ZANCO Journal of Pure and Applied Sciences
The official scientific journal of Salahaddin University-Erbil
https://zancojournals.su.edu.krd/index.php/JPAS

ISSN (print):2218-0230**, ISSN (online):** 2412-3986**, DOI: http://dx.doi.org/10.21271/zjpas**

RESEARCH PAPER

Biomonitoring of airborne heavy metals using *Brachychiton populneus (Schott & Endl.) leaves*

Halmat A. Sabr

Department of Forestry, College of Agricultural Engineering Sciences, Salahaddin University-Erbil, Kurdistan Region, Iraq

A B S T R A C T:
Trees growing close to emission sources have higher metal concentrations in their leaves, which is an indication of how polluted these location are. Additionally, the accumulation of heavy metals such as Fe, Zn, Cu, Cd, and Pb in various tree species has increased as a result of industrial and mining operations. The aim of the present study was to use *Brachychiton populneus (Schott & Endl.)* tree leaves as biomonitor to evaluate air pollution of Erbil city. Samples were collected from 6 different locations. Chlorophyll content, stomata number and heavy metals in leaves were determined. The result of the present study indicated that the highest mean of chlorophyll content was recorded for control (42.76), while there was not significant effect of pollution from traffic density was recorded for location 5. Non significant effect of roadsides of stomata density was observed in leaves. Surprisingly locations 2 showed that the leaves accumulated the lowest concentration of heavy metals as compare to control location. In addition, long side roads and parks, and the study species can has the capacity to accumulate the atmospheric pollution. As an alternative to other an expensive approaches thus may play an essential part in monitoring pollution of Erbil city. Finally the measurement characteristics may be employed as a bioindicator. It is also recommended to apply air pollution tolerance index (APTI) to determine suitability for selection of tree species as biomonitor and green belt plantations.

KEY WORDS: *Airborne heavy metals, Brachychiton populneus, Chlorophyll content, Heavy metal accumulation, Leaves, Stomata density*
DOI: http://dx.doi.org/10.21271/ZJPAS.35.6.18
ZJPAS (2023) , 35(6);179-188

1.INTRODUCTION :

Brachychiton populneus (Schott & Endl.) belongs to Sterculiaceae family which is naturally an Australian genus. It is recognized as a native to southern Queensland to Victoria which has a commonly distribution (Guymer, 1988). It is straightforward to propagate for seedling production and owing many interesting facial appearance. The species is an evergreen with a moderate size, widely canopy with 10–20 m in tree height, usually with a solid trunk. It is extensively planted in Erbil city as an ornamental tree. Contrasting the organic materials, heavy metals which are giving thought to as industrial contaminants therefore, they can accumulate in the living organisms (Yabanli et al., 2014). In terms of the preferred minerals concentration the toxicity can be defined. It is well recognized that heavy metals found in the soil at low levels nevertheless owing to pollution occurring from a variety of human activities and natural disasters (Omaka et al., 2014).

It is known that air pollution is a critical problem in many urbanized regions in the world (Kambezidis et al., 1996). In general, rural areas have lower pollution than metropolitan areas (Sawidis et al., 2001). Metropolitan soils located surrounded by the suburban and marginal farmlands are a key part of urban ecological system which takes part in an important role in the urban people. Green areas provide different ecological and regulating services inside urban settings such as decreasing air temperature, carbon storage, air pollution improvement and

* **Corresponding Author:**
Halmat A. Sabr
E-mail: halmat.sabr@su.edu.krd or halmat.forest86@gmail.com
Article History:
Received: 01/05/2023
Accepted: 04/06/2023
Published: 15/12 /2023

hydrological quality. Due to a rapid increase of urbanization and industrialization these areas are influenced by a wide array of materials that can cause air contamination.

Vehicle emissions lead an increase in heavy metals; particul plant metabolism ate matter and aerosols in the city roadway environment. Viskari et al., (2000) stated that motor vehicle exhausts air pollutants which have both direct and indirect impact on the metabolism plant roadsides for that reason, planting trees in cities are essential part for the citizens, but may also be exposed to danger for pollution (Pourkhabbaz et al., 2010). Heavy metals precipitation on soil and vegetation may affect morphology and physiology of leaves, as well as may prohibit metabolic processes and many enzyme systems (Kabata-Pendias, 1986). High concentrations of heavy metals may injure plants directly through preventing photosynthesis process, reducing growth, damaging roots, and eventually, reasoning plant death in urban soils (Kabata-Pendias, 2000).

Many researches performed in different areas of the world proved that heavy metal pollution in urban soils has been aggravated in extent during the last decades (Gu and Gao, 2018 and Kabata-Pendias, 2000). A study conducted by Rate (2018) that contamination in urban soils by cadmium is intense in Australia and Asia. In addition, heavy metal concentrations of zinc, lead and copper were within the pollution normal range in both of Mexico and Italy (Tang et al., 2019). Many authors have recommended by the use of bio-indicators for assessing and monitoring of air pollution in the period of the last decade (Brighigna et al., 1997).

The majority techniques used for air pollution monitoring are not capable to assess the assimilates exhibition influences on the organism of all kinds of air pollutants, however as an alternative supply only a physico-chemical suggestion about the explanation to an individual pollutant (Falla et al., 2000). Assessment of various plant species as potential bio-indicators typically consists of plant restraints to heavy metal exposition thus heavy metals in the soil are more than normal range in charge for the decreased chlorophyll content in leaves of the present plants in polluted locations (Baycu et al., 2006). Furthermore, it may be get involved in the chlorophyll procedure biosynthesis in the photosynthetic membranes (Chettri et al., 1998).

