EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2023, 24(4), 200–209
https://doi.org/10.12912/27197050/161955
ISSN 2719-7050, License CC-BY 4.0

Received: 2023.02.01
Accepted: 2023.03.27
Published: 2023.04.10

Satellite and In Situ Detection of Air Pollution in Urban Area – Case Study of El Eulma Town (North East of Algeria)

Amina Beldjazia[1*], Ibtissem Samai[2], Khaled Missaoui[1,3], Akram Kout[1,4], Somia Lakehal Ayat[2]

[1] Departmnent of Plant Biology and Ecology, Faculty of Nature and Life Sciences, University of Ferhat Abbas Setif 1, Algeria

[2] Laboratory Researches of Soil and Sustainable Development, Department of Biology, Faculty of Sciences, Badji Mokhtar University. BP12, 23000 Annaba, Algeria

[3] Laboratory Urban Project, City and Territory, Faculty Architecture and Earth Sciences, University of Ferhat Abbas Setif 1, Algeria

[4] MISC Laboratory, Constantine, MISC Laboratory, University of Abdelhamid Mehri, Ali Mendjeli Campus, 25000 Constantine, Algeria

* Corresponding author's e-mail: beldjaziaamina@yahoo.fr

ABSTRACT

Drust in urbain city can be reduced throught plants. Besides, the majority among of the drusts are accumulated on their leaves, that's why they are used as an indicator to estimate the air quality. This work illustrates the interest of the urban vegetation and satellite data to detect the air pollution in the town of El Eulma (North East of Algeria). To achieve this, our use of remote sensing make it easy to understand the temporal and spatial distribution of air pollution, and its effect on the ecosystem througout Normalized Pigment Chlorophyll Ratio Index (NPCI). In the other hand, the analysis of leaves of most dominant plants make it possible to understand the air quality in this region. Four species are selected from different plots in the study area as well as: nerium (*Nerium oleander*), planetree (*Platanus acerifolia*), wax-leaf privet (*Ligustrum japonicum*) and white mulberry (*Morus alba*). Our finding show a variation of the ratio fresh matter/dry matter of plant leaves from site to another which is very weak in places marked by high anthropic action. Also, the statisical analysis found that this ration is very important in planetree and white mulberry. The high concentration in dust registered in nerium leaves contributes to the decrease of the ratio fresh matter/dry matter in this species. The results of NPCI are verry weak in nerium compared to other species, while a very large amount of dust has been recorded on their leaves, which prevents the photosynthetic reaction. The findings of this work might contribute to the plant species selection for urban vegetation and the important of the use of NPCI index in evaluation of the pollution intensity which accord to ratio fresh matter/dry matter results.

Keywords: drust, pollution, vegetation, remote sensing, fresh matter, dry matter, NPCI.

INTRODUCTION

In recent decades, population growth, increased energy use, industries and the development of infrastructure in Algeria have contributed to increasing gas and particulate emissions that cause damage on the health. El Eulma, first economic city in Algeria with many big markts, dense population and low, make it one of the highly dusty area in Algeria. In this case, important aspects of air quality is to minimise human exposure. Deposition of dry pollutants on vegetation surfaces might help reduce huma exposure to traffic emissions (Janhall, 2015). Tree are excellent indicator to evaluate the status of air quality in polluted parks and urban surfaces (Carvalho-Oliveira et al., 2017). In recent decades, the use of living organisms to assess the pollution intensity, the accumulation of pollutants in the atmosphere, is a very effective environmental technique (Berrayah et al., 2016). Leaves are the moste important part of tree that can receive air pollutants (Carvalho-Oliveira et al., 2017) through leaf stomata (Pesch and Schroeder, 2006). Atmospheric particulate matter are retaining from air by the use of certain characteristics of the leaf surface (Duran Rivera and Alzate Guarin, 2009). Atmospheric pollution can affect plant photosynthesis form their changing and other physiological indexes such as the meseare of plant photosynthesis capacity to produce oxygen and quantity of chlorophyll *a* (Cen, 2015). According to biochemical, physiological and morphological characteristics plant are able to tolerate air pollutants (Singh and Verma, 2007).

Many measurement with their sensitivity to environmental variations can used to estimate air quality such as: leaf area (LA) and leaf dry matter content (Rodríguez-Alarcón et al., 2020 ; Montes-Pulido, 2014). Also the use of remote sensing according several vegetation index can offred important information to enhance in situ evaluation of different plant parameters (Jerry et al., 2010). Chlorophyll content is essential int plant growth, and so it can be used to illustrat the stress of plants (Yoshio et al., 2016; Liang et al., 2017). Many studies in Algeria are established in order to choose of plant species adopted in urban green (Samadi, 1993; Rahali, 2003; Maatoug et al., 2010; Berrayah et al., 2016). But we can not generalized over different areas because of their biogeographic and climatics characteristics. In this case, this study was realized in the town of El Eulma to assess air pollution tolerance dust-assimilating potential of plant species used along the road section according satellite data and in situ observations.

