Monitoring of Air Pollutants Using Plants and Co-Located Soil – Egypt: Characteristics, Pollution, and Toxicity Impact

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Monitoring of air pollutants using plants and co-located soil – Egypt: characteristics, pollution, and toxicity impact

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Highlights

- Characterization and monitoring of the air quality in terms of pollution and toxicity impact.
- The concentrations of 35 and 40 elements were determined using two analytical methods.
- Instrumental neutron activation analysis and atomic absorption spectrometer.
- The enrichment factor, pollution load index, potential ecological risk, risk index, and human and ecotoxicity were assessed.
Graphical abstract

Human toxicity and terrestrial ecotoxicity results including soil and vegetation
Monitoring of air pollutants using plants and co-located soil - Egypt: characteristics, pollution, and toxicity impact

Abstract:
The present work was conducted to characterize and monitor the air quality in terms of pollution and toxicity impact using two evergreen tree leaves, *Eucalyptus globulus* Labill and *Ficus benjamina* L as biomonitors. Thirty tree leaves and an equal number of co-located soil samples from different regions of Egypt (urban Greater Cairo Metropolitan GC and rural Menoufia Governorate MG) were collected. The concentrations of 34 and 40 elements were determined using instrumental neutron activation analysis and atomic absorption spectrometer. Bivariate and multivariate statistical analysis were implemented. The air pollution was assessed using enrichment factor, pollution load index, potential ecological risk, and risk index. In addition, human and ecotoxicity were evaluated based on the ReCiPe method. The mean concentration values of the obtained elements in tree leaves in urban Greater Cairo and rural Menoufia Governorate show that the major elements are slightly higher in *F. benjamina* than in *E. globulus*. Likewise, the mean values of elements in soil from Greater Cairo and Menoufia Governorate show no significant difference except for major elements (Fe, Al, Mg, K, Na, and Ti) in Menoufia Governorate. The normalized concentrations of tree species and soil show that the accumulated elements by *F. benjamina* is slightly higher than in *E. globulus* in Greater Cairo GC and Menoufia Governorate MG. While in terms of the investigated area, the concentrations of elements in MG is considerably higher than in GC. PLI spatial distribution over investigated areas showed that despite high population density, heavy traffic, and urban pollution, the Cairo samples exhibit significantly lower values as compared to those from Menoufia, which is most likely due to the uncontrolled industrial and domestic waste disposal outside Cairo. PER was significant for As in Soil and for As and Cd for tree species. Human toxicity shows higher values in urban locations. Contrariwise, in the terrestrial ecotoxicity aspect, the rural locations are much higher than in urban ones.

Keywords: Plants biomonitoring; INAA; AAS; pollution indices; toxicity impact

1. Introduction

Air pollution becomes one of the most serious problems caused by human activities. Air pollutants are made up of a mixture of gas, liquid, and solid compounds of the air and particulate matter (PM). They may cause adverse health effects in humans and affect plant life and cause detrimental changes in the atmosphere of the earth (Brunekreef and Holgate, 2002; Kampa and Castanas, 2008; Rai, 2016). Heavy metals can easily be linked to terrestrial food webs (Gall et al.,
They are steady in the environment and are dangerous in case of intake via different pathways (ingestion, inhalation, and dermal contact) by a human. The sources of pollution are dramatically increasing. For instance; processes of urbanization expansion, industrialization, and economic development (Acosta et al., 2015; Hassanien, 2011; Rai, 2016; Salim Akhter and Madany, 1993; Yekeen et al., 2016).

The quality of soil and plants is affected mainly by the growing demand for agricultural food due to population growth and urbanization (Shah et al., 2019). Heavy metals are accumulated in trees through the foliage, and it is considered the major pathway, specifically in polluted areas (Farahat, 2011). Trees are quite efficient in trapping atmospheric deposited particles. The utilization of tree leaves as biomonitors in accumulating metals has acquired great ecological and ecotoxicological importance (Farahat, 2011; Yalaltdinova et al., 2018). In the recent Anthropocene, a variety of urban and rural roadside trees is now increasingly recognized as an environmentally sustainable tool for monitoring and mitigating the effects of air pollution. The deposition of PM particulates in the foliar surface of tree leaves causes structural and functional changes in plants (Panda and Rai, 2015; Rai, 2016). Tree leaves as biomonitors are an accessible and inexpensive tool for the evaluation of atmospheric air deposition.

Some methods may also be utilized, such as moss and lichen. Because of their root system, they ultimately accumulate pollutants from the atmosphere, and the crustal association is minimal (Christensen et al., 2018; Steinnes, 1995; Steinnes et al., 1994; Steinnes et al., 1992; Steinnes et al., 2017; Vuković et al., 2016). As biomonitors and vascular plants, the main similarities and differences between moss and lichens are as follows; both of them act as good biomonitors. However, moss and lichens are mainly grown in wetland regions and barely find them in arid and hot countries like Egypt. Therefore, high plants have a root system, and tree leaves act as good biomonitors (Farahat, 2011; Gorelova and Frontasyeva, 2017; Jiang et al., 2018; Kabata-Pendias, 2011; Norouzi et al., 2015; Panda and Rai, 2015; Peterson and Girling, 1981); Quénéa et al. (2019); (Rai, 2016; Ukpebor et al., 2010). The Egyptian population is 98 M, and almost 40 % is mainly inhabited in Delta Nile, according to CAPMS (2019). Greater Cairo Metropolitan consists of three main governorates are Cairo, Giza, and Kalyobia, where approximately 24 M is inhabited, and population density is 51029, 7416, and 5356 pop/km$^2$, respectively (CAPMS, 2019). Therefore, Greater Cairo Metropolitan (GC) is an overpopulated city and one of the most populated cities in the world.

Because of the expensive cost of monitoring instrumentation and difficulties in associated sampling methods, the suitability of two commons, ubiquitously distributed, and ornamental plant species in Greater Cairo (GC) and Menoufia Governorate (MG) as biomonitors and as effective bioaccumulators of atmospheric trace metals have been evaluated. *Eucalyptus globulus Labill* and...
Ficus benjamina L. 1767 were selected as biomonitors, and the concentrations of 32 elements were determined. Both E. globulus and F. benjamina are evergreen tree species planted in the Mediterranean environment (Fife et al., 2008). E. globulus is a forest tree widely grown for woody biomass production in Mediterranean climates (Wilson, 1993). E. globulus mature leaves are narrow, sickle-shaped with a length of 8 to 12 cm and about 1 cm wide. Whereas, F. benjamina leaves are oval with 5 to 12 cm long and 2 to 6 cm wide. Therefore, these properties could influence aerial dust retention capacity. The adjacent soils were sampled and evaluated in terms of trace elements for 40 elements. Two complementary analytical methods were used in the analysis; instrumental neutron activation INAA and atomic absorption spectrometer AAS. All the elements were determined through INAA, except Cu, Cd, and Pb in plants only were determined using AAS.

