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ENVIRONMENTAL STATUS OF A CITY BASED ON HEAVY METAL CONTENT OF THE TREE-RINGS OF URBAN TREES: CASE STUDY AT SZEGED, HUNGARY

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Abstract

Urban vegetation, especially urban trees could act as ecological archives, as they reflect various elements of their environment. The main aim of the study is to evaluate the spatial and temporal variations of environmental conditions in the city of Szeged (Hungary) based on long-term monitoring of the heavy metal content of tree-rings (soft wood). In general, the living conditions of the urban trees (and other organisms as well) at Szeged was the worst in 2001/05, when the heavy metal pollution was the greatest, therefore the biomass production of the sampled trees decreased. Fortunately, the environmental conditions became better, only there are some points in the industrial area, where the heavy metal pollution of the environment is gradually increases. The temporal change in lead pollution (considerable decline in 2013/17) could be explained by the obligatory usage of lead-free petrol since 1999 and the diversion of through-traffic from the town (2011). The introduction of unleaded petrol had delayed favourable results, as the dust particles containing lead probably circulated in the air for a while before they were gradually become fixed in the soil or they were washed out from the town during heavy rains. The cadmium pollution also declined after the traffic diversion, as it is connected to the usage of brake-linings. Whilst the lead and cadmium content of the tree-rings decreased during the studied decades, the trees accumulated increasing amount of zinc throughout the studied periods, as this element could be up-taken from the ground-water, as the larger the canopy of a tree the denser and deeper its root system is.

Keywords: heavy metal, pollution, urban vegetation, environmental stress, long-term monitoring

INTRODUCTION

Urban vegetation is exposed to various noxious environmental effects, especially along busy roads. The most important disturbances are related to (1) increased air and soil pollution in connection to traffic and heating; (2) compaction and burial of soils, which decrease the water availability and impede the transpiration of the root-system; (3) mechanical injuries; (4) extreme water-household and temperature conditions in connection to urban heat-island and built-in areas; and (5) extra salt input into soils linked to defrosting of roads during winter (Gulyás and Kiss, 2007). These disturbances are usually overlapped aggrading each-other's effects, and leading to growth irregularities and water-household imbalances (Ballach et al., 1998). At the same time the state of the urban vegetation reflects the environmental status of an area, which is related to the social, economic, cultural and health status of an urban neighbourhood (Lányi, 2000). Urban vegetation, especially urban trees could act as ecological archives, as they reflect various elements of their environment (Alestalo, 1971; Kern and Popa, 2009), therefore they could be used to map the environmental status of urban areas and to identify those neighbourhoods which are more prone to environmental load.

The main aim of the study is to evaluate the spatial and temporal variations of environmental conditions in the city of Szeged (Hungary) based on the heavy metal content of tree-rings (soft wood). In the frame of the research we had sampled urban trees, as (1) they indicate the amount of heavy metals which could bio-accumulate in the living organisms, (2) the tree-rings reflect the temporal changes of (air) pollutants, and (3) the tree-rings could be repeatedly sampled without hurting the tree itself.

Heavy metals could get in into the tree-rings through the leaves, the root-system or the bark, but the ratio between these uptakes is different depending on the species or local factors (Lepp, 1975). However, the most important route of heavy metal uptake is through leaves (Lin et al., 1995), but it is not proven in case of all urban species (Watmough, 1999). Despite of the uncertainties, the tree-rings are declared to be good archives of atmospheric fallout of heavy metals, thus the pollution history (Brabander et al., 1999; Watmough, 1999; Padilla and Anderson, 2002), or the spatio-temporal variations in traffic could be reconstructed based on a dendrological study (Kadell and Larsson, 1978).

Specific aims of the research were to found an urban bio-monitoring system at Szeged, to monitor the spatial and temporal changes in heavy metal load, and to evaluate the environmental status of the city. The monitoring system was founded at Szeged in 2000 involving 75 urban trees, which represent the entire area of the city, and the same specimens were sampled three times, thus the pollution history of a relatively long period (1996-2017) could be reconstructed.