MATERIALS AND METHODS

Study space

Plots were selected from diffrent roads in El Eulma town (36° 8'N and 5° 41'E), which is in North east of Algeria an elevation of 944–966 m

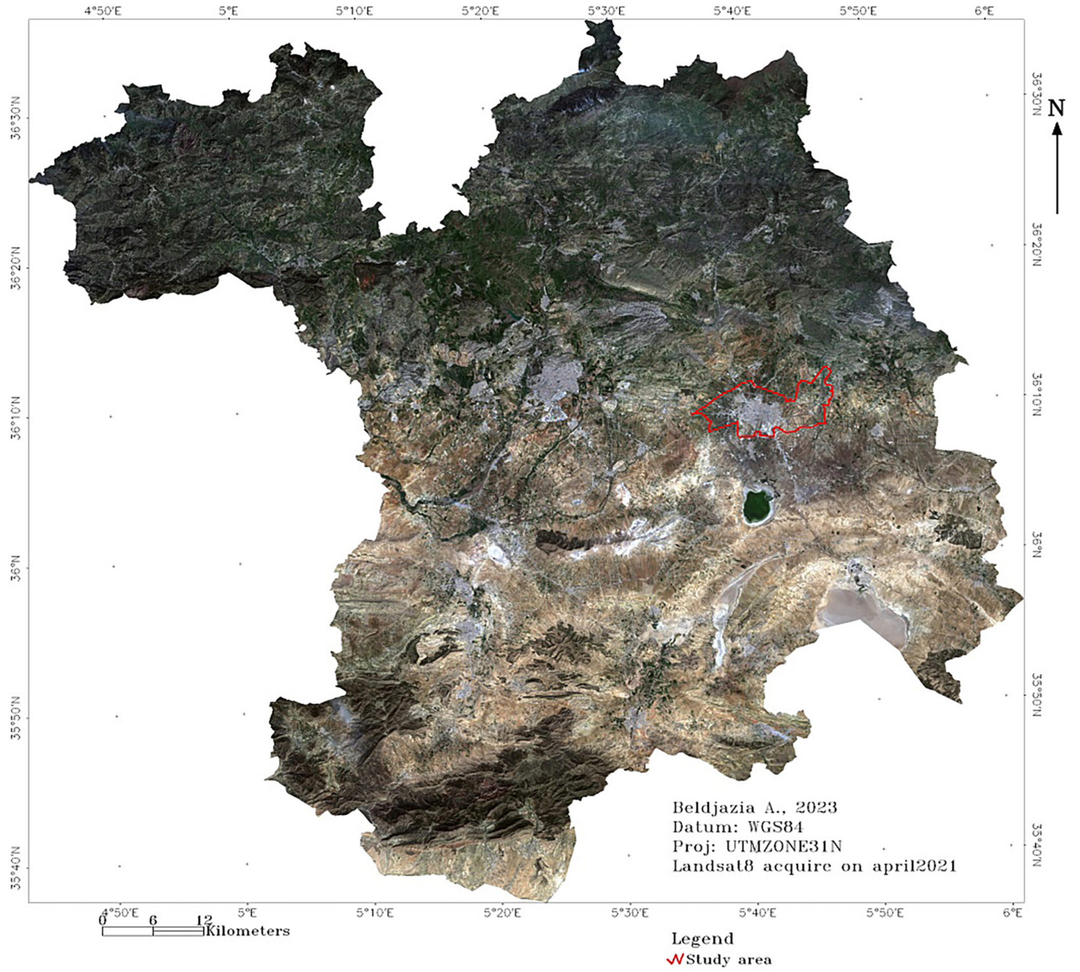

Figure 1. Map of study area with sampling plots over true color composition map obtained from Landsat 8 satellite processed with ENVI 5.1 software

(Fig. 1). The climate is a semi-arid continental, among a mean monthly temperature varied from 5.2 °C in Janury to 26.3 °C in July and about 386 mm annual precipitation (period from 1990 to 2020). Heavy traffic and industries are the main sources of air pollutants in the el Eulma town.

Plant samples collection

Plots were choosen from the center to the outskirts of the town El Eulma. The sampling points were done randomly along the roads and determined according to the presence of the species studied. Along roads on the sidewalks, four most abundant plant species were choose for the diagnostic which they were *Nerium oleander*, *Platanus acerifolia*, *Ligustrum japonicum* and *Morus alba*. For each species we have selected three individual trees, and also four leaves. Leaf samples were collected from diferent levels of the trees with equal age and breast diameter to avoid other type of (Babacar, 1998) in spring season in 2021.

The collection of fresh mature leaves was done early in the morning hours (07:00–08:30) after about one week without rain, and kept in polythene bags to brought them to the laboratory for further analysis.

Imagery data sources

We have used the Landsat 8 satellite image acquired in April 2021 downloaded from the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov/). Our date selection accorded to experimental studies. Tow spectral bands were used for this study (Table 1).

Air pollution index, Total Chlorophyll

This research contribute to examine the reflection of trees to air pollution in several plots during the spring season. The total chlorophyll content was determinated using remote sensing methods according to Normalized Pigment Chlorophyll Ratio Index (NPCI) (Merzlyak et al., 1999). It was measured using the blue and red bands from image of Landsat 8 using this formula:

Table 1. Properties of the spectral bands

Spectral band	Wavelength (µm)	Resolution (m)
Blue	0.450–0.510	30
Red	0.630–0.680	30

$$NPCI = R - B/R + B \quad (1)$$

where: R and B – respectively the red and blue band. The NPCI Correlated to chlorophyll content.