Up to date, many important studies have paid attention to heavy metal sampling, analysis, and toxicity assessment using topsoils, biomonitors, and vascular plants. Tong et al. (2020) Tong et al. showed an overview of heavy metal pollution studies in the urban soils throughout 71 cities of China, based on data from online literature, during the period 2003–2019. The study focused on As, Cd, Cr, Hg, Pb, Cu, Zn, and Ni heavy metals. The study also introduced and evaluated the pollution index, potential ecological risk index, and hazard index. The results show that eight heavy metals' mean values all exceeded the soil background values in China.

Morton-Bermea et al. (2009) studied an assessment of heavy metal pollution (Cr, Cu, Ni, Pb, Zn, and V) in 135 urban topsoil samples from the metropolitan area of Mexico City. Using the pollution indices, the metal accumulation with respect to the background values was calculated in this study. The study showed that the assessment of heavy metal pollution in urban topsoil is an effective approach to determine the environmental damage from industry and human activities.

Related with soil contamination in an urban and agricultural area, Shifaw (2018) reviewed and analyzed national scale heavy metals soil contamination in urban and agricultural areas in China. With 100 individual studies, the concentration, pollution level, sources, remedial actions, and impacts of soil heavy metals in China were investigated.

Yalaldinova et al. (2018) studied the atmospheric inorganic pollutants and the relevant potential toxic impacts on humans and the ecosystem. In this study, the trace elements deposited from the atmosphere using Populus nigra as a bioaccumulative indicator and potential human and ecotoxicity impacts were evaluated and quantified.

El-Khatib et al. (2020) investigated the ability of Ficus nitida and Eucalyptus globulus, bark, and soil as biomonitors in some industrial zones in Minya governorate. In this research, the concentrations of Pb, Cu, and Cd were determined. Also, the highest concentrations were observed in tree leaves, which, in turn, suggests the implementation of tree leaves as biomonitors for metal-air quality assessment.
An up-to-date overview of information about the assessment of the inorganic metal air pollution and its impact on both human and terrestrial ecosystem by the implementation of tree leaves in Egypt is presented. Although some attempts have been made to address this issue, it is still a lack of information that could give a wide-scale and comprehensive description of the investigated areas as these studies are characterized mainly by local zones and areas.

The objectives of the current investigations can be summarized as i) determination of the concentrations of trace elements in tree leaves and adjacent soils, ii) identifying of the pollution extent using different pollution indices, and finally, iii) assessment and calculation of human toxicity and terrestrial ecotoxicity from selected elements and locations, iv) extracting more information about the main sources of pollution by implementing bivariate and multivariate statistical analysis, and iv) delivering the qualitative and quantitative estimation of the metal-air pollutants in GC and MG.

2. Materials and methods

Investigated area

The Greater Cairo contains three interlocked cities Cairo, Giza, and Kalyoubia (30°03’N 31°22’E), as shown in Fig. 1. Cairo is the capital of Egypt and the largest city in the Middle East, and the second-largest in Africa after Lagos. Its metropolitan area is the 15th largest in the world. Located near the Nile Delta, it was founded in 969 CE. Based on the recent statistics reported by CAPMS (2019), Cairo, Giza, and Kalyoubia are 100, 60, 42 % are urban zones, respectively. The continuous expansion of the urbanization around GC involves significant geomorphic impacts and has unfavorable geomorphological consequences (Csima, 2010). In addition to the industrial and urbanization expansion and dense population, Egypt houses almost 7.9 M vehicles, and out of this figure, Cairo is the governorate with the largest number of vehicles (2.2 million), followed by Giza (921500) and Alexandria (702100). Vehicles and vehicular traffic emissions represent the main pollution sources. Moreover, GC is surrounded by two industrial zones from the northern and southern borders (Shoubra El-Kheima and Helwan, respectively), which significantly increase the concentrations of air pollutants (Farahat, 2011). For comparison purposes, a governorate Menoufia (30° 38' 14.88`` N, 30° 54' 53.73'' E) was examined in terms of metal-air pollution where Menoufia is a rural region and characterized by agricultural activities. The Menoufia Governorate population is about 4.5 million, and the population density is 1807 pop/km² (CAPMS, 2019). Menoufia Governorate is characterized by a rural nature and an urbanized zone of 21.2%. It is located 60 km North-West of Cairo.
Sampling strategy

Thirty evergreen tree leaves samples of *E. globulus* and *F. benjamina* and twenty-nine of adjacent soil samples were collected from Greater Cairo Metropolitan and Menoufia Governorate, respectively. The samples were collected from various districts in Greater Cairo and Menoufia Governorate. A total of 20 leaf samples were collected from Greater Cairo, and ten samples were collected from Menoufia Governorate. Leaves from the two species of trees, *E. Globulus* and *F. Benjamina* were selected because they are found in a widespread distribution in Egypt. *E. Globulus* and *F. Benjamina* are characterized by their ability to uptake of particulates more than other tree species at the same sampling site. They are suitable for biomonitoring in dry countries (Freer-Smith et al., 2004). Leaves were randomly taken from all sides of the trees at approximately 2 meters height. The sampling process was conducted according to the recommendations and guidelines reported by Tomašević et al. (2011); Yalaltdinova et al. (2018). The full description of the sample number and the corresponding collecting points is provided in Table 1SM (Supplementary Materials).

Sample preparation

The tree leaves were triple washed with distilled water and dried at room temperature. Then, they dried in the drying oven at a temperature of 40 degrees for seven days. The dried samples were grinded into agate grinders. Two aliquots, each of 0.3 g of the obtained powder was packed in polyethylene zipped bags. Samples were pressed in the mechanical piston to obtain pellets of 1.5 cm diameter and 0.3 cm height. These pellets were packed in Aluminum cups and
polyethylene bags for long and short-lived isotopes irradiation. Soil samples were cleaned from plants and roots. Later on, they were air-dried at a temperature of 105 °C for 4 hours to a constant weight, crushed with a non-metal grinder. The grinder was thoroughly cleaned and dried after every grinding to avoid any contamination among samples, as reported by Al-Khashman et al. (2011).

For atomic absorption spectrometry (AAS), an aliquot of 0.2 g of tree leaves was placed in a Teflon vessel and decomposed with 3 mL of concentrated nitric acid (HNO₃) and 2 mL of hydrogen peroxide (H₂O₂) in a microwave digestion system (Mars; CEM, Matthews, NC, USA) for complete digestion. A detailed description of the digestion mechanism was published elsewhere by Chaligava et al. (2020); Madadzada et al. (2019).

Analytical techniques

A variety of analytical methods can be reliably utilized for the assessment of the elemental composition in the tree leaves and soil samples. These several analytical techniques available, each of which offers complimentary advantages such as X-ray fluorescence XRF and X-ray diffraction XRD. Among these techniques, instrumental neutron activation analysis INAA and atomic absorption spectrometry AAS. Instrumental neutron activation analysis INAA is a powerful technique in determining the inorganic pollutants in tree leaves and soil. Likewise, the complementary analytical method AAS was employed mainly to determine Cu, Cd, and Pb in tree leaves.

