POLLUTION ASSESSMENT IN URBAN AREAS USING AIR POLLUTION TOLERANCE INDEX OF TREE SPECIES

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ABSTRACT

Air pollution has a large impact on the biochemical and morphological parameters of plants, and also decreases their growth and overall health. Therefore, biomonitoring is a reliable and cost-effective method to assess air quality. The tolerance of plant species can be assessed with the use of Air Pollution Tolerance Index (APTI), which is calculated from ascorbic acid content, relative water content, leaf extract pH, and total leaf chlorophyll content of tree leaves. In this study, we reviewed published studies from several countries around the world about APTI. Performance of APTI was also evaluated comparing industrial, roadside and urban areas. In our work, APTI of Tilia sp. and Celtis occidentalis were used and evaluated in Debrecen city, Hungary. Leaf samples were collected from 12 areas in the city. Similar to earlier studies, ascorbic acid content was determined by titration with iodine solution. Chlorophyll was extracted from leaf samples with ethanol, and it was measured using spectrophotometric analysis. Relative water content was measured by the weight method. Comparison of selected studies showed that China and India are the most polluted countries and they had plant species with the highest APTI values. Lowest APTI was reported from Iran which is one of most air-polluted regions in the world. In Hungary, APTI was moderate compared to other countries. The tolerance of plant species at different study sites decreased in the following order: industrial > roadside > urban areas. This suggests the best conditions for sensitive species' development and growth in urban areas, while the presence of industrial activities in certain areas demands higher tolerance from plants.

Keywords: ascorbic acid, biomonitoring, leaf extract pH, relative water content, total leaf chlorophyll, tree leaves.

1 INTRODUCTION

Nowadays, environmental pollution is a well-recognized and serious problem of our society on the global scale. In most of the modern cities, industrialization and urbanization cause increasing air pollution. In an urban environment the largest contributor to air pollution is the emission from vehicular traffic. Traffic related pollution consist of exhaust and also non-exhaust emissions. The latter includes brake, tire, clutch and road surface wear as well as resuspension of previously deposited dust and soil dust [1]. The impact of industries on the vegetation is reported by several earlier studies [2]–[5]. Dust emission is one of the main form of pollution from both vehicular traffic and industrial activities. Naturally, suspended particulate matter show seasonal and even daily variations in quality and quantity depending on weather conditions like temperature, humidity, and rain [6]. Deposition speed of suspended particles is influenced by their shape and size, which determine the mechanisms of sedimentation, diffusion, impaction, and precipitation [7].

Plants, especially trees act as living filters in polluted areas. Tree leaves multiply the ground area of a single tree, resulting in a rather large surface area for the accumulation of pollutants. Pollutant capturing capacity varies among species, and it is determined by leaf surface geometry, foliage characteristics and tree height. Aside from adsorption of dust on the leaf surface, finer pollutants are also absorbed and accumulated inside the leaf tissue through stomatal pores [6]. Tree leaves are continuously exposed to the atmosphere. Thus, air quality is apparently reflected on the plant health through morphological and biochemical

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changes [8]. Therefore, biomonitoring of plants is a useful tool to assess the impact of pollutants released into the atmosphere. Roadside vegetation and flora around factories, power plants and industrial sites are the most common subjects of researches carried out in the field of biomonitoring.

Stress caused by air pollutants can affect the number of leaves, flowers and fruits, leaf area, length of stem and roots, germination of seeds, photosynthetic pigments, relative water content, leaf extract pH, ascorbic acid etc. [7], [9]. Primary productivity of plants, growth and development of biomass depend on chlorophyll content, which is greatly affected by pollution load [10]. Loss of chlorophyll content in plants is a common indication of degraded air quality; however, tolerant species can even have enhanced chlorophyll content at polluted sites as a defence mechanism under stressful conditions. Thus, higher chlorophyll content overall favours tolerance. Relative water content (RWC) is the momentary water in the leaves relative to their full turgidity. Higher RWC also improves plants' tolerance, as it helps maintaining physiological balance under stress condition through increased transpiration rates. Leaf extract pH influences stomatal permeability of air pollutants. It is reported that acidic compounds in the atmosphere reduce the leaf pH [11]. The more sensitive a certain species is, the more drastic the rate of this reduction is [12]. Generally, plants with leaf pH value maintained around 7 are considered to be tolerant, as acidic pH conditions greatly hinder photosynthetic activity [10]. Ascorbic acid or vitamin C is a natural antioxidant, which is essential for several physiological mechanisms and also protects from oxidative, pollution related compounds. Consistently, higher ascorbic acid content in plant tissue indicates higher pollution tolerance.