STUDY AREA

The city of Szeged is located on the Hungarian Great Plain, close to the Romanian and Serbian border (Fig. 1). Therefore, the international transit traffic through the town was considerable, thus the air- and dust pollution originating from traffic have reached the health limits at certain times (Pasinszki, 1996). However, the traffic situation had changed in 2011, when a ring-road highway (M43) was built, thus the roads became less busy within the town. Another factor, which could have influenced the environmental load is the usage of lead-free petrol, which became obligatory in Hungary in 1999. The industrial activity in the town is limited, only some chemical, food and textile companies operate, however it is surrounded by agricultural fields.

The city is dissected by the Tisza River, which influences the ground-water conditions. It could affect the heavy metal accumulation of the trees too, as north of the town the Maros River joins to the Tisza. This tributary transports large amount of pollutants (mainly copper and zinc; Kiss and Sipos, 2001) originating from the geological background of the catchment and from mining activity (Waijandt and Bancsi, 1989).

METHODS

Sample collection

Tree-ring samples were collected from the entire area of the city with almost equal spatial distribution in 2000, 2005 and 2017 (Fig. 1). During the planning of the bio-monitoring system such tree species had to be selected, which (1) are abundant in the whole city; (2) accumulate heavy metals in the same manner and rate; and (3) were affected by similar environmental effects (e.g. situated along roads). These criteria were fulfilled by *Tilia platyphyllos* and *Populus nigra ssp. italica*. If the individuals of the two species appeared next to each other, we sampled both of them, to compare the differences in their heavy metal bio-accumulation.

During the first field campaign 73 trees were sampled. Later some of the trees were cut, therefore in 2005 only 67 of them existed, and in 2017 only 57 remained. At each sampling campaign the same individuals were sampled to decrease the errors originating from the different (1) metabolism of individuals; (2) location; and (3) exposure. To evaluate the spatial changes of heavy metal pollution along roads, two main roads with heavy traffic were sampled (Bajai road and Kossuth road). To evaluate the effective distance from a main busy street the trees along a quiet street (Eszperantó str.) joining to a main road were also sampled.

The trees were sampled by increment borer (Lintab, Denmark) at 1.0 m height above ground (Figs. 2-3), at the side of the trunk facing towards the road. During each sampling campaign the outer 5 tree-rings (located in the soft wood) were separated, representing the periods of 1996-2000, 2001-2005, and 2013-2017. Samples were dried (moisture content <5%), and their weight (ranging between 0.5-2.0 g) was measured, so later we could evaluate the biomass production of the trees.

Analytical measurements

The samples represent a 5-year period, thus the heavy metal (Pb, Cd, Cu and Zn) content (ppm) is a mean value for the period. The sample preparations during each campaign were made in the same way. The tree-ring samples were treated in nitric acid (65%) for 24 hours, later they were boiled for 3 hours on 120°C, finally they were treated by $HClO_4$ (70%). Though the sample preparation was the same, the analytical devices changed during the study. The first two measurements were made using Perkin Elmer 3110