It is well understood that air pollution effect on stomata parameters (Alves *et al.*, 2008), may be well thought-out as essential characters in plants alter in morphology and density of stomata on a leaf surface (Bettarini et al., 1998). The impact of individual atmospheric gases on stomatal traits is commonly recognized by Elagoz *et al.*, (2006) and is dependent of the gaseous pollutant taking into consideration (Larcher, 2003). Additionally, there is not present study on response of *Brachychiton populneus* toward heavy metal accumulation in Erbil city due to this species is broadly planted in road sides, parks and near traffic densities. Therefore, the present study is aimed to find out using indentified species as a bioindictor for monitoring and assessing of heavy metals planted in different areas of Erbil city based on changing in leaf traits.

2. MATERIALS AND METHODS

2.1. MATERIALS

2.1.1 Leaf sampling collection:

The samples were collected from six locations during September 2022 in Erbil city. During the period of sampling, Garmin global position system (GPS) tool was used to determine the accurate locations, elevation and geographical coordinates (latitude and longitude) (table1). Tree sampled at each of the six locations: L1 (Shanadar park) as a control, L2 (Halabja road), L3 (Hadi chawshli road), L4 (New Zanko village road), L 5(120m highway road) and L6 (Nawroz road) (Figure 1). Leaves were sampled from *Brachychiton populneus* which is an evergreen tree widespread in the area. Samples were collected from same aged trees. Leaves were taken from about 1.5-2 m height. 20-25 fully matured leaves were collected randomly from all sides of a crown in each location. Directly after the sampling, the leaves were put down in plastic paper envelopes and transported to the laboratory.

Table 1: Coordinate system of the studied locations.

Location	N	E
L1	36.182381	44.002217
L2	36.181511	44.0038
L3	36.161347	44.01275
L4	36.138422	44.023083
L5	36.136992	43.997111
L6	36.16455	43.972239

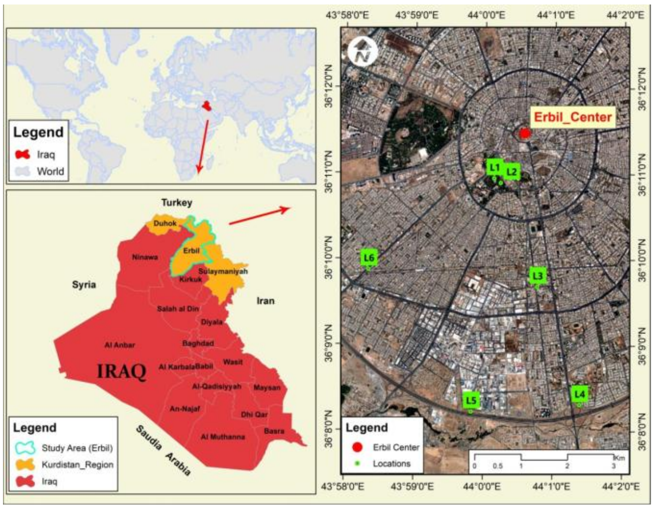

Figure 1: study locations of leaf samples.

2.2 Chlorophyll content:

atLEAF chlorophyll meter STD handle was used to measure total chlorophyll content in the leaves. The chlorophyll content is only measured by insertion the mature leaf into the space of the device as recognized by Mendoza-Tafolla et al., (*2019*).

2.3 Stomata density:

Clear nail varnish were used to paint the surface layer of the collected leaves, samples were let to dry, after that forceps was used to strip off the nail varnish, therefore they were laid on a dry microscope slide in order to examine leaf stomata density per cm^2.

2.4 Heavy metal concentrates (mg kg^{-1}):

All samples were dried at 65°C for 48 hours and then crushed to consistent size with a laboratory grinder, after that packed in plastic can and kept under constant laboratory conditions proceeding to chemical analysis. The grinder was carefully cleaned after each grind to keep away from any irritated contamination. After drying, sieving by 2mm and powdering of the material. Samples were analyzed by XRF (X-Ray Fluorescence analyzer) method and metals were measuring by portable (CIT-300 SMP) as documented by Sitko et al., (2004), in a laboratory College of Sciences-Salahaddin University.

2.5 Data analysis:

All measurements were evaluated statistically by using of SPSS software version 25. Duncan's Multiple Range post-hoc Test was used for comparison means of the studied parameters between sampling locations.

3. RESULTS AND DISCUSSION

3.1. Chlorophyll content and Stomata density:

The Table 2 indicates differences in changing chlorophyll content per leaf of selected tree species depicted to air pollution road sides and non polluted locations (control). It is found that this species showed a significant reduction in chlorophyll content in all locations except location 2 which was not significant as compared to control location. The highest mean was recorded for control (42.76), while there was no significant effect of pollution along roadsides or traffic density was recorded for location 5. In addition, a maximum decrease in chlorophyll content was observed in location 4 which was (30.71).

Based on polluted locations a variation in chlorophyll was found to be more significant in location 2 (36.78) and the rest of polluted areas. The data observed in table 2 explain that stomata numbers in the lower part leave epidermis of *Brachychiton populneus* tree was not significantly decreased in all locations. Surprisingly the highest mean numbers of stomata were found in polluted locations especially in location 5 and 3 Table (2).

