 2018. Analysis of PM concentrations in the urban area of Bejaia. Environment Protection Engineering **44(1),** 75–84. http://dx.doi.org/10.5277/epe18016

Benaissa F, Maesano CN, Alkama R, Annesi-Maesano I. 2016. Short-term health impact assessment of urban PM10 in Bejaia City (Algeria). Canadian respiratory journal **6(4),** 1–6. http://dx.doi.org/10.1155/2016/8209485

Bermejo-Orduna R, Mcbride JR, Shiraishi K, Elustondo D, Lasheras E, Santamaría JM. 2014. Biomonitoring of traffic-related nitrogen pollution using Letharia vulpina (L.) Hue in the Sierra Nevada, California. Science of the total environment **490,** 205–212. https://doi.org/10.1016/j.scitotenv.2014.04.119

Boamponsem LK, Adam JI, Dampare SB, Nyarko BJB, Essumang DK. 2010. Assessment of atmospheric heavy metal deposition in the Tarkwa gold mining area of Ghana using epiphytic lichens. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms **268(9),** 1492–1501. https://doi.org/10.1016/j.nimb.2010.01.007

Chen B, Stein AF, Castell N, Gonzalez-Castanedo Y, De La Campa ASA, De La Rosa JD. 2016. Modeling and evaluation of urban pollution events of atmospheric heavy metals from a large Cu-smelter. Science of the Total Environment **539,** 17–25. http://dx.doi.org/10.1016/j.scitotenv.2015.08.117

Conti Me, Finoia Mg, Bocca B, Mele G, Alimonti A, Pino A. 2012. Atmospheric background trace elements deposition in Tierra del Fuego region (Patagonia, Argentina), using transplanted Usnea barbata lichens. Environmental monitoring and assessment **184(1),** 527–538. http://dx.doi.org/10.1007/s10661-011-1985-y

Coufalík P, Matousek T, Krumal K, Vojtísek-Lom M, Beránek V, Mikuška P. 2019. Content of metals in emissions from gasoline, diesel, and alternative mixed biofuels. Environmental Science and Pollution Research **26(28),** 29012–29019. http://dx.doi.org/10.1007/s11356-019-06144-4

Cram S, De Leon Cap, Fernandez P, Sommer I, Rivas H. and MORALES L.M. 2006. Assessment of trace elements and organic pollutants from a marine oil complex into the coral reef system of Cayo Arcas, Mexico. Environmental monitoring and assessment **121(1-3),** 127–149. http://dx.doi.org/10.1007/s10661-005-9111-7

Cuny D, Davranche L, Thomas P, Kempa M, Van Haluwyn C. 2004. Spatial and temporal variations of trace element contents in *Xanthoria parietina* thalli collected in a highly industrialized area in northern France, as an element for a future epidemiological study. Journal of Atmospheric Chemistry **49(1-3),** 391-401. http://dx.doi.org/10.1007/s10874-004-1254-3

Daillant O. 2003. Lichens et accumulation des métaux lourds. Bull. Inform. Ass. Fr. Lichénologie **28(1),** 31–43. http://www.afl-lichenologie.fr/telecharger/Bull_AFL_old/Bull_2003/AFL_2003_1_31_43_O_Daillant.pdf

Demiray Ad, Yolcubal I, Akyol Nh, Çobanoğlu

G. 2012. Biomonitoring of airborne metals using the Lichen Xanthoria parietina in Kocaeli Province, Turkey. Ecological indicators **18,** 632–643. http://dx.doi.org/10.1016/j.ecolind.2012.01.024

Demkova L, Arvay J, Bobuska L, Hauptvogl M, Hrstkova M. 2019. Open mining pits and heaps of waste material as the source of undesirable substances: biomonitoring of air and soil pollution in former mining area (Dubnik, Slovakia). Environmental Science and Pollution Research **26(34),** 35227–35239. http://dx.doi.org/10.1007/s11356-019-06582-0

Demkova L, Bobulska L, Arvay J, Jezny T, Ducsay L. 2017. Biomonitoring of heavy metals contamination by mosses and lichens around Slovinky tailing pond (Slovakia). Journal of Environmental Science and Health *Part A* **52(1),** 30–36. https://doi.org/10.1080/10934529.2016.1221220

Demkova La, Obona J, Arvay J, Michalkova J, Losak T. 2019. Biomonitoring road dust pollution along streets with various traffic densities. Environment **28(5),** 3687–3696. https://doi.org/10.15244/pjoes/97354