Spectral reflectance measurements

Reflectance spectra were measured with using the ENVI 5.1 softwer according Normalized Pigment Chlorophyll Ratio Index for all studied species.

Ratio fresh matter / dry matter

The ratio fresh matter/dry matter (FM/DM) is a good indicator of air quality. It determines the pollution index. The lower of this ratio indicate that the plant shows a good water supply, which seems to behave well in the face of heavy pollution. For this, the fresh leaves of the plants are carefully cut and electronic balance was used to measure leaf weights. The dry matter is determined after passing through an oven set at 85 °C avout 48 hours. Once samples are completely dry (this is checked by constant weight), their dry weight is determined using a precision balance. Above ground dry biomass is expressed in milligrams.

Frequence of leaf dust capturing capacity

Dust through plant leaves as measured by gravimetric method (Prajapati and Tripathi, 2008). The selected sample were immersed in tow different sollution which the first contain distilled water and the second was HCL sollution. The selected leaves were immersed in in this batches for about 10 minutes. After that we have passed each solution through filter paper (W1) to collect dust fixed on leaf surfaces. And then this filter papers were dried at 60 °C to obtain weight constant (W2). The dust capturing capacity for each sample was calculated according the formula:

$$W = (W2 - W1)/S \quad (2)$$

where: W – dust capturing capacity (µg/cm^2); S – leaf surface area (cm^2) (Wang et al., 2011) calculated across the millimeter graph paper method.

Statistical analysis

Our results were checked the normal distribution and homology of variances by statistical analysis sofware (XLSTAT 2019 version 1.2) using

Breusch-Pagan & White heteroscedasticity tests. ANOVA analysis was applied on data results using XLSTAT 2019 software.

RESULTS AND DISCUSSION

Content of chlorophyll pigment

Chlorophyll content of selected plant species are studied using remote sensing methods. Reflectance patterns reveal several information about the changes in blue and red wavelengths. Understanding these meseare contribute to the interpretation of the air quality. The study area present very low values of NPCI due to weak vegetation cover in this urban area (Fig. 2).

Statistical analyse show that *Nerium* present very low NPCI values, on the other hand it was found that *Morus alba* present a very important NPCI values (Table 2, Fig. 3).

The results obtained with *Nerium oleander*, *Platanus acerifolia*, *Ligustrum japonicum* and *Morus alba* were compared. In general, plants

Table 2. Statistical analysis of NPCI values of different species

Species	Mean (sd)	Median	Min	Max	n	p	Test
Ligustrum japonicum	0.0334 (0.00248)	0.0320 [0.0320 - 0.0341]	0.0320	0.0363	3	0.017	Kruskal-Wallis
Morus alba	0.0370 (0.00115)	0.0363 [0.0363 - 0.0373]	0.0363	0.0383	3	-	-
Nerium oleander	0.0269 (0.000924)	0.0274 [0.0266 - 0.0274]	0.0258	0.0274	3	-	-
Platanus acerifolia	0.0299 (0.000611)	0.0300 [0.0296 - 0.0302]	0.0292	0.0304	3	-	-

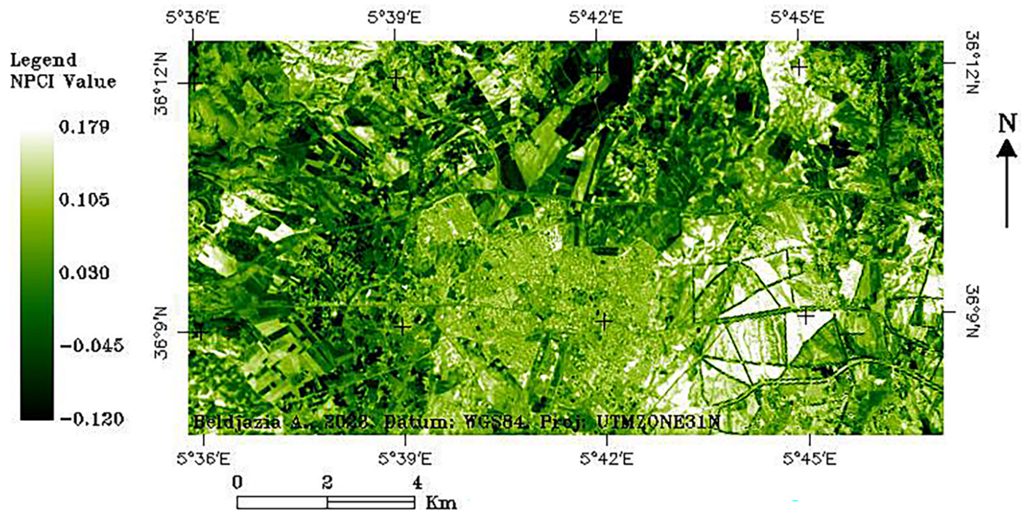

Figure 2. NPCI of the town El Eulma (North east of Algeria) processing with ENVI 5.1 software