Generally, *Brachychiton populneus* tree gave an idea about a reduction in total chlorophyll and no significant effect was observed in stomata density, but a decrease may be owing to air pollution or heavy traffics. An intense effect on the concentration of photosynthetic pigments can be in possession by air pollutants (Giri et al., 2013). Chloroplast that is the main productivity of which contains the photosynthetic pigments chlorophyll in green leaves of plants, thus chlorophyll takes part in an important function in plant metabolism (Karmakar et al., 2021).

According to Rai (2016) that the plant growths are straightly quantify by chlorophyll content concentration in leaves. The finding of the present study is in accordance with other works such as a study by Karmakar et al., (2021) that out of eighteen tree species only four of the studied species showed a positive response to air pollution the species include *Ziziphus mauritiana* Lam. *Artocarpus heterophyllus* Lam., *Mangifera indica* L and *Mimusops elengi* L. The level of pollution, the age of the leaves, and other biotic and abiotic factors such as temperature, water stress, and irradiance intensity all together influence the amount of chlorophyll in green plants. From one species to another the amount of chlorophyll in plant are different (Banerjee et al., 2018).

Plants are identified to be tolerant species because they are capable to sustain their chlorophyll concentrations in contaminated environments (Singh and Verma, 2007). From the perspective of maintaining chlorophyll content the studied trees in location (5) can be known as a tolerance trees but for location (4) trees were sensitive to high density of vehicles. Furthermore, Owing to the increasing levels of contaminants there has been diminishing in the production of chlorophyll and an increase in its degradation (Sandelius et al., 1995). In the work by Tripathi and Gautam (2007) species such as *Mangifera indica*, Linn., *Cassia fistula*, Linn., and *Eucalyptus hybrid* showed a decrease in chlorophyll content when were depiction to different air pollution. Other researchers found a significant decrease in leaves chlorophyll concentration such as Joshi and Swami (2007). In addition, the same result was also observed on leaves of conifer tree Aleppo pine **(***Pinus hallepensis* Mill) by Bacic and Ledic (1992). Ahmed and Sabr (2020) found a negative effect of air pollution from roadsides on chlorophyll content in leaves of *Platanus orientalis* L.

It is shown in table 2 that no significant effect of location with vehicle density on stomata number. Measuring stomata is one of the important measurements for monitoring and assessing air pollution. For the studied species stomata was observed in the lower part of epidermis. Due to there is no present study and updated data about this measurement in any location of Erbil city. This species is widely planted along roadsides. Many researchers reported that the location and density of these microscopic structures on the leaves surface are adjusted to various environmental stresses.

The rates of gas exchange between the atmosphere and leaf internal can be restrained in green plants through adjustment of stomata pore aperture (Kollist et al., 2014). In addition, stomata conductance is a process which is controlled by stomata aperture this mechanism can be enhanced via increasing in guard cell turgor pressure. A study on a perennial woody species *Eugenia uniflora* L. by Alves *et al.,* (2008b) in Brazil found that a significant increase in number of stomata was observed in metropolitan area as compare to countryside locations.

The regulation of gas exchange (gs) generally and the entry of pollutants via stomata especially can be best modified by increasing stomatal density and reducing stomatal size Alves *et al.*, (2008a). Given that it is simple to take and facilitates the merging of frequently differing findings of stomatal density, it is a useful feature. Also, it is this stomatal resistance that will affect how pollutants are exchanged between the atmosphere and the inside of the leaf (Kardel *et al.,* 2010). Regardless of the fact that stomatal responses to air pollution are complicated, differ between species, may be dependent on the age of the leaf and plant, and are a combination with other environmental stressors (Paoletti and Grulke, 2005).

Additionally, the stomata density is mainly responsible for the connection between the atmosphere and green plants. For that reason, stomata are good since they incorporate with air quality indicators. It is useful to assess the biomonitoring potential of *B. populneus* in other locations that the one studied such as climate pattern, temperature, drought stress need to be sought out, but this tree species is widely distributed in Erbil city and other cities.

Table 2: Total chlorophyll and stomata density in different locations.

Locations	Total Chlorophyll content	Stomata density in cm^2
L1	42.76 ± 8.31 a	42.66± 4.04 a
L2	36.78 ± 4.01 bc	44.33 ± 0.70 a
L3	34.62 ± 2.46 cd	45.33 ± 0.707 a
L4	30.71 ± 7.63 d	48.00 ± 9.14 a
L5	40.63 ± 2.94 ab	51.50 ± 2.0 a
L6	33.85 ± 4.86 cd	45.33± 13.61 a

Duncan's Multiple Range post-hoc Test was used for comparison means of the sampling locations. Means values with the same letters are not significantly different at 0.01% level.

3.2 Leave heavy metal concentration:

Heavy metals content of Lead (Pb), Manganse (Mn), Zinc (Zn), Copper (Cu), Cadmium (Cd), Silver (Ag) in leaf samples from studied tree species was indicated in Table 2. It was shown that samples of tree species had different Pb content and ranged from 91 (ppm) for location 4 to 63.3 (ppm) (Figure 2). In addition, particularly a higher accumulation of Mn was observed in location 6, but a lower concentration of this metals was obtained in location 2 (Figure 3). *Brachychiton populneus* tree could have a conforming with generally accepted ability to accumulate Zn in leaves as showed with a lower content 21.1ppm in location 2 as compare to location 5 that leaves in this location contained more 55 mg kg^{-1}. It is observed that for leaf samples were collected that the lowest concentration of both Cu and Cd were found in control location in comparison to location 4 and location 3 (Figure 5and 6).