Leaf samples were subjected to neutron activation analysis at the IBR-2 reactor of the FLNP JINR in Dubna, Russia. The detailed characteristics of the irradiation channels are reported elsewhere by Frontasyeva and Pavlov (2005). The samples were irradiated twice to determine the elements of short and long-lived isotopes. For short-lived isotopes SLI, each sample was irradiated for 3 min and measured for 15 min. Likewise, the long-lived ones were irradiated for three days under neutron flux of 1.8×10¹¹ n/cm²·sec. Later on, the samples were repacked and measured twice. The first measurement was performed after four days of decay for 30 min, and this is the so-called first long-lived isotopes LLI1. While the second one was achieved after 20 days of decay for 1.5 h, and this is called the second long-lived isotopes LLI2 (Chaligava et al., 2020; Madadzada et al., 2019; Sarhan et al., 2019).

AAS was used to determine the concentrations of Cu, Cd, and Pb in tree leaves samples via iCE 3300 AAS Atomic Absorption Spectrometer with electrothermal (graphite furnace) atomization (Thermo Fisher Scientific, Waltham, MA, USA).
Assessment of pollution, human toxicity, and terrestrial ecotoxicity levels

**Enrichment factor EF**

To avoid the significant variations in the absolute values that may mislead the interpretation of the relationships between elements, the concentrations of the entire set of elements is normalized to the corresponding values in the upper continental crust UCC or in the soil (Bargagli, 1989; Bargagli et al., 1995). The enrichment factor EF is given as follows:

\[
EF = \frac{[C_x/C_{Al}]_{tree \ leaves}}{[C_s/C_{Al}]_{Soil}} \tag{1}
\]

where \( C_x \) is the concentration of the elements \( x \) of concern in tree leaves. Whereas, \( C_s \) stands for the concentration of the same element in soil. Both concentrations are normalized to Al in tree leaves and soil, respectively (Bargagli, 1989). The interpretation of enrichment factor EF and the corresponding categories is provided in Table 2 SM (Supplementary Materials).

**Pollution load index PLI**

Before the calculation of PLI, the contamination factor CF for every single element was calculated as the ratio of the concentration of each element over the corresponding value in the reference plant RF (Markert, 1992) or upper continental crust UCC (Rudnick and Gao, 2014) for plants and soil, respectively. PLI is given as (Kowalska et al., 2018; Varol, 2011).

\[
PLI = \sqrt[n]{\prod_{i=1}^{n} CF_i} \tag{2}
\]

When PLI is greater than unity, it suggests that pollution exists and vice versa.

**Potential ecological risk index PER**

PER has been used to differentiate and sort out which studied areas should be paid attention in terms of pollution extent (Hakanson, 1980). The formula of \( PER_f^i \) for a single metal pollution is deduced as follows:

\[
PER_f^i = C_f^i \times T_f^i \tag{3}
\]
where $PER_f^i$ is a potential ecological risk index, $C_f^i$ is the contamination factor, and $T_f^i$ is the "toxic-response" coefficient for the given single metal/metalloid. The corresponding $T_f^i$ listed values are, Zn = 1, As = 10, Cr = 2, Ni = Cu = 5, and Cd = 30 (Badawy et al., 2018; Hakanson, 1980).

**Risk Index RI**

The potential toxicity response index (RI), a single-entity index combining all of the metals of interest, is calculated as:

$$RI = \sum_{i} PER_f^i$$

where RI is the sum of the $PER_f^i$ for each metal of interest (Hakanson, 1980). The categories are interpreted and given in Table 3SM (Supplementary Materials) (Badawy et al., 2018; Hakanson, 1980; Karuppasamy et al., 2017).

**Human and ecotoxicity assessment**

In the life cycle impact assessment methods, we used the ReCiPe method and characterization factors (De Schryver A and Goedkoop M, 2009; Dekker et al., 2019; Huijbregts M.A.J. and Van Zelm R, 2009; Struijs et al., 2010; Struijs J. et al., 2009), which comprises harmonized category indicators at the midpoint and the endpoint level. The characterization factors quantify the potential impacts that inputs and releases have on specific impact categories in common equivalence units. The below equation shows the characterization process.

$$I_m = \sum_i Q_{mi}m_i$$

where $m_i$ is the magnitude of intervention $i$ (e.g., the mass of heavy metal elements released to air), $Q_{mi}$ the characterization factor that connects intervention $i$ with midpoint impact category $m$, and $I_m$ the indicator results for midpoint impact category $m$. (De Schryver A and Goedkoop M, 2009; Goedkoop and Spriensma, 2001).

In the human toxicity and terrestrial ecotoxicity category in the ReCiPe method and characterization factors, many elements are considered in the air compartment (high population and low population area). In this study, Mg, V, Cr, Mn, Co, Ni, Zn, As, Br, Ag, Sb, and Ba elements (12 elements) were matched, and characterization results were calculated. In the soil compartment (agriculture soil, forestry soil, and industrial soil), Mg, Al, Cl, As, Se, Br, Cd, Sb, I, and Ba elements (10 elements) were matched, and characterization results were calculated.
Statistical data analysis

All the statistical analyses of chemical data and graphing were performed using the statistical package R (R Core Team, 2016). The data were handled in MS office Excel. GIS technology was used to map the spatial distribution of the pollution patterns. The data were interpolated based on the inverse distance weighting IDW method.

Results and discussion

Metal concentrations and inter-correlation

A total of 34 and 40 elements were determined in the examined two evergreen tree species \((E.\ globulus)\) and \((F.\ benjamina)\) and adjacent soil samples, respectively. The full descriptive statistics of the concentrations of the determining elements are stipulated in Tables 1 and 2 for plant species and soil, respectively.

Table 1: Concentrations of elements (mean ±SD) tree leaves samples collected from Greater Cairo GC and Menoufia. The corresponding values of the Reference Plant RP reported by Markert (1992) were added for comparison purposes. All values expressed in mg/kg.