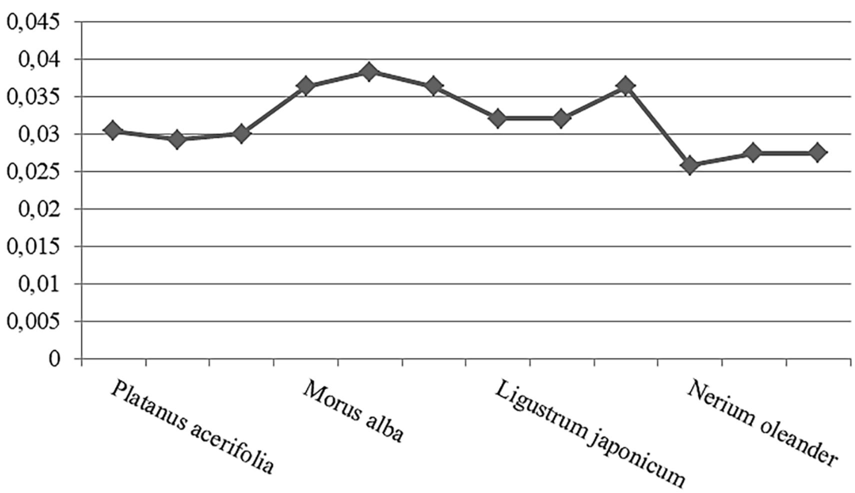

Figure 3. Variation of NPCI according to species

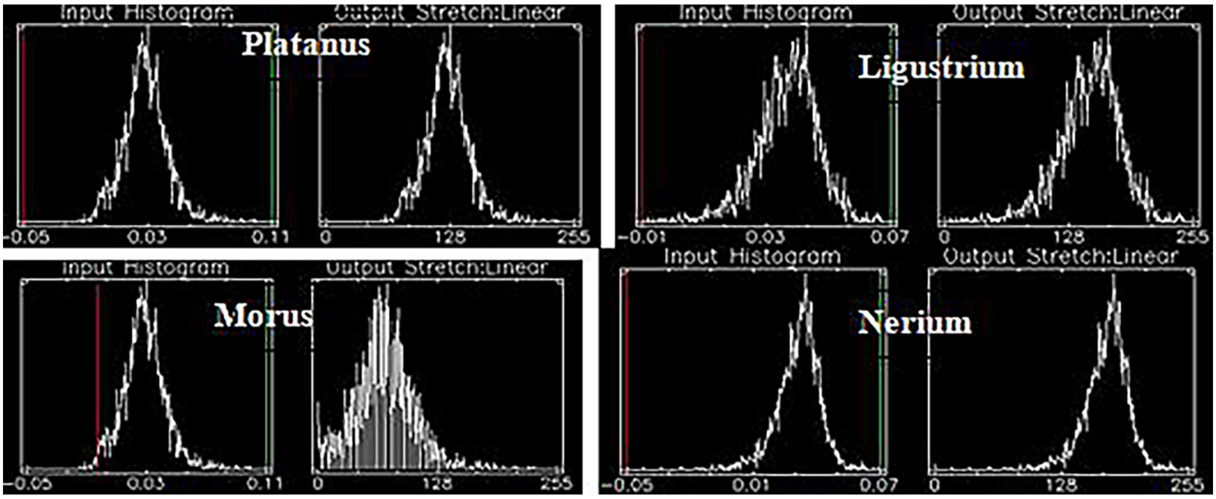

Figure 4. Reflectance spectra measured of NPCI spectral bands according to species Leaf dust capturing capacity

showed a decrease in photosynthetic pigments due to air pollution. Nerium oleander showed a significant reduction in total chlorophyll content, in the study period. Our results indicate that spectral reflectance reached higher values in Ligustrium than in the other species (Fig. 4).

The quantity of dust extracted by the two washing solutions allowed us to obtain quantities which vary in time and in space. Over surface of leaves we can see dust. Dust holding capacity was statistical analysis. The results show that the highest amounts of dust are observed in Nerium leaves and the minimum was observed in Morus leaves (Fig. 5).

The extraction of the dust using the two solutions (distilled water and HCL) allowed us to obtain quantities which varied according to the sampling stations.

Values in bold correspond to tests where the null hypothesis cannot be accepted with a level of significance alpha = 0.05.

According to test of the normality our data follow normal distribution, Fisher test is used to compare the groups (Fig. 6).