The rate of heavy metal content in collected leaf samples of Ag was higher in location 5 but, for location 2 no determination of Ag in leaves was found Figure 7. Generally, according to Markert (1993) that the following concentration ranges in leaves are characteristically regarded as toxic level for example, Pb: 3–20 mg g1 dry weight; Zn: >200 mg g1; Cu: >20 mg g1; and Cd: >10 mg g1.based on above classification that the highest content of both Pb and Cu were found in location 4. On the other hand, Cd concentration was higher than the normal range in all studied locations Table 2. Is it also found that the 0 concentration of Ag in location 2. In such tree species, related investigations have identified copper, manganese, and zinc, however, at lower amounts, and have generally reported similar findings (Nagajyoti *et al*., 2010). On the other hand, another work by Al-Obaidy *et al*., (20116) studied the impact of Zn concentration in two types of Eucalyptus tree (*E. microtheica* and *E. camaldulensis.*

The present study reveal their results demonstrated that lead content was higher than the world average of unpolluted soils. A good number of studies in the past are available information on accumulation of both Cd and Zn elements in many tree species resulting from short-term hydroponic or pot experiments with young plants (Pulford and Dickinson, 2005). According to this work screening of mature tree of *B. populneus* can accumulate significant quantities of heavy metals in aerial tissues, especially in leaves. This is a significant result for the long-term management of phytoextraction process since it suggests that when the researched species are applied, high levels of heavy metal concentration can be anticipated during the remediation period.

At any given location, it is likely that variations in the soil's characteristics will affect how plants absorb metals, although the climate and other environmental elements can be thought of as being largely constant. The concentration of all metals, pH, and organic matter are the main factors affecting metal solubility and bioavailability in soils (Adriano, 2001). Arbuscular mycorrhizal (AM) inoculation is known to reduce the abiotic stress of heavy metals in plants (Hildebrandt *et al.*, 2007). Al-Karaki *et al.*, 2013 confirmed that an application both of phosphor P fertilization and AM inoculation of plants considerably enhanced the growth of green plant in soils contaminated with heavy metals. The previously mentioned researchers came to the conclusion that application of p supplementation is the principal way that Arbuscular mycorrhizal fungi promote plant resistance to heavy metal stressors.

The accumulation of various compatible osmolytes and alter in hormone levels are non-nutritional mechanisms by which AM fungi increase plant tolerance to other abiotic stress, such as water stress. Other mechanisms include a delay in soil drying, an improvement in hyphal soil, an increase in photosynthetic rate, and changes in soil water status (Abu-Elsaoud *et al.*, 2017). Is it expected from the present study that no determination of Ag in leaves of location 2 may be due to Immobilization of heavy metals in mycorrhizal structures as documented by Birhane *et al.*, (2012).

Table 3: Leave heavy metal content in different locations (mg.kg^{-1} dry weight).

Leave heavy metal concentration (mg kg^{-1} dw)	L1	L2	L3	L4	L5	L6
Lead (Pb)	67.1	68.8	63.3	91	76	74.1
Manganse (Mn)	27.5	9.4	26.3	20.1	22.9	49
Zinc (Zn)	36.7	21.1	42.1	36.6	57.6	36.9
Copper(Cu)	7.1	23.4	27	38.8	18.1	27.9
Cadmium(Cd)	13.4	13.4	11.3	11.7	13.3	12.1
Silver (Ag)	115.9	0	80.8	99	168.5	116.6

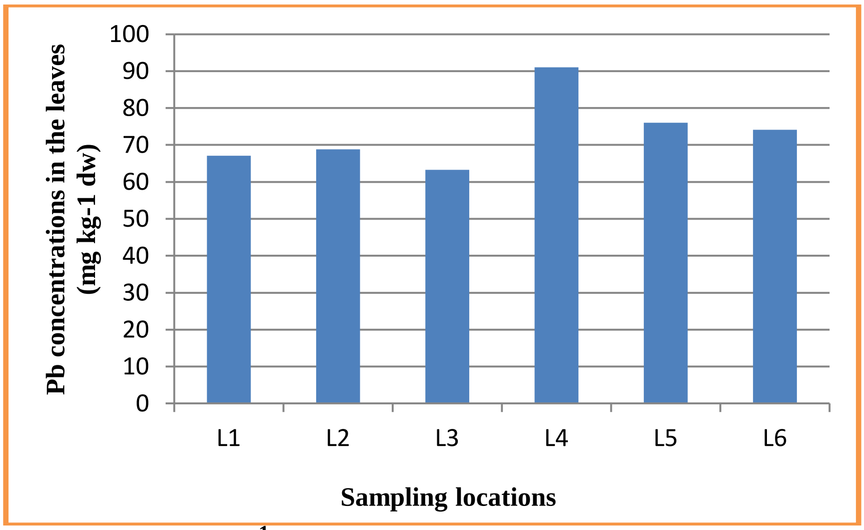

Figure 2: Lead concentration (mg kg^{-1} dw) in leaves of *Brachychiton populneus* in different locations.