| Element | Eucalyptus Globulus | Ficus benjamina | RP |
|---------|---------------------|-----------------|----|
|         | GC                  | MG              | GC | MG |
| Na      | 2842 ± 1232.39      | 2900 ± 1052.21  | 2036.9 ± 1388.73 | 2536.4 ± 1250.81 | 150 |
| Mg      | 453.8 ± 109.35      | 434.4 ± 131.24  | 521.7 ± 111.7    | 676.8 ± 210.3    | 2000 |
| Al      | 871.1 ± 331.98      | 1012.2 ± 208.47 | 1262.3 ± 535.69  | 3064 ± 2647.06   | 80 |
| Cl      | 6816 ± 3308.02      | 5094 ± 861.41   | 8288 ± 2595.85   | 5972 ± 1541.55   | 2000 |
| K       | 10205 ± 6705.75     | 6694 ± 2219.62  | 18470 ± 5659.02  | 12428 ± 4629.03  | 19000 |
| Ca      | 23400 ± 9872.07     | 19740 ± 8983.48 | 37990 ± 10358.41 | 41220 ± 14875.72 | 10000 |
| Sc      | 0.2 ± 0.09          | 0.47 ± 0.16     | 0.26 ± 0.21      | 0.79 ± 1.08      | 0.02 |
| Ti      | 119.9 ± 41.7        | 116 ± 50.88     | 156.2 ± 84.95    | 375 ± 353.85     | 5 |
| V       | 2.67 ± 1.13         | 2.54 ± 0.52     | 5.38 ± 4.91      | 7.89 ± 6.66      | 0.5 |
| Cr      | 2.55 ± 1.2          | 3 ± 0.77        | 3.37 ± 2.73      | 6.72 ± 7.18      | 1.5 |
| Mn      | 184.2 ± 125.54      | 202 ± 73.57     | 30.02 ± 10.62    | 123.2 ± 92.62    | 200 |
| Fe      | 851 ± 385.05        | 1638.4 ± 653.06 | 1173.4 ± 886.45  | 3597 ± 3845.02   | 150 |
| Co      | 0.38 ± 0.16         | 0.75 ± 0.19     | 0.57 ± 0.65      | 1.26 ± 1.32      | 0.2 |
| Ni      | 4.39 ± 1.94         | 4.43 ± 0.86     | 3.49 ± 5.08      | 4.11 ± 4.34      | 1.5 |
| Cu      | 10.95 ± 3.71        | 7.35 ± 0.57     | 11.04 ± 2.94     | 8.66 ± 1.95      | 10 |
| Zn      | 44.58 ± 33.14       | 23.08 ± 8.4     | 32.31 ± 19.8     | 32.96 ± 26.33    | 50 |
| As      | 1.14 ± 0.6          | 0.81 ± 0.3      | 1.13 ± 0.75      | 1.05 ± 0.53      | 0.1 |
| Se      | 0.32 ± 0.07         | 0.31 ± 0.07     | 0.29 ± 0.08      | 0.21 ± 0.15      | 0.02 |
| Br      | 26.6 ± 17.8         | 27.56 ± 7.92    | 31.49 ± 15.43    | 16.84 ± 5.63     | 4 |
| Rb      | 2.9 ± 2.01          | 2.05 ± 0.44     | 5.59 ± 4.37      | 3.6 ± 2.89       | 50 |
Table 2: Concentrations of elements (mean ± SD) soil samples collected from Greater Cairo GC and Menoufia. The corresponding values of the upper continental crust RP reported by Rudnick and Gao (2014) were added for comparison purposes. All values expressed in mg/kg.

| Element | GC       | MG       | UCC       | Element | GC       | MG       | UCC       |
|---------|----------|----------|-----------|---------|----------|----------|-----------|
| Na      | 6142.5 ± 4291.2 | 11837.8 ± 3558.6 | 24258.57 | Zr      | 193.1 ± 89.6 | 264.1 ± 88 | 193       |
| Mg      | 14671.5 ± 8356.8 | 24077.8 ± 10518.5 | 14953.85 | Ag      | 0.5 ± 0.3 | 0.9 ± 0.2 | 0.053     |
| Al      | 24760.0 ± 16051 | 41077.8 ± 19377.9 | 81510.71 | Sb      | 1.5 ± 1.4 | 1.5 ± 0.9 | 0.4       |
| Si      | 445900 ± 75377.6 | 353444.4 ± 62440.2 | 311405.14 | Cs      | 0.6 ± 0.4 | 1.1 ± 0.5 | 4.9       |
| Cl      | 3750.9 ± 5962.6 | 8179.3 ± 10127.1 | 370      | Ba      | 373.5 ± 281.2 | 205.8 ± 95.5 | 628       |
| K       | 6678 ± 2357.6   | 10653.3 ± 3127.5 | 23244.16 | La      | 13 ± 7.4 | 22 ± 9.3  | 31        |
| Ca      | 37350 ± 14065.9 | 37066.7 ± 11827.6 | 25657.49 | Ce      | 30.2 ± 18.7 | 63.9 ± 30.8 | 63        |
| Sc      | 8.1 ± 7.1       | 17 ± 9.6  | 14       | Nd      | 10 ± 6.7 | 20.7 ± 11.4 | 27        |
| Ti      | 4477 ± 3102.5   | 7862.2 ± 3915.5 | 3835.79  | Sm      | 4.8 ± 3  | 5.5 ± 2.4 | 4.7       |
| V       | 84.2 ± 64.2     | 137.2 ± 67.9 | 97       | Eu      | 0.7 ± 0.5 | 1.4 ± 0.6 | 1         |
| Cr      | 50 ± 28.3       | 85.4 ± 23.2 | 92       | Gd      | 0.5 ± 0.3 | 1.3 ± 1.7 | 4         |
| Mn      | 471.9 ± 322.9   | 1007.2 ± 302.1 | 774.46   | Tb      | 0.4 ± 0.3 | 0.7 ± 0.3 | 0.7       |
| Fe      | 27846 ± 21140.3 | 75388.9 ± 29845.2 | 39175.06 | Dy      | 3.4 ± 1.3 | 4.4 ± 1.6 | 3.9       |
| Co      | 11.7 ± 9.8      | 24.5 ± 11.9 | 17.3     | Yb      | 3.6 ± 2.5 | 2.8 ± 1  | 1.96      |
| Ni      | 32 ± 25.3       | 51.5 ± 17.6 | 47       | Hf      | 4.8 ± 2.2 | 6.7 ± 2.1 | 5.3       |
| Zn      | 170.1 ± 147.2   | 70.2 ± 40  | 67       | Ta      | 0.7 ± 0.4 | 1.3 ± 0.7 | 0.9       |
| As      | 2.9 ± 1.2       | 4.3 ± 1.3  | 4.8      | W       | 1.1 ± 0.6 | 2.6 ± 0.6 | 1.9       |
| Element | GC Mean ± SD | GM Mean ± SD | RF Mean ± SD | UCC Mean ± SD | UCC Mean ± SD |
|---------|--------------|--------------|--------------|---------------|---------------|
| Br      | 7.5 ± 4.6    | 9.8 ± 4.4    | 1.6          | 0.017 ± 0.02  | 0.006 ± 0.004 |
| Rb      | 21 ± 12      | 39 ± 13.6    | 84           | 2.9 ± 1.5     | 5.2 ± 2.1     | 10.5         |
| Sr      | 204.4 ± 94.6 | 296 ± 47.2   | 320          | 1 ± 0.3       | 1.6 ± 0.3     | 2.7          |

The interaction of the mean values in both tree species in GC (urban) shows that the mean values of the obtained elements are in a good matching to each other’s except for Ca, K, Cl, Na, Al, Fe, and Mg found to be higher in *F. benjamina* than in *E. globulus*. The major elements are shown to be accumulated in *F. benjamina* higher than *E. globulus* except for Na. Overall, the descending order of the elements accumulated by the two species are given as Ca > K > Cl > Na > Al > Fe > Mg > Mn > Sr > Ti > Zn > Br > Ba > Cu > Ni > Pb > Rb > V > Cr > As > I > La > Co > Th > Se > Sc > Sb > Cd > Hf > Sm > U > Tb > Cs > Ta.