Table 3. Summary of normality tests for all dependent variables

Dust	p-value
Dust from distilled water	0.727
Dust from HCL	0.953

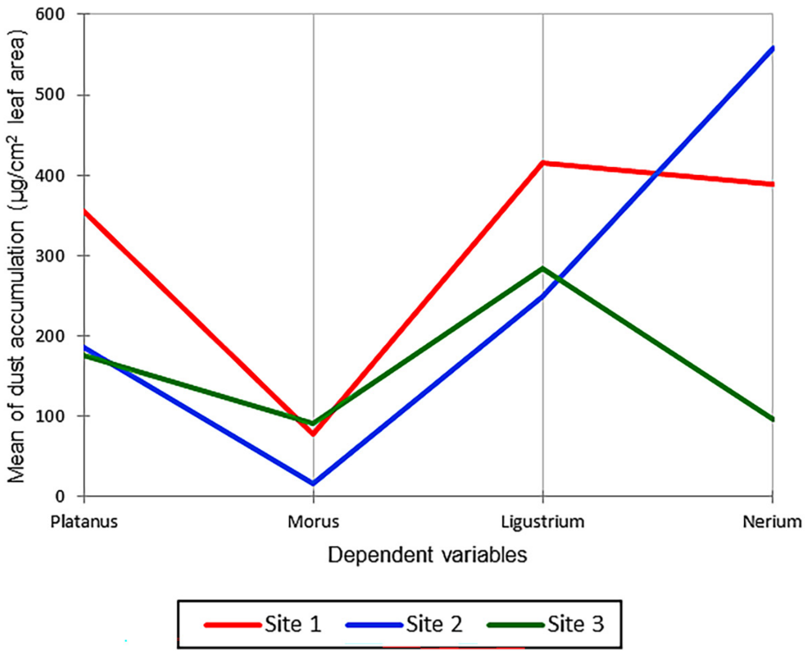

Figure 5. Dust accumulation per site in different plants under study ($\mu g/cm^2$)

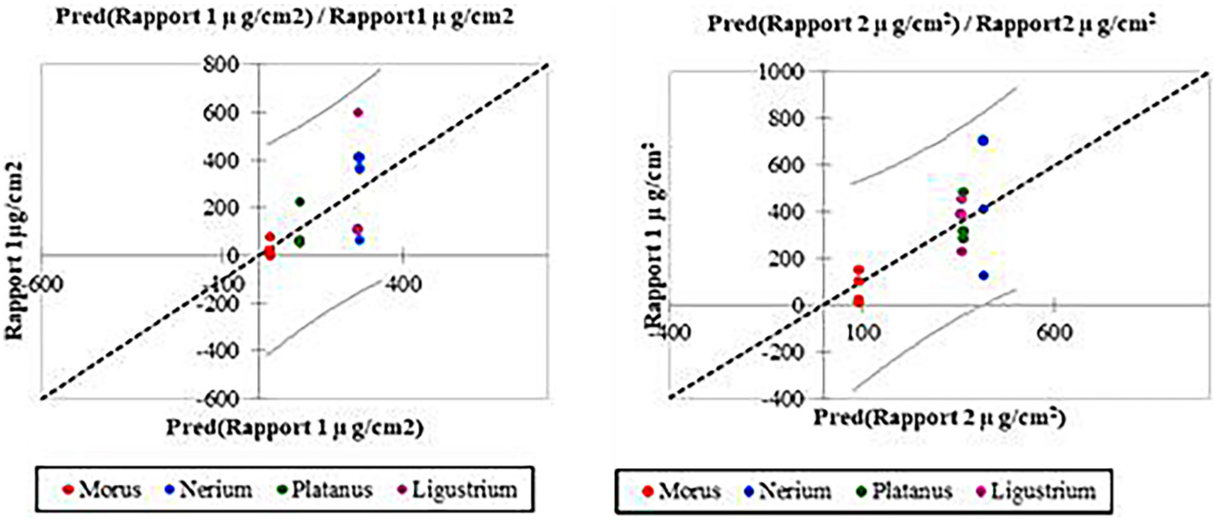

Figure 6. Normality test of dust accumulation in leaves according two period of the study

Fisher's multiple comparison test by pair shows a non-significant difference in the amount of dust accumulated by the different types of leaves according to the species that dust extract with distilled water (Table 4 and 5).

Within the use of HCL, the file test reveals the existence of three homogeneous groups, the first group of which includes the Morus leaves with the lowest dust content, and the last group corresponds to the Nerium leaves

Table 4. Fisher test of Distilled water of the differences in the modalities at 95% confidence interval

Contraste	Difference	Standardized difference	Critical value	Pr > Diff	Significatif
Morus vs Nerium	-247.345	-1.713	2.306	0.125	Non
Morus vs Ligustrium	-240.629	-1.667	2.306	0.134	Non
Morus vs Platanus	-82.193	-0.569	2.306	0.585	Non
Platanus vs Nerium	-165.152	-1.144	2.306	0.286	Non
Platanus vs Ligustrium	-158.435	-1.098	2.306	0.304	Non
Ligustrium vs Nerium	-6.717	-0.047	2.306	0.964	Non
LSD-value :			332.888		

Table 5. Fisher's test (LSD of the differences in the modalities at 95% confidence interval from dust extracted with distilled water

Modality	Mean estimed (µg/cm^2)	Standard error	Lower bound (95%)	Upper bound (95%)	Groups
Morus	33.381	102.076	-202.006	268.768	A
Platanus	115.575	102.076	-119.813	350.962	A
Ligustrium	274.010	102.076	38.623	509.397	A
Nerium	280.727	102.076	45.339	516.114	A

Table 6. Fisher test of HCL of the differences in the modalities at 95% confidence interval extracted with HCL

Contraste	Difference	Standardized difference	Critical value	Pr > Diff	Significatif
Morus vs Nerium	-323.829	-2.359	2.306	0.046	Oui
Morus vs Platanus	-271.671	-1.979	2.306	0.083	Non
Morus vs Ligustrium	-267.574	-1.949	2.306	0.087	Non
Ligustrium vs Nerium	-56.255	-0.410	2.306	0.693	Non
Ligustrium vs Platanus	-4.097	-0.030	2.306	0.977	Non
Platanus vs Nerium	-52.158	-0.380	2.306	0.714	Non
LSD-value:			316.591		