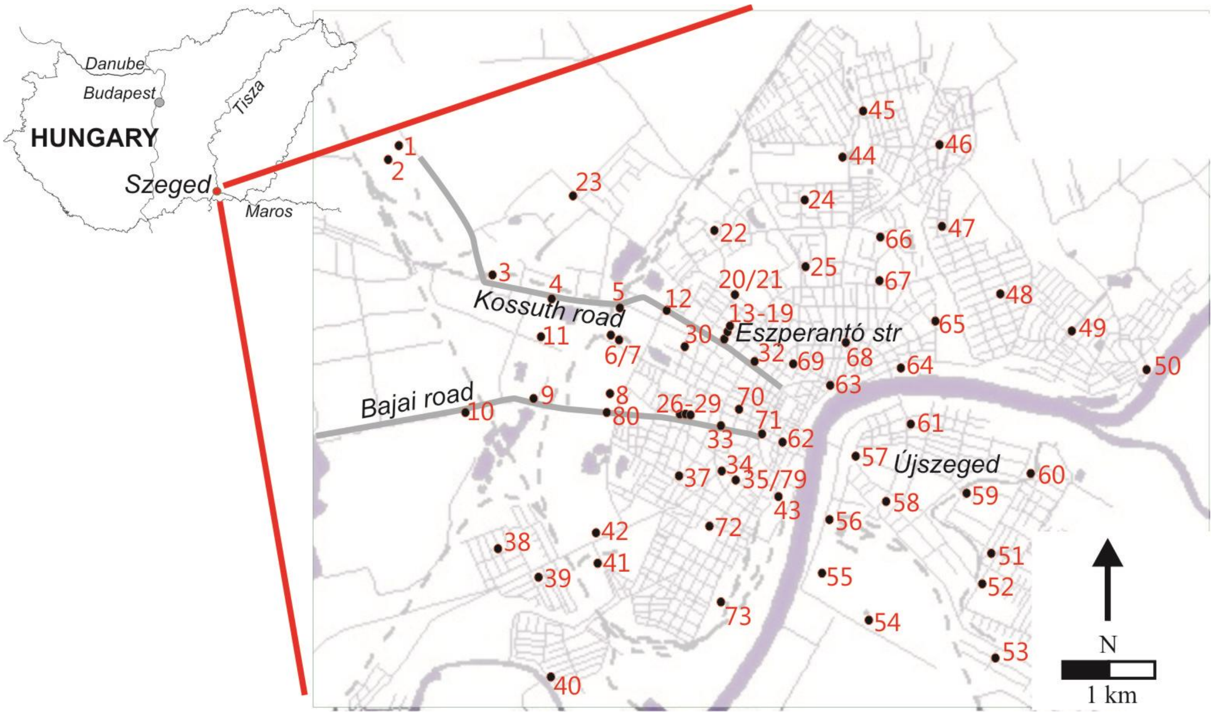

Fig. 1 Location of Szeged (Hungary) and the sampled urban trees

atomabsorptic and emission spectrometer, whilst the last measurement was made by Perkin Elmer 7000DV ICP-OES spectrometer. Based on simultaneous tests, there is no considerable difference between the results of the two devices, though the second one has much better resolution.

Fig. 2 The trees were sampled by increment borer

Fig. 3 Location of former cores and the latest coring at the same poplar tree

Spatial analysis of the results

Based on the range of heavy metal content of the tree rings, the samples were divided into five even classes. The members of class No. 1. contain the lowest amount of certain heavy metal, while trees belong to the class No. 5 accumulated the greatest amount of a given heavy metal. To evaluate the total heavy metal load of a tree and to evaluate the environmental status of the area, the indices of the classes were summarized, and reclassified. In this way the total environmental load of an urban tree at a given location and at a given time could be evaluated (very good / good / medium / satisfactory / bad).

RESULTS

Biomass changes of the tree-rings

The weight or width of tree-rings refers the biomass production of a tree, which reflects its living conditions and the rate of environmental load of the area. In the first period (1996/2000) the mean weight of the 5 tree rings was 0.29 g (Fig. 4), and it reduced to 0.22 g in the next period (2001/05). This considerable decrease (-28%) undoubtedly refer to the declining living conditions of the sampled urban trees. In the last period (2013/17) the mean value did not decrease further on, and some trees even could increase their biomass. These trees are usually along quiet roads where the water supply is more favourable (e.g. less paved surfaces).

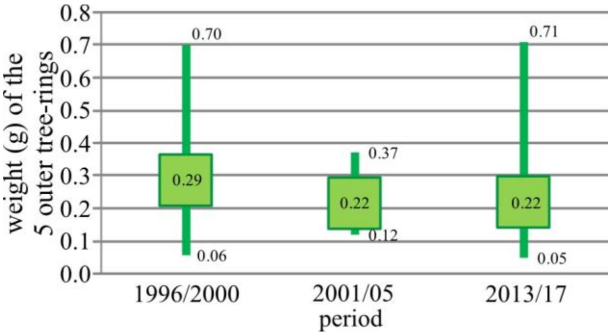

Fig. 4 Weight changes of the sampled 5 tree-rings (representing the maximum, mean and minimum values)

Temporal changes in heavy metal pollution of tree-rings

The amount of accumulated heavy metals considerably changed during the studied period (Table 1). Between the first and second survey the mean lead (Pb) and zinc (Zn) content increased by 2-3 times, whilst of the cadmium (Cd) and copper (Cu) by one order. At the same time the minimum and maximum vales became more similar, reflecting, that whilst in the first period some sites were polluted and others could be considered as unpolluted, in the second period the entire city was more evenly and higher polluted. However, by the third survey (2013/17) the situation improved. The lead pollution decreased by 97% compared to the previous period. The amount of cadmium has also declined by 96%. Similar decrease was detected in case of copper (-88%). However, the amount of zinc gradually increased: until the early 2000s its amount tripled (+288%), and until nowadays it increased by further 51%.