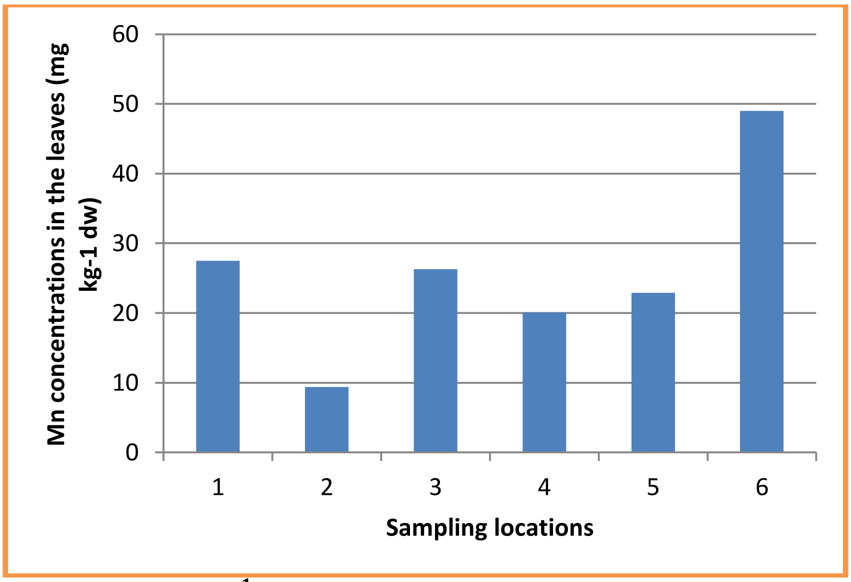

Figure 3: Mn concentration (mg kg^{-1} dw) in leaves of *Brachychiton populneus* in different locations.

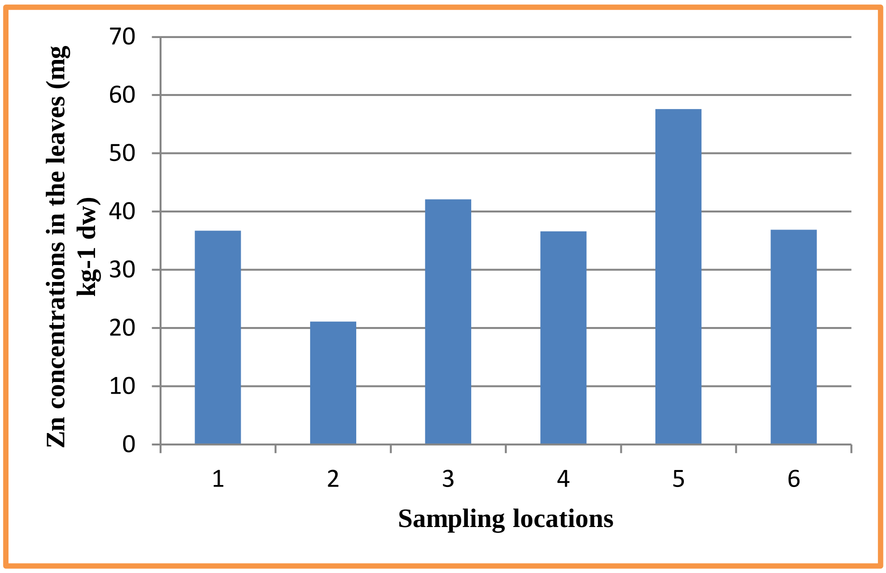

Figure 4: Zn concentration (mg kg^{-1} dw) in leaves of *Brachychiton populneus* in different locations.

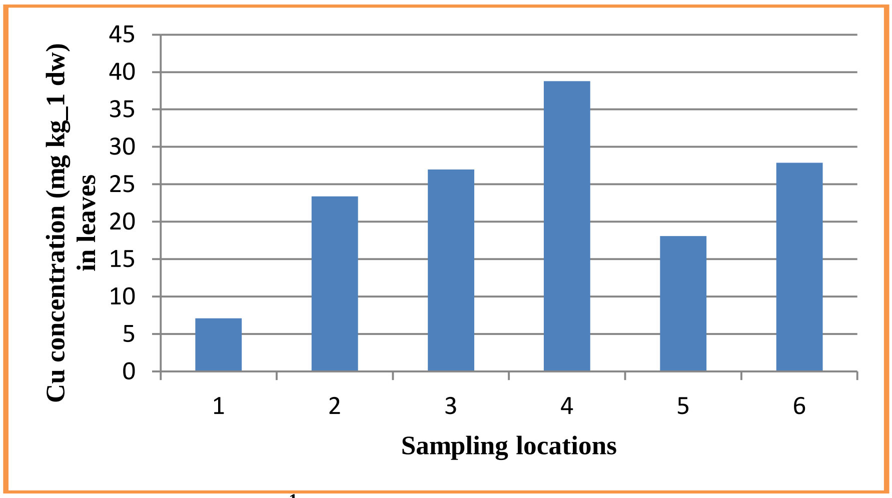

Figure 5: Cu concentration (mg kg^{-1} dw) in leaves of *Brachychiton populneus* in different locations.

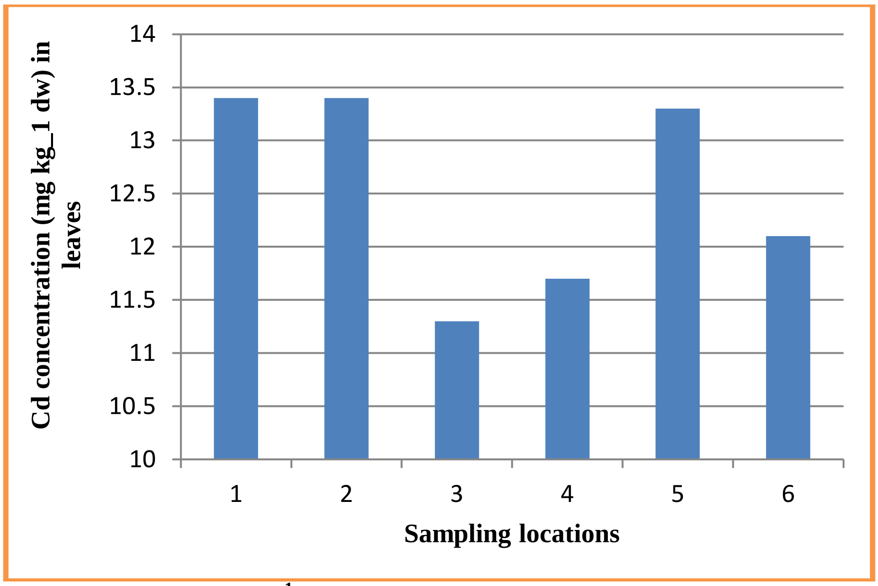

Figure 6: Cd concentration (mg kg^{-1} dw) in leaves of *Brachychiton populneus* in different locations.