Air Pollution Tolerance Index (APTI) became a common and useful method for evaluating the sensitivity of species against pollution. It is calculated from total chlorophyll content, relative water content, leaf extract pH and ascorbic acid content. Higher APTI value means that the plant species is more tolerant to pollution, and therefore it can be planted at polluted sites for improvement of air quality. Sensitive species, on the other hand, are expected to have low values of APTI, and they can be used as indicators of pollution present in the environment. In this work, we reviewed studies from several countries around the world about APTI of plants in urban and industrial areas, and along roadsides, and compared the data with the findings of our research in Hungary.

2 METHODOLOGY

2.1 Data collection of earlier studies

We collected articles about APTI from several countries around the world to compare their findings. The number of articles found suitable for this purpose was relatively low, and it was further reduced by some restrictions. For example, there are regions where the local vegetation mostly consists of herbaceous plants, and in some cases only ornamental [13] or climber plants [14] were studied. To improve urban air quality trees or larger shrubs perform best as pollution sinks due to their total foliage surface. In this aspect, herbs might be less relevant. In this paper, we assessed the tolerance of tree, so data about herbs and minor shrubs were excluded from our comparisons. Most of the data was from India [6]–[8], [10], [14]–[21], and from a few other Asian and African countries, such as Iran [12], China [11], [22], Indonesia [23] and Nigeria [24]. The selected studies are listed in Table 1 along with a short description of each study area.

Table 1: Description of areas of earlier studies.

References	Country	Study area	Site description
Liu and Ding 2008 [22]	China	industrial	Near a Beijing steel factory.
Molnár et al., 2018 [25]	Hungary	urban	In Debrecen city, with moderate traffic, far from industrial pollution.
Choudhury & Banerjee 2009 [8]	India	industrial	In an industrial belt with a large variety of industries present.
Gupta et al. 2016 [16]	India	industrial	In the industrial area of Sahibabad.
Acharya et al. 2017 [15]	India	roadside	In an area adjacent to the National Highway 5.
Rai & Panda 2013 [21]	India	roadside	Along the roadside in polluted areas.
Pathak et al. 2011 [20]	India	urban	In Varanasi, on the banks of the Ganges.
Sulistijorini et al. 2008 [23]	Indonesia	roadside	Along a highway with high traffic volume.
Gholami et al. 2016 [12]	Iran	urban	In Ahvaz, one of the most polluted cities in the world.
Ogunkunle et al. 2015 [24]	Nigeria	urban	On the perimeter of the campus of University of Ilorin

2.2 Study area and sample collection

We selected the *C. occidentalis* and *Tilia* sp. to test the usefulness of APTI in Hungary. The studied species' leaves were collected in Debrecen city, similarly to earlier studies [25]–[27]. The average particulate matter concentration (PM_{10}) in the city ranged between 27–40 µg m^{-3} between 2005–2017 [28]. The sample collection was executed on the same day in the autumn of 2017, when 12 sampling points were chosen evenly across the city. Tree leaves were collected in paper bags from individuals of *Celtis occidentalis* and *Tilia sp.* from a height of 1–1.5 m above the ground.

2.3 Sample preparation

Chlorophyll content was extracted from approximately 20 mg leaf tissue with 5 ml 96% ethanol. The total chlorophyll content (TChl) was measured through spectrophotometric analysis and it was calculated from the following equation, expressed in mg g^{-1} fresh weight

$$TChl\ (mg\ g^{-1}) = (17.12 \times E_{666} - 8.68 \times E_{653}) \times \frac{V}{m} \times 1000. \quad (1)$$

E_{666} and E_{653} are the absorbance at 666 nm and 653 nm minus the absorbance at 750 nm, respectively, V is volume (ml) of leaf extract and m is the fresh weight (g) of leaf sample.