The heavy metal content of the tree-rings increased at almost every sampling point in the second period (2001/05), however in the third period (2013/15) it decreased. To visualise these changes, the heavy metal content of tree-rings in a period was plotted against the next period (Fig. 5 a, b).

Table 1 Temporal changes in heavy metal content (ppm) of the tree-rings

	lead (Pb)			*cadmium (Cd)*			*copper (Cu)*			*zinc (Zn)*		
	1996-2000	*2001-2005*	*2013-2017*	*1996-2000*	*2001-2005*	*2013-2017*	*1996-2000*	*2001-2005*	*2013-2017*	*1996-2000*	*2001-2005*	*2013-2017*
min	0.0	6.2	0.0	0.0	2.8	0.0	0.0	0.6	1.2	0.0	0.5	4.2
mean	6.4	11.0	0.3	0.3	5.0	0.2	2.3	27.0	3.4	4.4	12.7	19.3
max	47.7	21.0	1.0	3.6	9.1	1.0	48.9	338.2	20.2	55.1	37.2	82.2

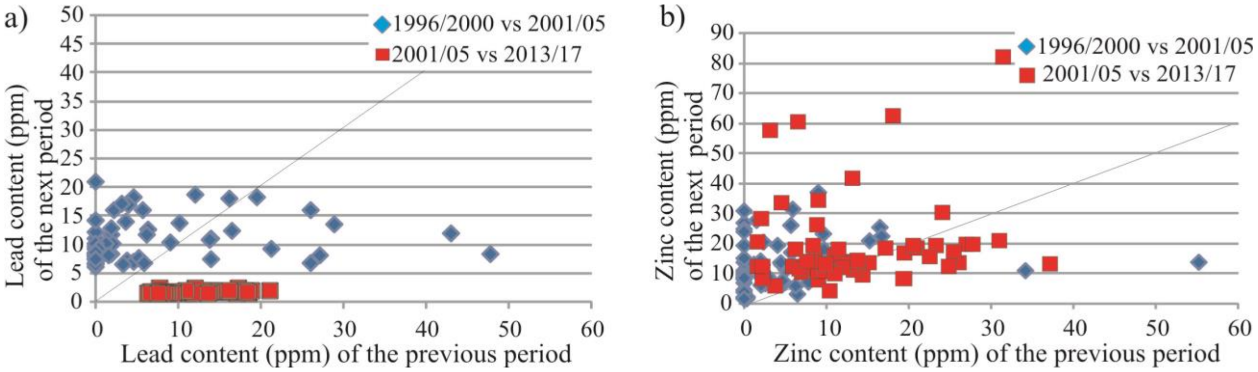

Fig. 5 Comparison of a) lead and b) zinc content (ppm) of the tree-rings measured at the different periods. If a point falls below the line, the concentration decreased by time, but if it is above, the concentration increased compared to the previous period.

In case the rate of bio-accumulation of the have metal remains the same, the point representing a tree should fit to the x = y equation (line). Comparing the results of the first and second period reflects that almost all points fall above the line in case of all studied heavy metals, referring to increased bio-accumulation of these elements in the tree-rings. In contrary, the comparison of the second and third period reflects that the points usually fall below the line in case of lead, cadmium and copper, thus their uptake and accumulation in the trees decreased. The exception is the zinc, as in 60% of the sampled trees its concentration had increased even in the third period.

Spatial distribution of the studied heavy metals

Spatial distribution of lead pollution

The usage of lead-free petrol became obligatory in Hungary after 1999, thus the studied timeframe represent a period (1) when considerable amount of Pb was emitted to the environment by traffic (1996/2000), (2) consequently after the banning of leaded petrol (2001/05), and finally (3) when (2013/17) the recovery of the environment was more advanced and no lead of traffic origin could get in the air. As most of the lead pollution is considered to have traffic origin, we evaluated it from three different points: (1) spatial distribution in the entire city; (2) along the main traffic routes; and (3) by the distance from a busy road.

In the first period (1996/2000) the lead pollution of the city was low in general, as at 64% of the sampling sites its concentration was below 5 ppm (Fig. 6). However, in 2001/05 it increased, at in all cases it was above 5 ppm. The most polluted areas were along the busy roads, despite of the fact, that at this time the usage of lead-free petrol was already obligatory in Hungary. By the third period (2013/17) the lead content of all sampled trees reduced bellow 5 ppm, reflecting better environmental conditions in the entire city.