Likewise, the mean values of elements in the two-tree species in GM (rural) show that all the concentrations of the obtained elements in *F. benjamina* are higher than in *E. globulus* except Na, Mn, Br, Ni, and Se are observed to be higher in *E. globulus* versus *F. benjamina*. The concentrations of the major elements viz., Ca, K, Cl, Fe, Al, Na, Mg, Ti, and Sr. The mean element content in the two species of plants is described in the descending order of Ca > K > Cl > Fe > Al > Na > Mg > Ti > Sr > Mn > Ba > Zn > Br > Pb > Cu > V > Cr > Ni > Rb > I > Co > La > As > Sc > Sm > Cd > Th > Se > Hf > Sb > U > Cs > Tb > Ta. Generally, the concentrations of obtained elements are noticed to be higher in *F. benjamina* than in *E. globulus*.

Similarly, the concentration mean values mg/kg of the adjacent soil samples were determined in Greater Cairo GC (urban) and Menoufia Governorate MG (rural) and the results show that the mean values are in line for the two examined governorates. The major elements namely Si, Ca, Fe, Al, Mg, K, Na, and Ti were observed to be higher in MG than in GC, except Si and Ca were higher in GC than in GM. The descending order of the elements in GC and GM is given as Si > Ca > Fe > Al > Mg > K > Na > Ti > Cl > Mn > Ba > Sr > Zr > Zn > V > Cr > Ni > Ce > Rb > La > Co > Nd > Sc > Br > Hf > Sm > Yb > Dy > As > Th > Sb > W > U > Eu > Ta > Cs > Ag > Gd > Tb > Au, and Si > Fe > Al > Ca > Mg > Na > K > Cl > Ti > Mn > Sr > Zr > Ba > V > Cr > Zn > Ce > Ni > Rb > Co > La > Nd > Sc > Br > Hf > Sm > Th > Dy > As > Yb > W > U > Sb > Eu > Ta > Gd > Cs > Ag > Tb > Au, for GC (urban) and MG (rural), respectively. The concentrations of the elements in *F. benjamina* are higher than in *E. globulus* and in MG is higher than in GC.

The obtained concentrations of the elements in tree leaves and soil were normalized to the corresponding values of the elements in the reference plants RF reported by Markert (1992) and upper continental crust UCC reported by Rudnick and Gao (2014). For tree leaf species, the obtained results show significant concentrations of Th, Ti, Ta, Al, Sc, Na, As, V, and Br; Th, Ti, Na, Ta, Se, As, Al, Sc, Br, and Fe in GC samples for *F. benjamina* and *E. globulus*, respectively.

Whereas, significant concentrations are observed for Ti, Th, Ta, Sc, Al, Fe, Na, V, As, and Se for...
F. benjamina and Th, Ta, Sc, Ti, Na, Se, Al, Fe, As, and Br for *E. globulus* in MG. These findings are box plotted in Fig. 2 A). Overall, the accumulated elements by *F. benjamina* is slightly higher than in *E. globulus* in GC and MG. While in terms of the investigated area, the concentrations of elements in MG is considerably higher than in GC.

Similarly, the boxplot illustrated in Fig. 2 B) shows remarkable concentrations in the studied soil in GC for Au, Cl, Ag, Br, Sb, Zn, and Yb. While, the concentrations of Cl, Ag, Br, Au, Sb, Ti, and Fe were noticed to be higher than those in the corresponding values reported by (Rudnick and Gao, 2014) for UCC. To sum up, the concentrations of the elements in the studied soil are significantly higher in MG than GC.

To test the differences between the mean values of the concentrations in tree species and soil in different areas (rural and urban) and validate the previous findings, a Tukey test of pairwise comparisons was implemented as shown in Table 3. The Tukey test was used to differentiate the differences in the mean values of the elements in different tree species in different areas. At a significance level of 0.05, the probabilities of rural MG vs urban GC municipalities are (*p*= 0.03973) and the probabilities of *F. Benjamina* vs *E. Globulus* are (*p*= 0.03432). Both of the probabilities are lower than the significant level, and this leads to rejecting the null hypothesis and concluding that there are significant differences in mean values for these tree species and areas.

Similarly, the probability of rural vs urban areas in the case of soil is *p*= 0.02615, which suggests the same hypothesis.

| Vegetation          | Soil          |
|---------------------|---------------|
| Rural - Urban       | Rural - Urban |
| *P*-Value           | *P*-Value     |
| 0.039               | 0.034         |
| *F. Benjamina* - *E. Globulus* | 0.026 |

There are significant differences in all cases (*p*<0.05)

As a summing up, the mean values of elements in tree leaves (Ta, Hf, Tb, Sm, La, Sr, Ni, Co, Cr, Ca, and Cl) are at least three times higher and (U, Br, Na, Se, As, Fe, V, Sc, and Al) are 5-10 times higher than those reported in reference plant reported by (Markert, 1992), respectively.

The mean values of Th and Ti are higher by 20 times.

Similarly, the overall results for the normalized concentrations of soil samples with the corresponding values reported by Rudnick and Gao (2014) for UCC are higher than 2-5, 5-10, and 10-65 for Sb, Cr, Hf, Ni, Ca, Co, Sm, Cl, Cd, La, Sr, Tb, Pb; U, Br, V, Fe, As; and Se, Na, Al, Sc, Ta, Ti, Th, respectively. Whereas Rb, Cs, Mg, I, Mn, K, Zn, Ba, Cu, and Au are less than UCC.
Fig. 2: Box-plots illustrating the distribution of investigated elements in Cairo and Menoufia for *Eucalyptus globulus* and *Ficus bejamina*. All concentrations normalized to RP (A) and soil after normalization to UCC B).
Statistical analysis of the chemical data

**Principal component analysis (PCA)**

The so-called PCA dimensionality reduction technique was used to get more information about geochemical symmetrical elements and their origin. The data was centered log-ratio transformed CLR prior to the implementation of PCA (Badawy et al., 2018; Faith, 2015). The obtained PCAs were plotted and partitioned into clusters using K-means method.

A total of 34 and 34 out of 40 elements were selected to perform PCA for tree species and soil, respectively. Whereas the other elements of soil samples were excluded from the matrix because they tended to form separate groups. PCA was performed for tree species independent of the type of tree leaves and sampling location. For PCA, we assume that the different tree leaves species accumulate the elements of the atmospheric deposition equally. This assumption was proved by plotting the 1\textsuperscript{st} two PCAs for GC and GM, as shown in Fig 1:4 SM (Supplementary materials).

The obtained PCAs based on the aforementioned number of elements, the eigenvalues, and percentage of variance (in parentheses) for the first three dimensions were calculated to be 10.1 (33.5%), 4.2 (13.8%), 2.9 (9.7%) in tree species for GC and GM. The first two PCAs express 47.3 % of the data cumulative percentage of the variance. Therefore, the first two dimensions can sufficiently explain the data.

Based on the K-mean method, the 1\textsuperscript{st} two PCAs of the variables were plotted and clustered as in Fig. 3 (A). It is obvious from the figure that four clusters were created and can be described as follows:

- The 1\textsuperscript{st} cluster contains ten elements, namely Sc, Cr, Fe, Co, Cs, La, Sm, Hf, Ta, and U. It is obvious from the elements, of which this cluster was reproduced that there is a significant association of crustal elements. This combination of elements suggests the geogenic provenance of the elements.