Relative water content (RWC) was measured using the following parameters: the fresh weight of leaves (FW), the turgid weight (TW) that was recorded after the leaves were immersed in water overnight, and finally the dry weight of the leaves (DW) after letting them dry in an oven at 70 °C. RWC was calculated from the following formula:

$$RWC\ (\%) = \frac{FW-DW}{TW-DW} \times 100. \tag{2}$$

The acidity of the leaf extract was measured by a digital pH meter.

The ascorbic acid content was measured by titration method. 2 g of leaf was crushed and homogenized in deionised water, then after filtration the samples were titrated using iodine solution and starch indicator. Ascorbic acid content was expressed in mg g^{-1}.

APTI of species was determined by using the following formula:

$$APTI = \frac{A(T+P)+R}{10}, \tag{3}$$

where A is the ascorbic acid content, T is the total chlorophyll content, P is the leaf extract pH and R is the relative water content.

According to the categorization introduced by Singh et al. [29], a tree species is regarded to be sensitive when the index value is 14 or less. The APTI value of an intermediate and moderately tolerant species range from 15 to 19, and 20 to 24, respectively. The APTI values of a tolerant species is above 24.

2.4 Statistical analysis

Statistical calculations were performed by the SPSS/PC+ statistical software package. We tested the variables for normal distribution with the Shapiro-Wilk test. The homogeneity of variances was tested with Levene's test. Analysis of variance (ANOVA) in General Linear Models (GLM) module was used to compare APTI values among countries and study area types.

3 RESULTS AND DISCUSSION

3.1 Comparison of APTI among countries

We compared several countries based on the APTI values in the selected studies. The highest APTI values were in China: it was significantly higher than in Hungary ($p < 0.001$), India ($p < 0.05$), Iran ($p < 0.001$) and Nigeria ($p < 0.001$). APTI in India was ranked as second one, and it was significantly higher than in Hungary ($p < 0.05$) and Iran ($p < 0.001$) (Fig. 1). Basically, China and India were the most polluted countries among the studied countries, and they had plant species with relatively high APTI. This means that in these regions environmental conditions are mainly suitable for tolerant species. The higher level of pollution may be the cause of higher tolerance level of native species which is a plain defence mechanism. There is already a growing interest in the application of plants to reduce air pollution in India, which explains the high amount of studies in the country. India is a quickly developing country, and it has undergone intense industrialization and urbanization in the last decades [7], which caused a rapid increase in pollution levels.

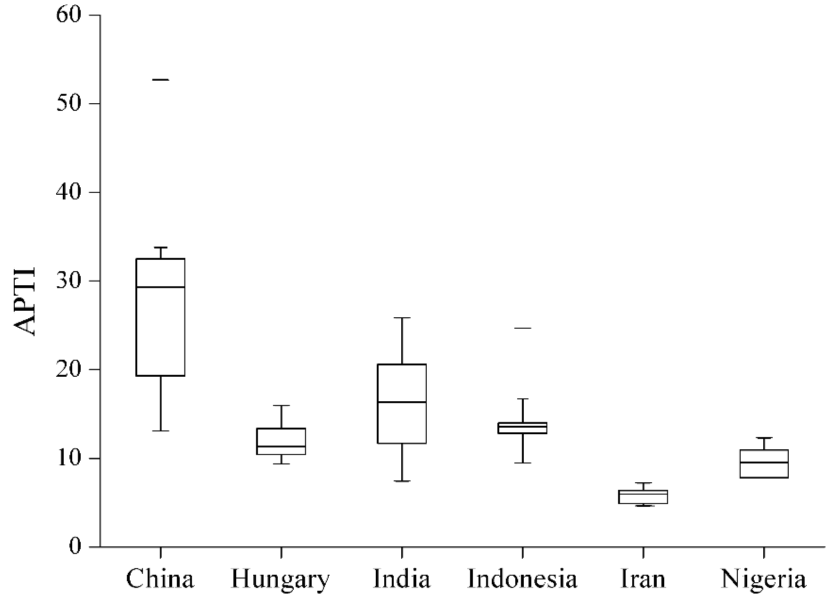

Figure 1: Reported APTI values in the studied countries.