Table 7. Fisher's test (LSD) of the differences in the modalities at 95% confidence interval from dust extracted with HCL

Modality	Mean estimed (µg/cm^2)	Standard error	Lower bound (95%)	Upper bound (95%)	Groups
Morus	90.442	97.078	-133.421	314.305	A
Ligustrium	358.016	97.078	134.153	581.879	AB
Platanus	362.113	97.078	138.250	585.977	
Nerium	414.271	97.078	190.408	638.135	B

with the highest dust content strong medium (Table 6 and 7).

According to Canadian research on the interception capacity of plants of suspended particles and more particularly in urban trees has shown that a healthy mature tree can capture 7000 suspended particles per liter of air, it can also intercept up to 'at 20 kg of dust per year (Vergriete and Labrecque, 2007).

Garrec and C. Van Haluwyn (2002) andicate that gaseous and particulate organic pollutants mainly accumulate on leaf surfaces due to the highly lipophilic properties of cuticular waxes, with little disruptive effects for plants. The leaves of Terminalia catapa accumulate about twice as much lead as the leaves of Nerium oleander due to their shape and properties (Madany et al., 1990).

Determination of the fresh matter/ dry matter ratio (MF/DM)

Results obtained show that the MF/MS ratio is low for Ligustrium and Nerium leaves, which are the most affected during the two sampling periods (Fig. 7). The foliar desiccation of the leaves of Ligustrium and Nerium makes it possible to assess the quality of the air in the city better than does the platanus tree and the Morus. Indeed, the low weight of fresh matter in these sites is explained by the probable effect of pollution from road traffic and industrial discharges on the vigor and physiological activity of the plant, which grows in conditions associated with to road traffic.

We have used the linear regression test as a parametric method to study the effect of species at the measured parameter (MF/MS). According to test of the normality our data follow normal distribution (Table 8, Fig. 8).

Values in bold correspond to tests where the null hypothesis cannot be accepted with a level of significance alpha = 0.05

Table 8. Summary of normality tests for all dependent variables

Modality	p-value
Platanus	0.240
Morus	0.141
Ligustrium	0.887
Nerium	0.916

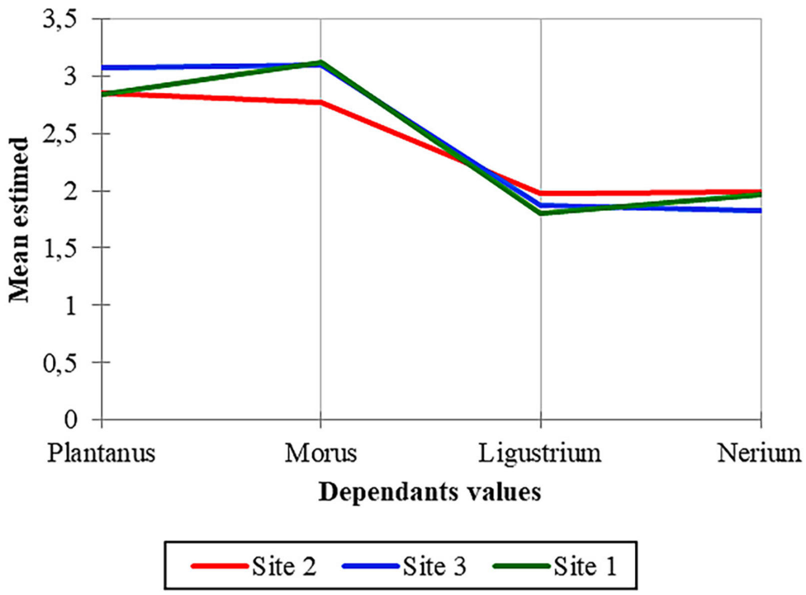

Figure 7. Variation in the average content of the MF/MS ratio according to the species in different sites

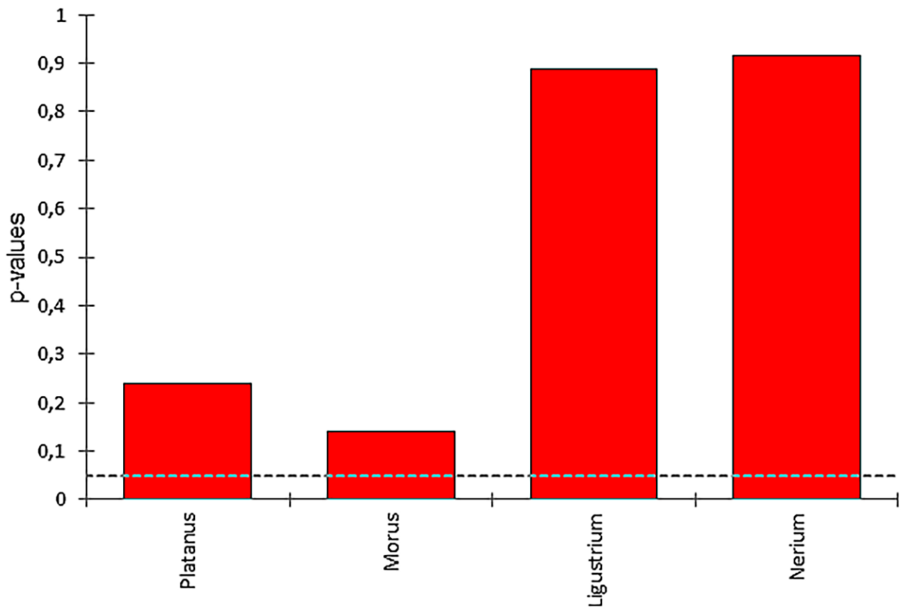

Figure 8. Summary of normality tests from the set dependents variables of FM/DM ratio