- The 2\textsuperscript{nd} cluster includes 11 elements viz., Mg, Cl, K, Ca, Cu, Zn, Rb, Sr, Cd, Pb, and Th. It is clear from the elements that are containing the cluster that they have a mixed source (geogenic and anthropogenic). Besides, the highly toxic potential elements (Cu, Cd, and Pb) have a significant association with this cluster. Mainly, due to the industrialization and urbanization processes.

- The 3\textsuperscript{rd} cluster has three elements; Al, Ti, and V. These elements are often found in the oil and gas production fields. Considerable concentrations of these elements were observed near to Cairo Thermal Power Plant in Shubra El-kheima and El-sayyeda Zainab. These
regions are characterized by dense populations for GC. Remarkable contributions to these elements were found in Al shuhadaa City near MG adjacent to the central Railroad station. Therefore, the elevated concentrations of the elements containing this cluster may be due to the emission and maintenance processes.

- The 4th cluster is formed from Na, Mn, Ni, As, Br, and I. It is apparent from the set of the clustered elements that there is a remarkable association of sea elements (Na, Br, and I). Whereas, the existence of Ni and As mainly due to relevant industries to Nickel such as the burning of fossil fuels, wind-blown dust, and brick kilns which was noticed in high concentrations in Shubra El Kheima power station, then in Al Shuhadaa.

Likewise, the 1st two PCAs for grouping the locations are plotted and illustrated in Fig. 3 (B). The biplot revealed two clusters. The produced clusters could be described as follows:

- The 1st group includes 19 locations namely; 1, 2, 3, 5, 6, 8, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 23, 25, 28.
- The 2nd cluster contains 11 locations viz., 4, 7, 9, 10, 21, 22, 24, 26, 27, 29, 30

It is clear from fig. 3 (B) that the 1st cluster has a low contribution to the 1st PCA. Whereas a remarkable contribution was noticed for locations # 23 and 15 for Sadat City (industrial zone) and al-Amireyya (dense population), respectively. Contrariwise, the 2nd cluster has a considerable presentation on the plane. Specifically, locations # 4, 7, and 27. Based on the description of the locations given in Table 1SM the significant contributions were registered for el-Sayyeda Zainab (dense population), Shubra el-Kheima (power station), and al-Shuhadaa (railway train station), respectively.
Fig. 3: The Principal component analysis PCA bi-plot of PC1 and PC2 for tree leaves results illustrating the existence of significant clusters of determined elements A) and investigated collecting points B).

To identify the effect that may be raised from the adjacent soil, a total of 34 out of 40 elements were selected to perform PCA, as clearly shown in Fig. 4. The PCAs accounted for 14.7 (43.2 %), 4.2 (12.4 %), and 3.4 (9.9 %) of the eigenvalues and percentage of variance (in parentheses) for the first three PCAs, respectively. The 1st two PCAs express 55.6 % of the data cumulative percentage of the variance and can sufficiently explain the data.

In a similar manner to the plant analysis, the 1st two PCAs of the variables were plotted and clustered as illustrated in Fig. 4 (A). it is apparent that three clusters were created and can be described as follows:

- The 1st cluster contains nine elements, namely Na, Cl, K, Ca, Zn, As, Br, Sb, and Ba. The significant contribution of Na, Cl, and Br suggests a weathering from sea elements and/or the excess use of fertilizers and pesticides that may lead to an increment of the salinity of the soil. Considerable amounts of these elements were noticed in MG to be higher than in GC. K and Ca be explained by the agricultural nature of MG. While As, Zn, and Sb most probably due to brick kilns, and vehicles and vehicular traffic emissions (Farahat, 2011).
- The 2nd cluster is grouped by both geogenic and anthropogenic elements viz., Mg, Al, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Rb, Cs, La, Ce, Sm, Eu, Tb, Ta, and Th. This cluster is containing rare earth, oil production, and crustal elements.
- The 3rd grouped from Sr, Zr, Ag, Hf, W, and U. The set of elements that formed the 3rd cluster is naturally occurring and wind-blown soil.

Likewise, the 1st two PCAs for clustering of locations are plotted and illustrated in Fig. 4 (B). The biplot revealed two clusters and could be described as follows:

- The 1st cluster contains 13 locations namely; 8, 9, 11, 13, 16, 18, 20, 21, 22, 25, 27, 29, and 30. Out of 13 locations, 6 locations are in MG, and the others are in GC. Greatly, clustered locations have common traits. For instance, locations # 8, 9, 11, 13, 16, 18, and 20 are characterized by heavy traffics, wind-blown sand and dust, highways, ring road, and significant crustal dust associations (urbanized areas) and are located in GC. Whereas, 21, 22, 25, 27, 29, and 30 are agricultural land (rural areas) and are located in MG.
- The 2nd cluster is grouped from 16 elements viz., 1, 2, 3, 4, 5, 6, 7, 10, 12, 14, 15, 17, 19, 23, 24, and 28. This cluster contains locations that are located in GC except for three locations. These findings prove that the locations # 1, 2, 3, 4, 5, 6, 7, 10, 12, 14, 15, 17, and 19 have similar characterization. These locations mainly are located in GC and are coded for Shubra el-Kheima, Ramsis, Tahrir, el-Sayyeda Zainab, el-Sahel, el-Sharabeya, Shubra el-Kheima (power station), El-Maadi, Basus, el-Haram, Nasr City, al-Amireyya, el-Basateen, and al-Azhar park, respectively. These places are characterized by heavy traffic and vehicular traffic, densely populated, and wind-blown sand and dust. Due to these facts, industrial objectives and urban waste are the main sources of anthropogenic contamination in investigated areas. Whereas, the locations 23, 24, and 28 are rural regions in MG and are characterized by continuous aerial road dust circulation.
Fig. 4: The Principal component analysis PCA bi-plot of PC1 and PC2 for soil results illustrating the existence of significant clusters of determined elements A) and investigated collecting points B).

**Discriminant analysis DA**

The Sc-La-Th ternary discriminatory diagram (Hallinan, 2012) is illustrated in Fig. 5 a and b for leaves and soil, respectively. For comparison, the upper continental crust (UCC) data by Rudnick and Gao (2014), and reference plant values by Markert (1992) are added. It is obviously that all the tree leaves points are within the vicinity of UCC, except some samples taken from one of the highest populated regions of Greater Cairo (Shubra El-Kheima) and marked by a red circle on diagram Fig. 5 a.
Fig. 5: Sc-La-Th discriminating diagrams in the case of tree leaves (a) and soils (b). The corresponding values for reference plant RP and upper continental crust reported by Markert (1992) and Rudnick and Gao (2014), respectively were added. It is obviously that all the tree leaves points are within the vicinity of UCC, except some samples taken from one of the highest populated regions of Greater Cairo (Shubra El-Kheima) and marked by a red circle on diagram (a).