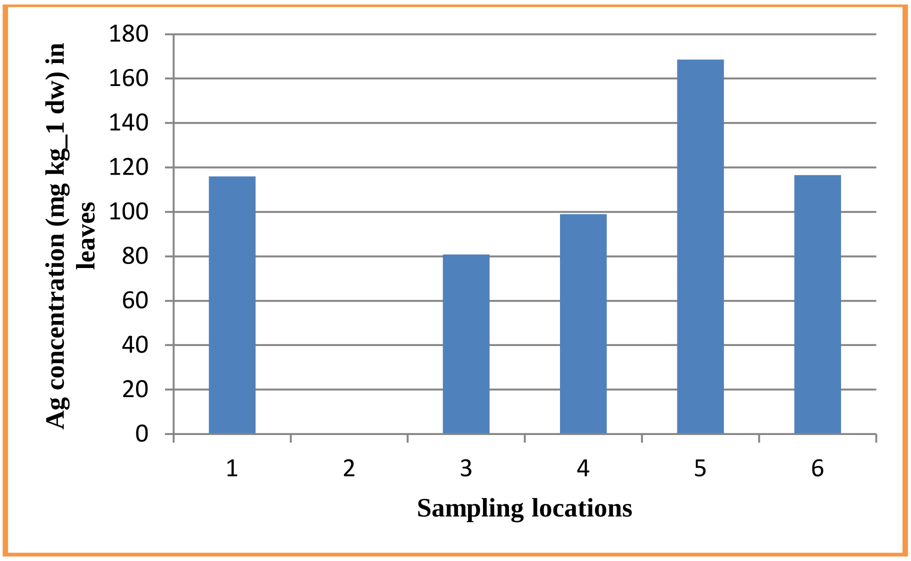

Figure 7: Ag concentration (mg kg^{-1} dw) in leaves of *Brachychiton populneus* in different locations.

4 CONCLUSIONS

Chlorophyll content and heavy metal concentration in leaves of *B. populneus* were measured. Stomata density of collected samples was increased in all locations. It is an evergreen tree that may be planted successfully as an attractive tree near roads and parks, and it has the ability to gather atmospheric pollution. This trait could be used as a bioindicator as an alternative to more expensive methods that are crucial in monitoring and evaluating pollution. Researching the root causes of air pollution's effects on the ecosystem, educating the public about this serious environmental issue, and disseminating brochures in local communities are all strategies to deal with the issue. Finding out the range of pollution levels in various study regions is another significant aspect of the study.

ACKNOWLEDGEMENTS

The Author acknowledges with many thanks to Forestry department, college of Agricultural Engineering Sciences for providing a location to conduct a study.

CONFLICT OF INTEREST (1)

REFERENCES

BABA, S. A. & MALIK, S. A. 2014. Evaluation of antioxidant and antibacterial activity of methanolic extracts of Gentiana kurroo royle. *Saudi J Biol Sci,* 21**,** 493-8

ABU-ELSAOUD, A. M., NAFADY, N. A., & ABDEL-AZEEM, A. M. (2017). Arbuscular mycorrhizal strategy for zinc mycoremediation and diminished translocation to shoots and grains in wheat. *PLoS One*, *12*(11), e0188220.

ADRIANO, D.C., 2001. Trace Elements in the Terrestrial Environment. Biogeochemistry, Bioavailability and Risks of Metals, second ed. Springer, New York.

AHMED, I. T., & SABR, H. A. (2020). Response of Plane Tree (*Platanus orientalis* L.) toward Environmental Pollution of Erbil City. *Zanco Journal of Pure and Applied Sciences*, *32*(6), 150-157.

AL-KARAKI, G.N., 2013. The role of mycorrhiza in the reclamation of degraded lands in arid environments. Developments in soil classification, land use planning and policy implications: Innovative thinking of soil inventory for land use planning and management of land resources, pp.823-836.

AL-OBAIDY, A. H. M., MAHMOD, M. A., & AL-MASHHADY, A. A. (2016). Efficiency of *E. microtheica* and *E. camaldulensis* Tree to Remove Lead Element (Pb) from the Province of Baghdad Environment. *Engineering and Technology Journal*, *34*(3 Part (B) Scientific).

ALVES, E.S., MOURA, B.B., DOMINGOS, M., 2008a. Structural analysis of *Tillandsia usneoides* L. exposed to air pollutants in Sa˜o Paulo city-Brazil. Water Air Soil Pollution 189, 61–68.

Alves, E.S., Tresmondi, F., Longui, E.L., 2008b. Leaf anatomy of *Eugenia uniflora* L. (Myrtaceae) in urban and rural environments, Sao Paulo State, Brazil. *Acta Botanica Brasilica* 22, 241–248.