Among the selected studies, tree species with the lowest average APTI were found in Ahvaz, Iran. Ahvaz was ranked as the world's most air-polluted city by the World Health Organization in 2013 [12]. The climate in this region is hot and humid, and there is an abundance of dust. Based on APTI, tree species had rather low tolerance against pollution. This shows that at extremely polluted sites, air pollutants can degrade biochemical parameters (such as chlorophyll or ascorbic acid content) of plants to a degree that they become overly sensitive against air pollution. APTI determined by us in Hungary was moderate compared to the APTI values of other countries. It was significantly lower than in China ($p < 0.001$) and India ($p < 0.05$), where the most tolerant species were present.

3.2 Comparing APTI among study areas

We identified three types of area: industrial area, roadsides, and urban area. Highest average APTI was found at industrial sites, which differed significantly from the roadsides ($p < 0.05$) and the urban areas ($p < 0.001$; Fig. 2). APTI values at roadsides were significantly higher than in urban areas ($p < 0.05$). Accordingly, the tolerance of plant species decreased in the following order: industrial > roadside > urban areas. Thus, presumably, the level of overall pollution revealed the same trend: it was the highest at industrial sites and the lowest in urban areas. This suggests the best conditions for development and growth of sensitive species in urban areas, while the presence of industrial activities in certain areas demands higher tolerance from plants.

Result of APTI corresponds with other researches that studied urban areas [20], [24]. Debrecen is far from any direct industrial emission, and the air quality is mainly determined by the local pollution sources that are specific to urban areas such as vehicular traffic, households [27], and it is reflected in the APTI values.

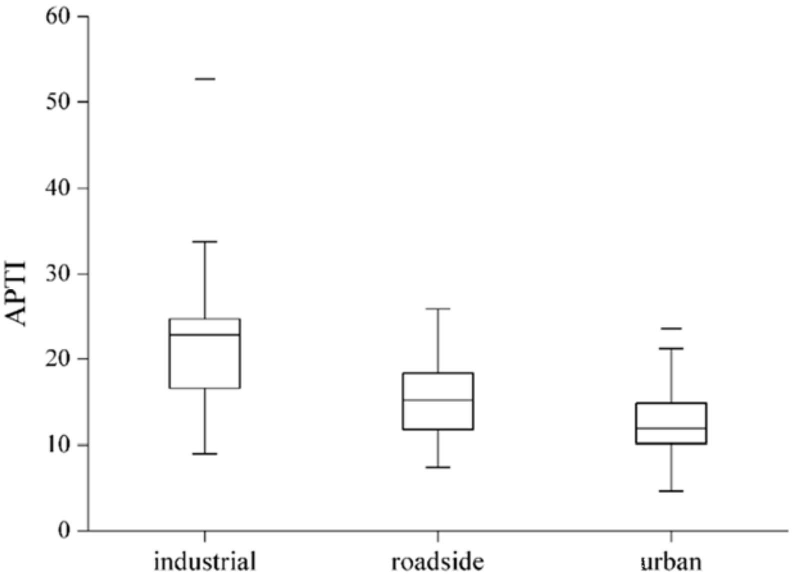

Figure 2: Boxplots of APTI values by study areas.

4 CONCLUSIONS

Air pollution is presently a severe environmental problem in many countries. It has a large impact on vegetation near emission sources. Evaluation of Air Pollution Tolerance Index (APTI) can be used to find suitable plant species for reduction of pollutants and to identify possible indicators of such pollutants. We collected studies reporting APTI values from several countries and compared their findings with our data from Hungary. The comparison revealed that the most tolerant species were present in highly polluted countries, in China and India. Our results in Hungary significantly differed from the above countries, suggesting better conditions for sensitive species. Values of APTI was also compared among industrial, roadside and urban areas. Literature review suggests that industrial emissions have a profound impact on sensitivity of plants, as such polluted areas were mostly suitable for species with high tolerance. Based on the results of our study we recommend to plant tree species that are tolerant to air pollution in polluted countries, especially near direct emission sources. Meanwhile in urban areas, where the environment also favours sensitive species, such plants should be planted and used to indicate changes in air quality. Based on our findings, the species studied in Hungary were classified as sensitive, thus these species are useful species as bioindicators of air pollution.

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