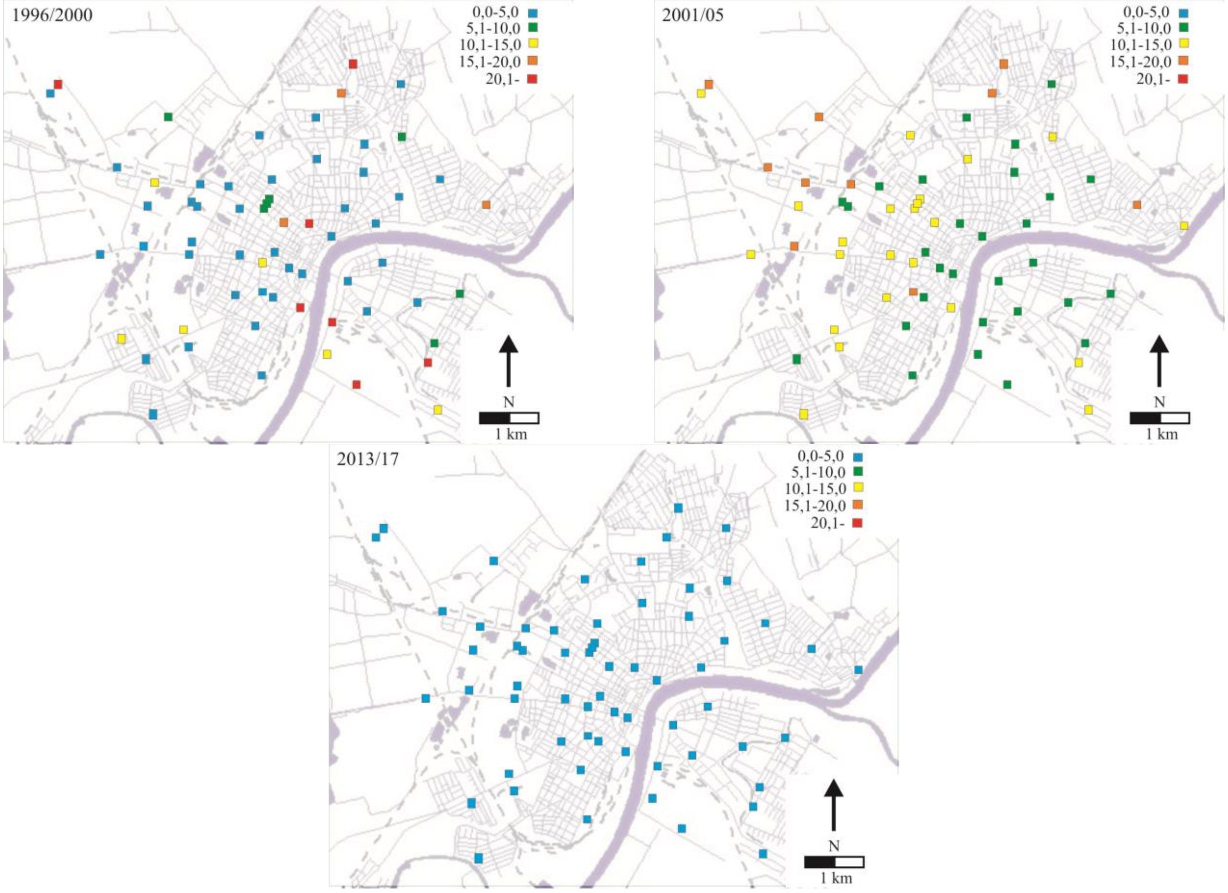

Fig. 6 Spatial distribution of lead content (ppm) in tree-rings at Szeged in the periods of 1996/2000, 2001/05 and 2013/2017