Table 9. Linear regression test of FM/DM ratio of the species

Parameter	Platanus	Morus	Ligustrium	Nerium
R^2	0.706	0.549	0.612	0.856
F	10.804	5.486	7.083	26.770
$Pr > F$	0.004	0.028	0.014	0.000
Sites	10.804	5.486	7.083	26.770
	0.004	0.028	0.014	0.000

Table 10. Test of the differences in the modalities at 95% of confidence interval

Parameter	Platanus	Morus	Ligustrium	Nerium
Site 2	2.849 a	2.775 a	1.980 b	1.983 b
Site 3	3.073 b	3.094 b	1.875 ab	1.821 a
Site 1	2.845 a	3.118 b	1.803 a	1.961 b
$Pr > F$(Model)	0.004	0.028	0.014	0.000
Significatif	Oui	Oui	Oui	Oui
$Pr > F$(Sites)	0.004	0.028	0.014	0.000
Significatif	Oui	Oui	Oui	Oui

Accordin the p-value our information provided is significantly better compared to what would explain the average of the dependent variable alone.

Statistical analysis reveals that the FM/DM ratio is low in Ligustrium and Nerium leaves, whereas we have recorded high values in the Platanus and Morus leaves (Table 10).

Toxicity of a pollutant can give rise, depending on the case, to specific symptoms visible on the surface such as necrosis, spots, etc., and alter certain physiological functions of the plant. The fresh matter/dry matter ratio (FM/DM) is one of the indicators of plant health in a given region. Indeed, the healthier the air, the more normal the development of the plant (the gravity of the fresh matter is normal); on the other hand, if the air is degraded, the evolution of the plant is disrupted, leading to chlorosis, necrosis, etc., to detriment of the fresh material (Belouahem, 1993). Values obtained from the FM/DM ratio for the plane tree are close to those found by Maatoug et al. (2007) during work carried out on the detection of air pollution by plane trees and cypresses for the city of Tiaret. The comparison of the values of the FM/DM ratio for the four species (Nerium, Ligustrium, Plantanus, and Morus), sampled in the city of El Eulma, with those measured by Maatoug et al. (2007) in control sites (which are far from any source of air pollution contamination) shows that the ratio is low compared to the control. This shows that these species are affected by pollution.

Several studies indicate that vegetation reduce dust from the ambient environment by leaf surfaces morphologycal characteritics. This propreties is more important in woodland vegetation than in shrub and grass land (Fowler et al., 1989; Bunzl et al., 1989). Excess of dust may is advantage of stomatal closure and consequently a decline ofphotosynthesis (McDowell et al., 2008; van der Molen et al., 2011). This paper indicate that low values of NPCI in the study area are significant of low productivity of plants due to dust deposition on plant leaves.

CONCLUSION

Air pollution affects biodiversity in various forms at the level of species, plant communities and ecosystems. Our results show, contrary to the tests carried out in this field by the quality control laboratories of industrial discharges, that dust has a negative effect on photosynthesis. The fresh matter/dry matter ratio (FM/DM) is a good parameter of air quality in the investigation town. The values obtained for the FM/DM ratio are low for the leaves of Ligustrium and Nerium, which are the most affected during this period, compared to the leaves of Plantanus and Morus. This was explained by the very important dust accumulated in their leaves reducing the photosynthetic of these specie.

Acknowledgements

The authors are thankful to Ferhat Abbas Setif 1 University, Algeria for providing necessary facilities.