Douibi C, Ramdani M, Khelfi A, Benharket R, Lograda T, Chalard P. 2015. Biomonitoring of heavy metals by lichens in Setif area, east of Algeria. United Journal Environmental Science and Toxicology **1(1),** 001–013. http://www.unifiedjournals.org/ujest

Dron J, Austruy A, Agnan Y, Ratier A, Chamaret P. 2016. Biomonitoring with lichens in the industrial oportuary zone of Fos-sur-Mer (France): Feedback on three years of monitoring at a local collectivity scale. Pollution atmosphérique N **228(1),** 1–17. https://doi.org/10.4267/pollutionatmospherique.5392

Garty J. 2001. Biomonitoring atmospheric heavy metals with lichens: theory and application. Critical Reviews in Plant Sciences **20(4),** 309–371. https://doi.org/10.1080/20013591099254

Gauslaa Y, Yemets OA, Asplund J, Solhaug KA. 2016. Carbon based secondary compounds do not provide protection against heavy metal road pollutants in epiphytic macrolichens. Science of the Total Environment **541,** 795–801. https://doi.org/10.1016/j.scitotenv.2015.09.114

Gonzalez-Castanedo Y, Moreno T, Fernandez-Camacho R, De La Campa AMS, Alastuey A, Querol X, Rosa J. 2014. Size distribution and chemical composition of particulate matter stack emissions in and around a copper smelter. Atmospheric Environment **98,** 271–282. https://doi.org/10.1016/j.atmosenv.2014.08.057

Gu JD. 2018. Mining, pollution and site remediation. International Bio deterioration and Biodegradation **128,** 1–2. http://dx.doi.org/10.1016/j.ibiod.2017.11.006

Hamma W, Petrişor AI. 2018. Urbanization and risks: case of Bejaia city in Algeria. Human Geographies **12(1),** 97–114.

Hébrard-Labit C, Meffray L. 2004. Comparaison de méthodes d'analyse des éléments traces métalliques (ETM) et des hydrocarbures aromatiques polycycliques (HAP) sur les sols et les végétaux. [Rapport de recherche] Centre d'études sur les réseaux, les transports, l'urbanisme et les constructions publiques (CERTU) 120 p. http://www.bv.transports.gouv.qc.ca/mono/0968637.pdf

Kazimirova A, Peikertova P, Barancokova M, Staruchova M, Tulinska J, Vaculik M, Vavra I, Kukutschova J, Filip P, Dusinska M. 2016. Automotive airborne brake wear debris nanoparticles and cytokinesis-block micronucleus assay in peripheral blood lymphocytes: a pilot study. Environmental research **148,** 443–449.

http://dx.doi.org/10.1016/j.envres.2016.04.022Li,Z.

Kittner N, Fadadu RP, Buckley HL, Schwarzman MR, Kammen DM. 2018. Trace metal content of coal exacerbates air-pollution-related health risks: the case of lignite coal in Kosovo. Environmental Science and Technology **52(4),** 2359–2367. http://dx.doi.org/10.1021/acs.est.7b04254

Kresovich JK, Erdal S, Chen HY, Gann PH, Argos M, Rauscher GH. 2019. Metallic air pollutants and breast cancer heterogeneity. Environmental Research **177,** 108639. http://dx.doi.org/10.1016/j.envres.2019.108639

Lin M, Gui H, Wang Y, Peng W. 2017. Pollution characteristics, source apportionment, and health risk of heavy metals in street dust of Suzhou, China. Environmental Science and Pollution Research **24(2),** 1987–1998. http://dx.doi.org/10.1007/s11356-016-7934-0

Liu HJ, Fang SB, Liu SW, Zhao LC, Guo XP, Jiang YJ, Liu XD, Xia Y, Wang YD, Wu QF. 2016. Lichen elemental composition distinguishes anthropogenic emissions from dust storm inputs and differs among species: Evidence from Xilinhot, Inner Mongolia. China Scientific reports **6,** 34694. http://dx.doi.org/10.1038/srep34694

Liu HJ, Zhao LC, Fang SB, Liu SW, Hu JS, Wang L, Liu XD, Wu QF. 2016. Use of the lichen *Xanthoria* mandschurica in monitoring atmospheric elemental deposition in the Taihang Mountains, Hebei, China. Scientific reports **6,** 23456. http://dx.doi.org/10.1038/srep23456