BACIC, T. AND LEDIC, A., 1992. Changes of pigments content in needles of Pinus halepensis Mill. *Acta Biologica Cracoviensia. Series Botanica*, (34-35).

BALASOORIYA, B.L.W.K., SAMSON, R., MBIKWA, F., VITHARANA, W.A.U., BOECKX, P., VAN MEIRVENNE, M., 2009. Biomonitoring of urban habitat quality by anatomical and chemical leaf characteristics. *Environmental and Experimental Botany* 65, 386–394.

BAYCU, G., TOLUNAY, D., ÖZDEN, H. AND GÜNEBAKAN, S., 2006. Ecophysiological and seasonal variations in Cd, Pb, Zn, and Ni concentrations in the leaves of urban deciduous trees in Istanbul. *Environmental pollution*, *143*(3), pp.545-554.

BETTARINI, I., VACCARI, P., MIGLIETTA, F., 1998. Elevated CO2 concentrations and stomatal density: observations from 17 plant species growing in a CO2 spring in central Italy. *Global Change Biology 4*, 17–22.

BIRHANE, E., STERCK, F.J., FETENE, M., BONGERS, F. AND KUYPER, T.W., 2012. Arbuscular mycorrhizal fungi enhance photosynthesis, water use efficiency, and growth of frankincense seedlings under pulsed water availability conditions. *Oecologia*, *169*, pp.895-904.

BOZDOGAN SERT, E., TURKMEN, M., & CETIN, M. (2019). Heavy metal accumulation in rosemary leaves and stems exposed to traffic-related pollution near Adana-İskenderun Highway (Hatay, Turkey). *Environmental monitoring and assessment*, *191*, 1-12.

BRIGHIGNA, L., RAVANELLI, M., MINELLI, A., ERCOLI, L., 1997. The use of an epiphyte (*Tillandsia caput-medusae Morren*) as bioindicator of air pollution in Costa Rica. *The Science of the Total Environment* 198, 175–180.

CAMARGO, M.A.B. AND MARENCO, R.A., 2011. Density, size and distribution of stomata in 35 rainforest tree species in Central Amazonia. *Acta Amazonica*, *41*, pp.205-212.

CHETTRI, M.K., COOK, C.M., VARDAKA, E., SAWIDIS, T., LANARAS, T., 1998. The effect of Cu, Zn and Pb on the chlorophyll content of the lichens Cladonia convoluta and Cladonia rangiformis. *Environmental and Experimental Botany* 39 (1), 1e10.

DICKINSON, N.M., PULFORD, I.D., 2005. Cadmiumphytoextraction using short-rotation coppice Salix: the evidence trail. *Environment International* 31, 609e613.

DINEVA, S.B. 2004. Comparative studies of the leaf morphology and structure of white ash *Fraxinus americana L. and* London plane *tree Platanus acerifolia* Willd growing in polluted area. *Dendrobiology journal*, *52*, pp.3-8.

ELAGOZ, V., HAN, S.S., MANNING, W.J., 2006. Acquired changes in stomatal characteristics in response to ozone during plant growth and leaf development of bush beans (*Phaseolus vulgaris L.*) indicate phenotypic plasticity. *Environmental Pollution* 140, 395–405.

FALLA, J., LAVAL-GILLY, P., HENRYON, M., MORLOT, D., FERARD, J.F., 2000. Biological air quality monitoring: a review. *Environmental Monitoring and Assessment* 64, 627–644.

GIRI, S., SHRIVASTAVA, D., DESHMUKH, K. AND DUBEY, P., 2013. Effect of air pollution on chlorophyll content of leaves. *Current Agriculture Research Journal*, *1*(2), pp.93-98.

GU, Y.G. AND GAO, Y.P., 2018. Bioaccessibilities and health implications of heavy metals in exposed-lawn soils from 28 urban parks in the megacity Guangzhou inferred from an in vitro physiologically-based extraction test. *Ecotoxicology and Environmental Safety*, *148*, pp.747-753.

GUYMER, G.P. (1988). A taxonomic revision of *Brachychiton* (Sterculiaceae). Aust. Syst. Bot., 1(3): 199-323.

HILDEBRANDT, U., REGVAR, M., & BOTHE, H. (2007). Arbuscular mycorrhiza and heavy metal tolerance. *Phytochemistry*, *68*(1), 139-146.

JOSHI, P.C. AND SWAMI, A., 2009. Air pollution induced changes in the photosynthetic pigments of selected plant species. *Journal of Environmental Biology*, *30*(2), pp.295-298.

KABATA-PENDIAS, A., 2000. *Trace elements in soils and plants*. CRC press.

KABATA-PENDIAS, A., PENDIAS, H., 1986. Trace Elements in Soils and Plants. CRC Press Inc., Boca Raton, Florida.

KAMBEZIDIS, H. D., SAKELLARIOU, N. K., TOPALIS, F. B., KANELLIAS, A. A., & PETROVA, V. D. 1996. Air pollution monitoring with a passive pyrheliometric scanner. *Fresenius Environmental Bulletin*, *5*(11), 631-636.

KARDEL, F., WUYTS, K., BABANEZHAD, M., WUYTACK, T., POTTERS, G., & SAMSON, R. 2010. Assessing urban habitat quality based on specific leaf area and stomatal characteristics of Plantago lanceolata L. *Environmental Pollution*, *158*(3), 788-794.

KARMAKAR, D., DEB, K. AND PADHY, P.K., 2021. Ecophysiological responses of tree species due to air pollution for biomonitoring of environmental health in urban area. *Urban Climate*, *35*, p.100741.