Findings of the pollution extent quantification

The pollution extent was quantified using the enrichment factor, pollution load index PLI, potential ecological risk PER, and risk index RI. These indices were calculated for both soil, and tree leaves samples from urban and rural regions. The corresponding values reported by Rudnick and Gao (2014) and those reported by Markert (1992) were used for soil and plants, respectively as normalizers.

The calculated results of EF are illustrated in Fig. 6. The crustal association was eliminated using the corresponding values of the adjacent soil and UCC for plants and soil, respectively. In terms of sampling locations, the results of EF show considerable values in GC and MG for Na, Cl, K, Ca, Mn, Zn, As, Br, Sr, and Ba (Fig. 6 A). Whereas E. globulus was observed to accumulate concentration of elements higher than in F. benjamina (Fig. 6 B). These findings are a bit differ from the normalized results and mainly due to the normalizing of the values to the corresponding ones in UCC for soil and RF in plants, respectively. Therefore, in air metal biomonitoring, it is highly recommended to set aside the influence of crustal association using the corresponding values in the soil contamination and then calculate EF (Bargagli et al., 1995).
It is apparent that the enriched elements have a mixed origin and most probably come from fuel and oil refining (As), woodworking and papermaking or weathering from the sea or fertilizers (Na, Cl, Zn), Pesticides and herbicides (Cl, Br), weathering from cement production or brick kilns (Ca). With high possibility, the other elements are due to the fine dust weathering (Frontasyeva, 2011).

The pollution load index PLI was calculated for soil and tree species. The results of soil samples show that the locations namely; 25, 21, 20, 9, 30, 27, 29, 16, and 22 are slightly higher than unity and classified as polluted regions. Whereas the tree species show that PLI in almost all the studied samples are higher than unity. Among all samples, location numbers 27, 7, 4, 18, 16, 2, 22, and 9 were observed to be considerably high and ranges from 3 to 9. Based on the description of the investigated locations in Table 1SM, in the case of soil, PLI is significantly higher in MG than in GC. Contrariwise, in case of plants, except two locations 27 and 22 (train station and brick kilns), respectively. It could be explained by the densely populated, traffic, and high ways in GC, which in turn, results in elevated concentration of elements in the air rather than in MG.

Also, for a better understanding of the local situation for the soil in the investigated areas, the concentration of potentially toxic elements in soil, namely; V, Cr, Mn, Co, Ni, Zn, As, Sb, Ba (average values for Cairo and Menoufia) were compared with the corresponding alert/intervention values in different countries worldwide according to their State Regulatory Norms as shown in Table 4. The average PLI of the Greater Cairo and Menoufia Governorate were calculated by normalizing the average values of potential pollutants to these alert/intervention limits for different countries. It is clear from the table that, despite the significant variability of different State Regulatory Laws, the investigated soil seems to be below the alert/intervention thresholds. Based on these findings, the investigated soils do not need any further action. However, regular monitoring is highly recommended to be able to follow up on the dynamics of the concentration of these elements in the soil.
Table 4: concentration (mg/kg) of potentially toxic elements in soil (average values for Cairo and Menoufia) and the corresponding alert/intervention values in different countries according to their State Regulatory Norms For a better understanding of the local situation, for comparison the corresponding values of the average Pollution Loading Index (PLI) for the Municipality of Greater Cairo and Menoufia Governorate were calculated by normalizing the average values of potential pollutants to these intervention/remediation limits in all cases, the investigated soils, despite the great variability of different State Regulatory Laws, seem to be below the alert/intervention thresholds.

| Element | Present work | Netherlands<sup>1</sup> 2009 | Australia<sup>2</sup> 2010 | Canada<sup>3</sup> 1997<sup>4</sup> | Romania<sup>4</sup> 1997 | US EPA<sup>5</sup> 2017 | Russian Federation<sup>6</sup> 1991<sup>7</sup> | Serbia<sup>7</sup> 2018 |
|---------|--------------|-----------------------------|---------------------------|--------------------------|-------------------|----------------|----------------|----------------|
| Cairo   | Menoufia     | Cairo | Menoufia | Cairo | Menoufia | Cairo | Menoufia | Cairo | Menoufia | Cairo | Menoufia | Cairo | Menoufia | Cairo | Menoufia | Cairo | Menoufia | Cairo | Menoufia | Cairo | Menoufia | Cairo | Menoufia | Cairo | Menoufia |
| V       | 84           | 137  | 250  | 50   | 200/200 | 200  | 39   | 150  | 250  | 200  | 39   | 150  | 250  | 200  | 39   | 150  | 250  | 200  | 39   | 150  | 250  | 200  | 39   | 150  | 250  |
| Cr      | 50           | 85   | 180  | 400  | ND     | 300  | 12000| ND   | 380  | 300  | 12000| ND   | 380  | 300  | 12000| ND   | 380  | 300  | 12000| ND   | 380  | 300  | 12000| ND   | 380  | 300  | 12000|
| Mn      | 472          | 1007 | ND   | 500  | ND     | 2500 | 180  | 1500 | ND   | 2500 | 180  | 1500 | ND   | 2500 | 180  | 1500 | ND   | 2500 | 180  | 1500 | ND   | 2500 | 180  | 1500 | ND   | 2500 | 180  | 1500 |
| Co      | 12           | 25   | 190  | 50   | 50/2   | 50   | 23   | ND   | 240  | 50   | 23   | ND   | 240  | 50   | 23   | ND   | 240  | 50   | 23   | ND   | 240  | 50   | 23   | ND   | 240  | 50   | 23   | ND   | 240  |
| Ni      | 32           | 52   | 100  | 60   | 100/150| 150  | 84   | 85   | 210  | 150  | 84   | 85   | 210  | 150  | 84   | 85   | 210  | 150  | 84   | 85   | 210  | 150  | 84   | 85   | 210  | 150  | 84   | 85   | 210  |
| Zn      | 170          | 70   | 720  | 20   | ND     | 600  | 2300 | 100  | 720  | 600  | 2300 | 100  | 720  | 600  | 2300 | 100  | 720  | 600  | 2300 | 100  | 720  | 600  | 2300 | 100  | 720  | 600  | 2300 | 100  | 720  |
| As      | 3            | 4    | 76   | 20   | ND     | 25   | 068  | 2    | 55   | 25   | 068  | 2    | 55   | 25   | 068  | 2    | 55   | 25   | 068  | 2    | 55   | 25   | 068  | 2    | 55   | 25   | 068  | 2    | 55   |
| Sb      | 2            | 2    | 22   | ND   | 20/20  | 20   | 31   | 45   | 15   | 20   | 31   | 45   | 15   | 20   | 31   | 45   | 15   | 20   | 31   | 45   | 15   | 20   | 31   | 45   | 15   | 20   | 31   | 45   | 15   |
| Ba      | 374          | 206  | 920  | 300  | ND     | 625  | 1500 | ND   | 625  | 625  | 1500 | ND   | 625  | 625  | 1500 | ND   | 625  | 625  | 1500 | ND   | 625  | 625  | 1500 | ND   | 625  | 625  | 1500 | ND   | 625  | 625  | 1500 |

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1<sup>1</sup>(ESdat, 2013)
2<sup>2</sup>(Department for Environment and Conservation, 2010)
3<sup>3</sup>(ESdat, 1997)
4<sup>4</sup>(Ministry of Waters Forests and Environmental Protection, 1997)
5<sup>5</sup>(US EPA, 2017)
6<sup>6</sup>(Russian Federal Service for Supervision of Consumer Rights Protection and Human Welfare, 2006)
7<sup>7</sup>(National Regulation of Republic of Serbia, 2018)
Fig. 6: boxplot illustrates of the statistics of enrichment factor EF in Cairo and Menoufia and in the two species studied.
Another powerful index is widely used to assess ecological risk is the potential ecological risk index PER. PER was calculated for selected elements in the studied soil and tree species samples. Specifically, the selected elements are Ni, Cr, Zn, and As in soil. While in tree species, Cr, Ni, Cu, Zn, As, and Cd were used. These elements were selected because their epidemiological data are available and given by (Hakanson, 1980; Karuppasamy et al., 2017).