Lodenius M, Kiiskinen J, Tulisalo E. 2010. Metal levels in an epiphytic lichen as indicators of air quality in a suburb of Helsinki, Finland. Boreal Environment Research **15(4),** 446–452. https://www.researchgate.net/publication/47930270_Metal_levels_in_an_epiphytic_lichen_as_indicators_of_air_quality_in_a_suburb_of_Helsinki_Finlad

Ma Z, Van Der Kuijp TJ, Yuan Z, Huang L. 2014. A review of soil heavy metal pollution from mines in China: pollution and health risk assessment. Science of the Total Environment **468,** 843–853. http://dx.doi.org/10.1016/j.scitotenv.2013.08.090.

Monaci F, Moni F, Lanciotti E, Grechi D, Bargagli R. 2000. Biomonitoring of airborne metals in urban environments: new tracers of vehicle emission, in place of lead. Environmental Pollution **107(3),** 321-327. https://doi.org/10.1016/S0269-7491(99)00175-X

Mwaanga P, Silondwa M, Kasali G, Banda PM. 2019. Preliminary review of mine air pollution in Zambia. Heliyon **5(9),** e02485. http://dx.doi.org/10.1016/j.heliyon.2019.e02485

Nascimbene J, Tretiach M, Corana F, Lo Schiavo F, Kodnik D, Dainese M, Mannucci B. 2014. Patterns of traffic polycyclic aromatic hydrocarbon pollution in mountain areas can be revealed by-lichen biomonitoring: a case study in the dolomites (Eastern Italian Alps). Science of the Total Environment **475**, 90–96. https://doi.org/10.1016/j.scitotenv.2013.12.090

Nguyen Van T, Ozaki A, Nguyen ThoH, Nguyen DucA, Tran ThiY, Kurosawa K. 2016. Arsenic and heavy metal contamination in soils under different land use in an estuary in Northern Vietnam. International Journal of Environmental research and public health **13(11)**, 1091. http://dx.doi.org/10.3390/ijerph13111091

Nimis PL, Lazzarin G, Lazzarin A, Skert N. 2000. Bio monitoring of trace elements with lichens in Veneto (NE Italy). Science of the Total Environment **255(1-3),** 97–111. https://doi.org/10.1016/S0048-9697(00)00454-X

Onakpa MM, Njan AA, Kalu OC. 2018. A review of heavy metal contamination of food crops in Nigeria. Annals of Global Health **84(3)**, 488. http://dx.doi.org/10.29024/aogh.2314

Pandey B, Agrawal M, Singh S. 2014. Assessment of air pollution around coal mining area: Emphasizing on spatial distributions, seasonal variations and heavy metals, using cluster and principal component analysis. Atmospheric Pollution Research **5(1),** 79–86.
http://dx.doi.org/10.5094/apr.2014.010

Paoli L, Winkler A, Guttová A, Sagnotti L, Grassi A, Lackovičová A, Senko D, Loppi S. 2017. Magnetic properties and element concentrations in lichens exposed to airborne pollutants released during cement production. Environmental Science and Pollution Research **24(13)**, 12063–12080.
http://dx.doi.org/10.1007/s11356-016-6203-6

Parviainen A, Casares-Porcel M, Marchesi C, Garrido CJ. 2019. Lichens as a spatial record of metal air pollution in the industrialized city of Huelva (SW Spain). Environmental Pollution **253,** 918-929.
http://dx.doi.org/10.1016/j.envpol.2019.07.086

Parzych A, Astel A, Zduńczyk A, Surowiec T. 2016. Evaluation of urban environment pollution based on the accumulation of macro-and trace elements in epiphytic lichens. Journal of Environmental Science and Health *Part A* **51(4),** 297–308.
http://dx.doi.org/10.1080/10934529.2015.1109387

Pascaud G, Leveque T, Soubrand M, Boussen S, Joussein E, Dumat C. 2014. Environmental and health risk assessment of Pb, Zn, As and Sb in soccer field soils and sediments from mine tailings: solid speciation and bio accessibility. Environmental Science and Pollution Research **21(6),** 4254–4264.
http://dx.doi.org/10.1007/s11356-013-2297-2.

Pelletier E, Campbell PG. 2004. Écotoxicologie moléculaire : Principes fondamentaux et perspectives de développement. Presses de l'Université du Québec, p 502.