KOLLIST, H., NUHKAT, M. AND ROELFSEMA, M.R.G., 2014. Closing gaps: linking elements that control stomatal movement. *New Phytologist*, *203*(1), pp.44-62.

LARCHER, W., 2003. Physiological Plant Ecology: Ecophysiology and Stress Physiology of Functional Groups, fourth ed. *Springer,* p. 437–450.

MARKERT, B., 1993. Plants as biomonitors.

MENDOZA-TAFOLLA, R.O., JUAREZ-LOPEZ, P., ONTIVEROS-CAPURATA, R.E., SANDOVAL-VILLA, M., IRAN, A.T. AND ALEJO-SANTIAGO, G., 2019. Estimating nitrogen and chlorophyll status of romaine lettuce using SPAD and at LEAF readings. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *47*(3), pp.751-756.

NAGAJYOTI, P. C., LEE, K. D., & SREEKANTH, T. V. M. 2010. Heavy metals, occurrence and toxicity for plants: a review. *Environmental chemistry letters*, *8*, 199-216.

OMAKA, N.O., OFFOR, I.F. AND EHIRI, R.C., 2014. Fe, Pb, Mn, and Cd Concentrations in Edible Mushrooms (*Agaricus campestris*) Grown in Abakaliki, Ebonyi State, Nigeria. *International Journal of Agricultural and Biosystems Engineering*, *8*(1), pp.84-88.

PAOLETTI, E., & GRULKE, N. E. 2005. Does living in elevated CO2 ameliorate tree response to ozone? A review on stomatal responses. *Environmental Pollution*, *137*(3), 483-493.

PICZAK, K., LES´NIEWICZ, A., Z´ YRNICKI, W., 2003. Metal concentrations in deciduous tree leaves from urban areas in Poland. *Environmental Monitoring and Assessme*nt 86, 273e287.

POURKHABBAZ, A., RASTIN, N., OLBRICH, A., LANGENFELD-HEYSER, R. AND POLLE, A., 2010. Influence of environmental pollution on leaf properties of urban plane trees, *Platanus orientalis* L. *Bulletin of environmental contamination and toxicology*, *85*(3), pp.251-255.

PULFORD, I.D. AND DICKINSON, N.M., 2005. 90 Phytoremediation Technologies Using Trees. *Trace elements in the environment: biogeochemistry, biotechnology, and bioremediation*, p.383.

RAI, P.K., 2016. Impacts of particulate matter pollution on plants: Implications for environmental biomonitoring. *Ecotoxicology and environmental safety*, *129*, pp.120-136.

RATE, A.W., 2018. Multielement geochemistry identifies the spatial pattern of soil and sediment contamination in an urban parkland, Western Australia. *Science of the Total Environment*, *627*, pp.1106-1120.

SANDELIUS, A.S., NÄSLUND, K., CARLSSON, A.S., PLEIJEL, H. AND SELLDÉN, G.U.N., 1995. Exposure of spring wheat (*Triticum aestivum*) to ozone in open-top chambers. Effects on acyl lipid composition and chlorophyll content of flag leaves. *New Phytologist*, *131*(2), pp.231-239.

SAWIDIS, T., CHETTRI, M.K., PAPAIOANNOU, A., ZACHARIADIS, A., STRATIS, J., 2001. A study of metal distribution from lignite fuels using tree as biological monitors. *Ecotoxicology and Environmental* Safety 48, 27e35.

SINGH, S.N. AND VERMA, A., 2007. Phytoremediation of air pollutants: a review. *Environmental bioremediation technologies*, pp.293-314.

SITKO, R., ZAWISZA, B., JURCZYK, J., BUHL, F. & ZIELONKA, U. 2004. Determination of High Zn and Pb Concentrationsin Polluted Soils Using Energy-Dispersive X-rayFluorescence Spectrometry. *Journal of Environmental Studies and Sciences*. 13(1): 91-96.

TANG, J., ZHANG, J., REN, L., ZHOU, Y., GAO, J., LUO, L., YANG, Y., PENG, Q., HUANG, H. AND CHEN, A., 2019. Diagnosis of soil contamination using microbiological indices: A review on heavy metal pollution. *Journal of Environmental Management*, *242*, pp.121-130.

TRIPATHI, A.K. AND GAUTAM, M., 2007. Biochemical parameters of plants as indicators of air pollution. *Journal of environmental biology*, *28*(1), p.127.

UNTERBRUNNER, R., PUSCHENREITER, M., SOMMER, P., WIESHAMMER, G., TLUSTOŠ, P., ZUPAN, M., & WENZEL, W. W. (2007). Heavy metal accumulation in trees growing on contaminated sites in Central Europe. *Environmental pollution*, *148*(1), 107-114.

VISKARI, E. L., & KÄRENLAMPI, L. (2000). Roadside Scots pine as an indicator of deicing salt use–a comparative study from two consecutive winters. *Water, Air, and Soil Pollution*, *122*, 405-419.

VOLENÍKOVÁ, M.; TICHÁ, I. 2001. Insertion profiles in stomatal density and sizes in *Nicotiana tabacum* L. plantlets. *Biologia Plantarum*, 44: 161– 16.

YABANLI, M., YOZUKMAZ, A. AND SEL, F., 2014. Heavy metal accumulation in the leaves, stem and root of the invasive submerged macrophyte Myriophyllum spicatum L.(Haloragaceae): an example of Kadin Creek (Mugla, Turkey). *Brazilian Archives of Biology and Technology*, *57*, pp.434-440.