PER was assessed, and the results are illustrated in Fig. 7. Based on the interpretation criteria for PER and risk index RI that are given in Table 3SM and Fig. 7 a) for the soil it can be concluded that there is a low PER as the calculated PER is less than 40. Whereas, in tree species the calculated PER for As and Cd are considerably high, and this may pose a significant hazard to the environment and hence to the humans.

The risk index RI was calculated, and according to the interpretation criteria in Table 3SM, the locations namely 19, 7, 26, 18, 4, 27, 23, and 10 are classified as considerable potential ecological risk locations, and 9, 28, 24, 5, 8, 6, 2, 21, 29, 16, 22, 1, 3, and 30 are moderate potential ecological risk locations. In comparison, the rest are low RI.
Fig. 7: Potential ecological risk index of selected elements from the examined soil and vegetation samples

**Findings of human toxicity and terrestrial ecotoxicity**

Human toxicity and terrestrial ecotoxicity were quantified using the ReCiPe method and characterization factors. Human toxicity and terrestrial ecotoxicity, expressed in mg 1,4-dichlorobenzene equivalents (1,4 DCB-eq), are used as a midpoint characterization factor. As shown in figure 8 and figure 9, in the result of the human toxicity, which considered soil and vegetation results, the human toxicity impacts in most urban locations (average 3.7E+07) are much higher than in rural locations (average 7.8E+06). The location 07 (1.1E+08), 04 (6.3E+07), 05 (5.9E+07), 01 (4.4E+07), 20 (4.4E+07), and 06 (3.6E+07) showed high human toxicity results. In
the terrestrial ecotoxicity aspect, the results of rural locations (average 2.9E+05) are much higher than the results in urban locations (average 1.9E+05).

Figure 8. Human toxicity and terrestrial ecotoxicity results, including soil and vegetation

Figure 9. Human toxicity and terrestrial ecotoxicity results in urban and rural locations

To be more specific, in the results of urban vegetation locations, mostly Ba (on average, 27%), Cl (on average, 26%), Al (on average, 21%), Se (on average, 16%), and As (on average, 10%) elements effect to the human toxicity. In the results of rural vegetation locations, mostly Cl (on average, 37%), Se (on average, 26%), As (on average, 20%), Al (on average, 16%), and Cd (on average, 1%) elements effect to the human toxicity. In the results of terrestrial ecotoxicity, Al (on average, 98%) and Cl (on average, 2%) element effect mostly in urban and rural vegetation locations.

In the results of urban soil locations, mostly Ba (on average, 73%), Mn (on average, 20%), V (on average, 4%), and As (on average, 3%) elements effect to the human toxicity. In the results of rural soil locations, similarly, like the results of urban soil locations, Ba (on average, 83%), V (on average, 6%), Mn (on average, 5%), and Zn (on average, 3%) showed high contributions to the human toxicity. In the results of urban soil locations, Zn (on average, 48%), V (on average, 26%),
Ni (on average, 13%), and Ag (on average, 7%) elements effect to the terrestrial ecotoxicity. In the results of rural soil locations, V (on average, 49%), Ag (on average, 25%), Co (on average, 7%), Br (on average, 7%), and Ni (on average, 5%) showed high contributions to the terrestrial ecotoxicity. (for more detailed human toxicity and terrestrial ecotoxicity information of each element, please see figure 5SM in Supplementary Material)

Conclusions

The present work achieved its main objectives of determining the elemental composition and quantifying the air quality in terms of metal content and associated human and terrestrial toxicity impact. The normalized accumulated metals in tree leaves show that F. benjamina is slightly higher than in E. globulus in GC and MG. In terms of the investigated areas, the concentrations of metals in MG are considerably higher than those in GC. Despite the densely populated and traffic in GC, the adjacent soil samples' analysis shows that the concentrations of the elements in MG are significantly higher than in GC. The concentrations of Cl, Br, Sb, Ti, and Fe were noticed to be higher than those in the corresponding values for UCC. PCA partitioned the obtained elements into four groups of geogenic provenance and anthropogenic ones. The main contribution of the anthropogenic impact comes from el Darb el Ahmr, Cairo Thermal Power Plant in Shubra El-kheima, al-Amireyya (densely populated areas), and El-sayyeda Zainab in GC. While in MG comes mainly from Al shuhadaa City near MG adjacent to the central Railroad station, Sadat City (industrial zone). DA analysis reveals that there is a considerable crustal association to the accumulated concentrations. It is highly recommended to remove out the crustal association prior to the calculation of enrichment factor to avoid the overestimation and misleading of the results. These data may be used as basic guidelines by regulatory bodies in Egypt to control the inorganic metal emission in the atmosphere. In addition, planting these trees would be of high importance in inorganic metal air polluted areas.

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Declarations

- Ethics approval and consent to participate
  Not applicable
- Consent for publication
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Figure 1

Map of sampling localities Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.
Figure 2

Box-plots illustrating the distribution of investigated elements in Cairo and Menoufia for Eucalyptus globulus and Ficus bejamina. All concentrations normalized to RP (A) and soil after normalization to UCC B).
Figure 3

The Principal component analysis PCA bi-plot of PC1 and PC2 for tree leaves results illustrating the existence of significant clusters of determined elements A) and investigated collecting points B).
Figure 4

The Principal component analysis PCA bi-plot of PC1 and PC2 for soil results illustrating the existence of significant clusters of determined elements A) and investigated collecting points B).

Figure 5

Sc-La-Th discriminating diagrams in the case of tree leaves (a) and soils (b). The corresponding values for reference plant RP and upper continental crust reported by Markert (1992) and Rudnick and Gao (2014), respectively were added. It is obviously that all the tree leaves points are within the vicinity of UCC, except some samples taken from one of the highest populated regions of Greater Cairo (Shubra El-Kheima) and marked by a red circle on diagram (a).
Figure 6

Boxplot illustrates of the statistics of enrichment factor EF in Cairo and Menoufia and in the two species studied
Figure 7

Potential ecological risk index of selected elements from the examined soil and vegetation samples
Figure 8

Human toxicity and terrestrial ecotoxicity results, including soil and vegetation. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 9

Human toxicity and terrestrial ecotoxicity results in urban and rural locations

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