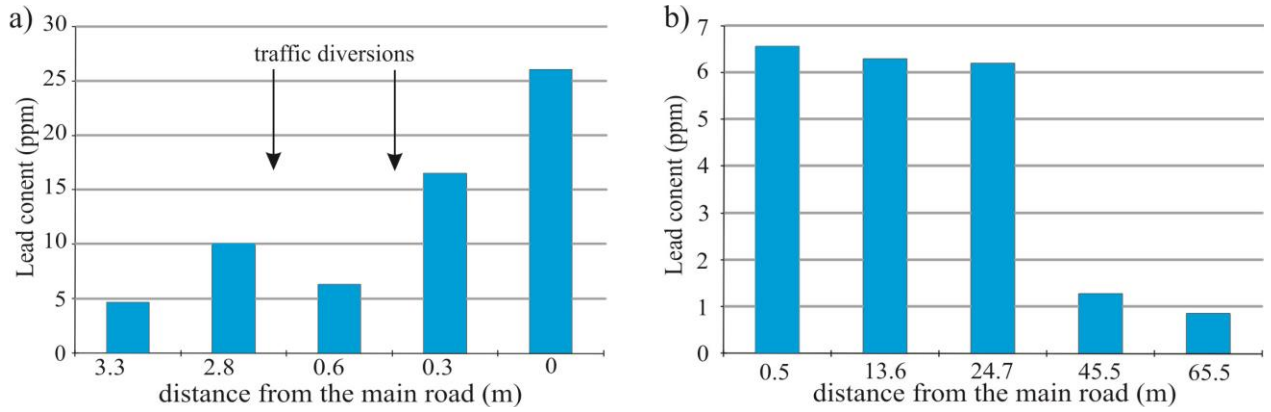

Fig. 7 Lead pollution along the busy Kossuth road towards the city centre in the first period (1996/2000; b) Lead content of the tree-rings in the quiet Eszperantó street, perpendicular to the busy Kossuth road in 1996/2000

Along the studied busy roads, the lead content of the tree-rings was high during the first two periods, almost twice as much than in those in the quiet streets and parks. However, during the last period the differences were not so high, though the along the busy roads the trees had higher lead accumulation. Along the Bajai road the lead content increased towards the city centre (Fig. 7a), parallel to the increasing amount of built-in areas and the lack of ventilation. However, the trees along the Kossuth road refer to another trend. In this case the lead content increases towards the city centre, however it is broken at the circular roads which divert considerable amount of the traffic.

The efficiency of lead pollution dispersal from the main, busy road was studied along relatively quiet street (Eszperantó str) perpendicular to a busy road (Kossuth road). In the first period (1996/2000) the sampled trees within 25 m distance from the main road accumulated almost the same amount of lead (Fig. 7b), only at 30-40 m far from the main road the accumulation started to decrease. The pattern of the pollution was similar in 2001/05, though the trees accumulated much more lead.

Spatial distribution of cadmium pollution

In 1996/2000 cadmium content above the detection limit (2.0 ppm) was measured in 31% of the trees, mainly along the busy roads. Its amount increased in 2001/05, as even in the small parks and quiet streets its amount was above 2.0 ppm. In the first period cadmium appeared just at the busy cross-roads of the city centre, but in 2001/05 it was detectable everywhere, especially along the main roads (Fig. 8), similarly to the spatial distribution of the lead (Fig. 5). In the third period (2013/17), the lead content decreased in every sampled tree to 0.01-1.3 ppm, though it still appeared everywhere. The cadmium pollution of the city – similarly to the lead pollution – was characteristic in the entire territory of the city, though lately less accumulated in the living organisms.

The spatial distributions of lead and cadmium reflect that both pollutants have the highest values at the same places. It could be explained by their origin, as both are related to traffic. The cadmium is emitted through the wearing of tires and burning of diesel fuel (Csathó, 1994). In the first period (1996/2000) cadmium pollution did not get into the quiet streets, thus no cadmium accumulated in the trees of the side street (Eszperantó str.). However, in the next period (2001/05) it was already detectable, and its amount only slightly decreased (from 6.00 ppm to 4.15 pp) with the decreasing distance from the main road.