REFERENCES

1. Babacar, M. 1998. La diffusion des métaux lourds autour du site des Chènevières (Genève. Visualisation des mesures sur la feuille de chêne. Ed Office Fédéral de l’Environnement, des Forêts et du Paysage (OFEFP).
2. Belouahem, D. 1993. Détection de la pollution atmosphérique fluorée d’origine industrielle à l’aide de certaines espèces végétales bioaccumulatrices dans les régions de Annaba et Taraf. Thèse de Magister. INA.
3. Berrayah, M., Maatoug, M., Azzaoui, M., Diallo, O., Sidibé, A., Manaa, K.H. 2016. Biosurveillance De La Qualite De L’air D’un Milieu Urbain Par Des Mousses Et Des Lichens. Cas De La Ville De Tlemcen (Algerie). European Scientific Journal, 12(9), 1857–7881.
4. Bunzl, K., Schimmack, W., Kreutzer, K., Schierl, R. 1989. Interception and retention of Chernobyl-derived 134,137Cs and 100Ru in a spruce stand. Sci. Total Environ., 78, 77–87.
5. Carvalho-Oliveira, R. 2017. Efectiveness of trafc-related elements in tree bark and pollen abortion rates for assessing air pollution exposure on respiratory mortality rates. Environ. Int., 99, 161–169.
6. Duran Rivera, B., Alzate Guarin, F., 2009. Intercepción de partículas suspendidas totales (PST) por cinco especies de árboles urbanos en el Valle de Aburrá. Rev. Fac. Ing. Univ. Antioq., 47, 59–66.
7. Fowler, D., Cape, J.N., Unsworth, M.H. 1989. Deposition of atmospheric pollutants on forests. Philos. Trans. R. Soc. A., 324, 247–265.
8. Janhall, S. 2015. Review on urban vegetation and particle air pollution – deposition and dispersion. Atmos Environ., 105, 130–137.
9. Jerry, L., Hatfield, A., John, H., Prueger, A. 2010. Agricultural Crop Characteristics at Different Growth Stages under Varying Management Practices. Remote Sensing., 2, 562–578. DOI: 10.3390/rs2020562
10. Liang, Y., Urano, D., Liao, K., Hedrick, T.L., Gao, Y., Jones, A.M.A. 2017. Nondestructive method to estimate the chlorophyll content of Arabidopsis seedlings. Plant Methods., 13, 1–10.
11. Maatoug, M., Medkour, K., Ait Hammou, M., Hellal, B. 2010. Cartographie de la pollution atmosphérique par le plomb d’origine routière à l’aide de transplantation d’un lichen bio-accumulateur *Xanthoria parietina* dans la ville de Tiaret (Algérie). Pollution atmosphérique, 205, 93–101.
12. McDowell, N., Pockman, W.T., Craig, D.A., Breshears, D.D., Cobb, N., Kolb, T., Plaut, J., Sperry, J., West, A., Williams, D.G., Yepez, E.A., 2008. Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought? New Phytol., 178, 719–739.
13. Merzlyak, M.N., Gitelson, A.A., Chivkunova, O.B., Rakitin, V.Y. 1999. Non-destructive optical detection of leaf senescence and fruit ripening. Physiol. Plant., 106, 135–141.
14. Montes-Pulido, C.R. 2014. Uso de rasgos funcionales de plantas como estimadores de carbono almacenado en biomasa aérea. Rev. Investig. Agrar. Ambient., 5, 237–243.

15. Pesch, R., Schroeder, W. 2006. Mosses as bioindicators for metal accumulation: Statistical aggregation of measurement data to exposure indices. Ecological Indicators, 6(1), 137–152.
16. Prajapati, S.K., Tripathi, B.D. 2008. Seasonal variation of leaf dust accumulation and pigment content in plant species exposed to urban particulates pollution. Journal of Environmental Quality, 37, 865–870.
17. Rahali, M. 2003. Etude de la pollution plombique et globale dans la région d'Alger, en utilisant les lichens comme indicateur biologiques. Thèse de doct Institut National d'Agronomie (Alger).
18. Rodríguez-Alarcón, S.J., Pinzón-Pérez, L., López-Cruz, J., Cabrera-Amaya, D. 2020. Rasgos funcionales de plantas leñosas en áreas verdes de Bogotá, Colombia. Biota Colomb., 21, 108–133.
19. Semadi, A., Deruelle, S. 1993. Détection de la pollution plombique à l'aide de transplants lichéniques dans la région d'Annaba (Algérie). Pollution atmosphérique Octobre-Décembre, 1993, 86–101.
20. Shihong, C. 2015. Biological Monitoring of Air Pollutants and Its Influence on Human Beings. The Open Biomedical Engineering Journal, 9, 219–223.
21. Singh, S.N., Verma, A. 2007. Phytoremediation of air pollutants: a review. In: Singh SN, Tripathi RD, editors. Environmental bioremediation technologies. Berlin, Heidelberg: Springer, 293–314.
22. Van Der Molen, M.K., Dolman, A.J., Ciais, P., Eglin, T., Gobron, N., Law, B.E., Meir, P., Peters, W., Phillips, O.L., Reichstein, M., Chen, T., Dekker, S.C., Doubkova, M., Friedl, M.A., Jung, M., van den Hurk, B.J.J.M., de Jeu, R.A.M., Kruijt, B., Ohta, T., Rebel, K.T., Plummer, S., Seneviratne, S.I., Sitch, S., Teuling, A.J., van der Werf, G.R., Wang, G. 2011. Drought and ecosystem carbon cycling. Agr. Forest. Meteorol., 151, 765–773.
23. Vergriete, Y., Labrecque M. 2007. Rôles des arbres et des plantes grimpantes en milieu urbain : revue de littérature et tentative d'extrapolation au contexte montréalais, janvier 2007. Conseil Régional de l'environnement de Montréal.
24. Yoshio, I., Martine, G., Frédéric, B., Andrew, S., Anatoly, G., Martin, S., Roshanak, D., Albert, O. 2016. Simple and robust methods for remote sensing of canopy chlorophyll content: a comparative analysis of hyperspectral data for different types of vegetation. Plant Cell Environ., 39, 2609–23.