Peng X, Shi GL, Zheng J, Liu JY, Shi XR, Xu J, Feng YC. 2016. Influence of quarry mining dust on PM 2.5 in a city adjacent to a limestone quarry: Seasonal characteristics and source contributions. Science of the Total Environment **550,** 940–949.
http://dx.doi.org/10.1016/j.scitotenv.2016.01.195

Piazzolla D, Scanu S, Frattarelli FM, Mancini E, Tiralongo F, Brundo MV, Tibullo D, Pecoraro R, Copat C, Ferrante M, Marcelli M. 2015. Trace-metal enrichment and pollution in coastal sediments in the Northern Tyrrhenian Sea, Italy. Archives of Environmental Contamination and Toxicology **69(4),** 470–481.
http://dx.doi.org/10.1007/s00244-015-0166-3

Ramic E, Huremovic J, Muhic-Sarac T, Đug S, Zero S, Olovcic A. 2019. Biomonitoring of Air Pollution in Bosnia and Herzegovina Using Epiphytic Lichen Hypogymnia physodes. Bulletin of Environmental Contamination and Toxicology **102(6),** 763–769.
http://dx.doi.org/10.1007/s00128-019-02595-0

Ratier A, Dron J, Revenko G, Austruy A, Dauphin CE, Chaspoul F, Wafo E. 2018. Characterization of atmospheric emission sources in lichen from metal and organic contaminant patterns. Environmental Science and Pollution Research **25(9),** 8364–8376.
http://dx.doi.org/10.1007/s11356-017-1173-x

Stamenkovic SS, Mitrovic TL, Cvetkovic VJ, Krstic NS, Baosic R, Markovic MS, Cvijan MV. 2013. Biological indication of heavy metal pollution in the areas of Donje Vlase and Cerje (southeastern Serbia) using epiphytic lichens. Archives of Biological Sciences 151–159.
http://dx.doi.org/10.2298/ABS1301151S

Tokalioglu S, Kartal S. 2006. Multivariate analysis of the data and speciation of heavy metals in street dust samples from the Organized Industrial District in Kayseri (Turkey). Atmospheric Environment **40(16),** 2797–2805.
https://doi.org/10.1016/j.atmosenv.2006.01.019

Vitali M, Antonucci A, Owczarek M, Guidotti M, Astolfi ML, Manigrasso M, Avino P, Bhattacharya B, Protano C. 2019. Air quality assessment in different environmental scenarios by the determination of typical heavy metals and Persistent Organic Pollutants in native lichen *Xanthoria parietina*. Environmental Pollution **254,** 113013. https://doi.org/10.1016/j.envpol.2019.113013

Wan D, Han Z, Yang J, Yang G, Liu X. 2016. Heavy metal pollution in settled dust associated with different urban functional areas in a heavily air-polluted city in North China. International Journal of Environmental Research and Public Health **13(11),** 1119. http://dx.doi.org/10.3390/ijerph13111119

Wang J, Wu Q, Liu J, Yang H, Yin M, Chen S, Guo P, Ren J, Luo X, Linghu W, Huang Q. 2019. Vehicle emission and atmospheric pollution in China: problems, progress, and prospects. Environmental Science PeerJ **7,** e6932. https://doi.org/10.7717/peerj.6932

Weinmayr G, Pedersen M, Stafoggia M, Andersen ZJ, Galassi C, Munkenast J, Pyko A. 2018. Particulate Matter Air Pollution components and incidence of cancers of the stomach and the upper aerodigestive tract in the European Study of Cohorts of Air Pollution Effects (ESCAPE). Environment international **120,** 163–171. http://dx.doi.org/10.1016/j.envint.2018.07.030

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. http://dx.doi.org/10.1016/j.ecolind.2017.03.017

Yamina O, M'hamed M, Nadera A, Amine H, Mokhtar A. 2015. Bioaccumulation de pollution plombique d'origine routière au moyen d'une mousse (*Bryum argenteum*) dans la ville de Tiaret (Algérie) : Classe de pollution et cartographie. European Scientific Journal **11(8),** 105–121. http://eujournal.org/index.php/esj/issue/view/174

Zhang Y, Horowitz H, Wang J, Xie Z, Kuss J, Soerensen AL. 2019. A Coupled Global Atmosphere-Ocean Model for Air-Sea Exchange of Mercury: Insights into Wet Deposition and Atmospheric Redox Chemistry. Environmental science and technology **53(9),** 5052–5061. http://dx.doi.org/10.1021/acs.est.8b06205