Spatial distribution of copper pollution

In the first period (1996/2000), the copper content of the tree-rings was below 5.0 ppm in 97% of the samples. The highest values (18.6 ppm and 48.9 ppm) were measured in the NW part of the city, in an industrial area, therefore, we assumed, that it had in industrial origin. Though in this area the pollution decreased in 2001/05, but all over the city the copper content of the tree-rings has increased, and the most polluted areas shifted from the industrial area towards SE and to the city centre (Fig.9). Only 14% of the trees accumulated less than 5.0 ppm of copper, and extremely high values (100-338 ppm) appeared in 5 trees, four of them located in the city centre. At the same time, newer polluted areas appeared in the N and SW parts of the city, where the trees accumulated 20-40 times more Cu than before. In the last period (2013/17) the copper pollution dropped, as in most of the trees the copper content decreased bellow 5.0 ppm. Only one tree, in the NW industrial area accumulated 20 ppm copper

Spatial distribution of zinc pollution

Among the studied pollutants only the amount of zinc has increased throughout the three studied periods, thus the zinc pollution is getting worse in Szeged (Fig. 10). In the first period (1996/2000) 86% of the trees accumulated less than 10 ppm of Zn, and only two trees had high zinc content (55 ppm and 34 ppm). In the next period (2000/2005) only 40% of the trees accumulated less than 10 ppm. In the latest period (2013/17) the Zn content of the tree-rings increased further on, only 12% of the trees had less than 10 ppm Zn. These trees are located in the city centre and in the suburb of Újszeged. Especially high amount of zinc (57-82 ppm) was found in the trees located in NW part of the city.

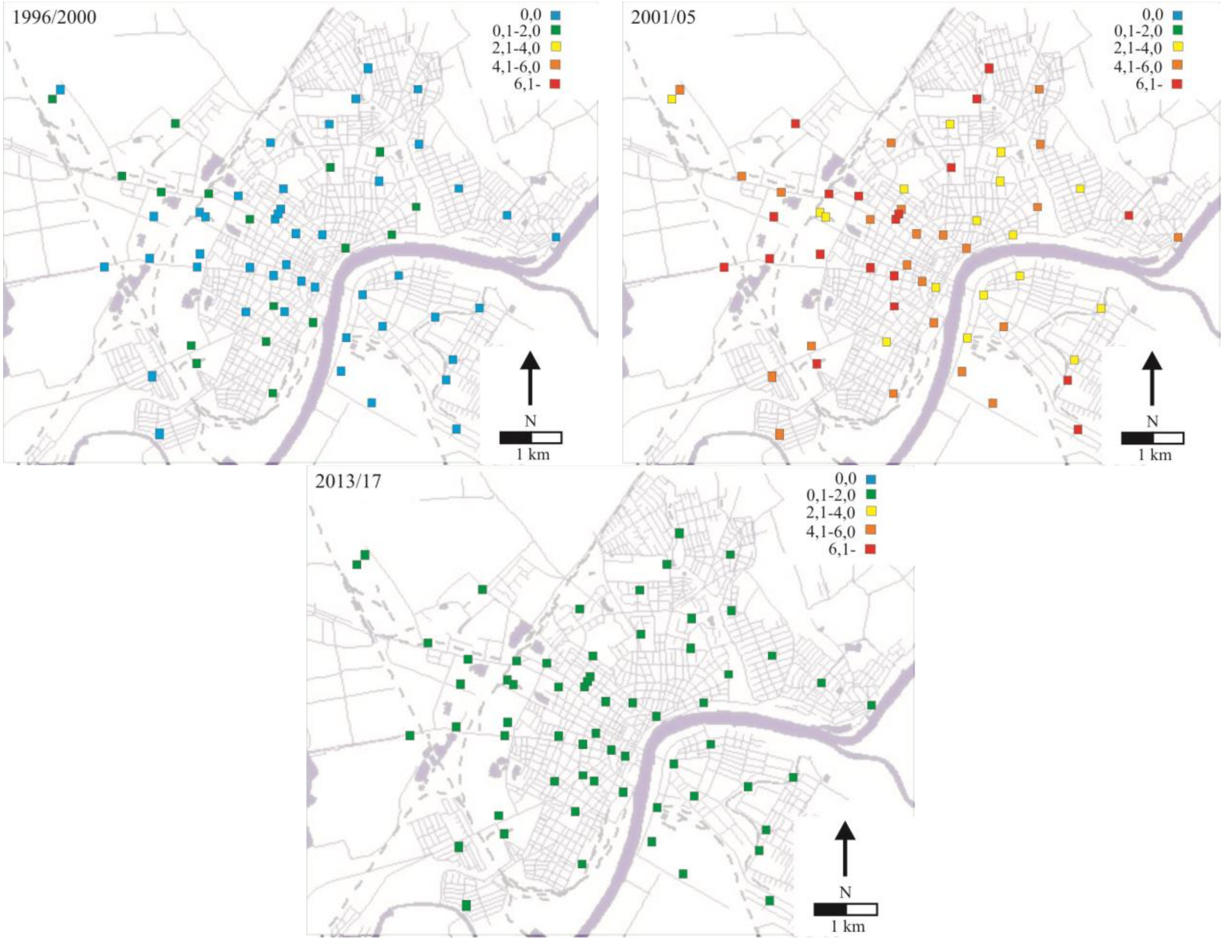

Fig. 8 Spatial distribution of Cd content (ppm) in tree-rings at Szeged in the periods of 1996/2000, 2001/05 and 2013/2017.

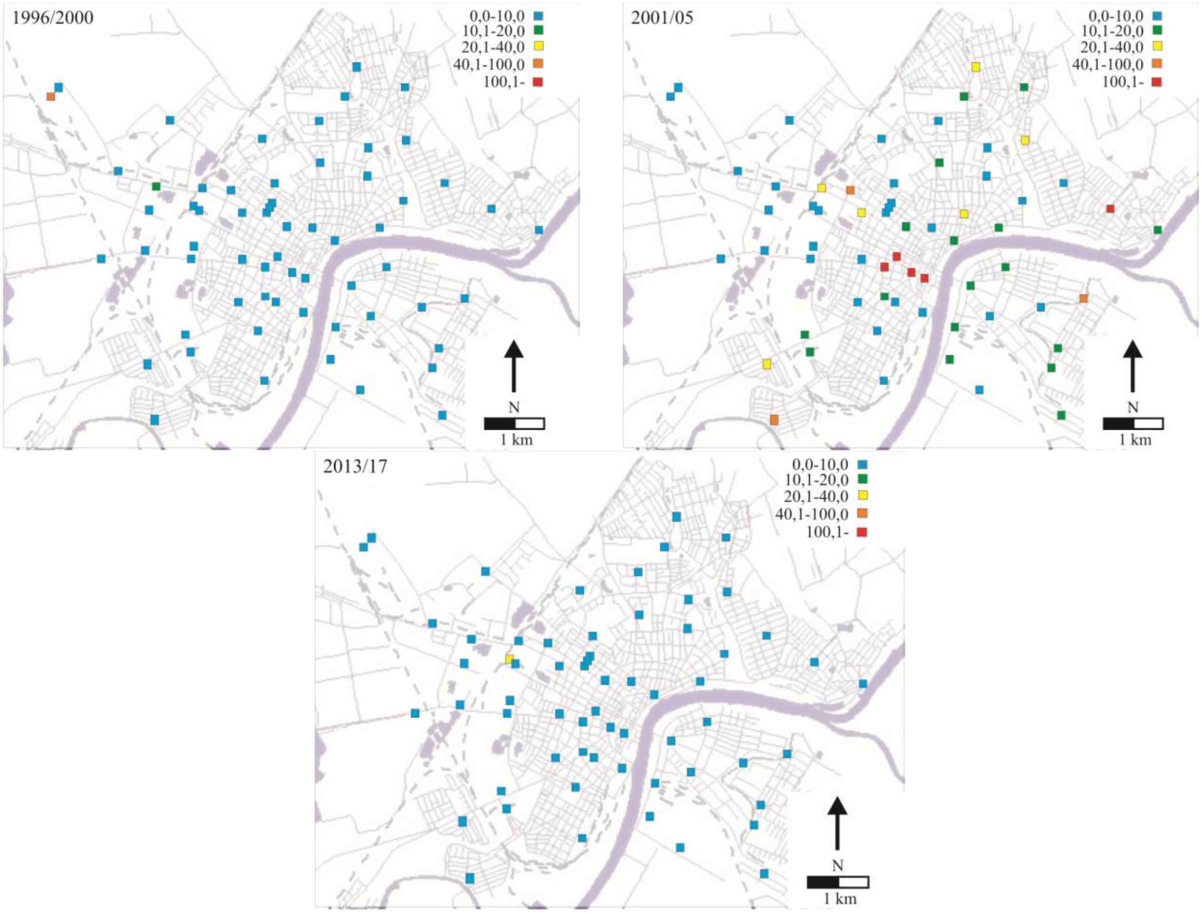

Fig. 9 Spatial distribution of Cu content (ppm) in tree-rings at Szeged in the periods of 1996/2000, 2001/05 and 2013/2017

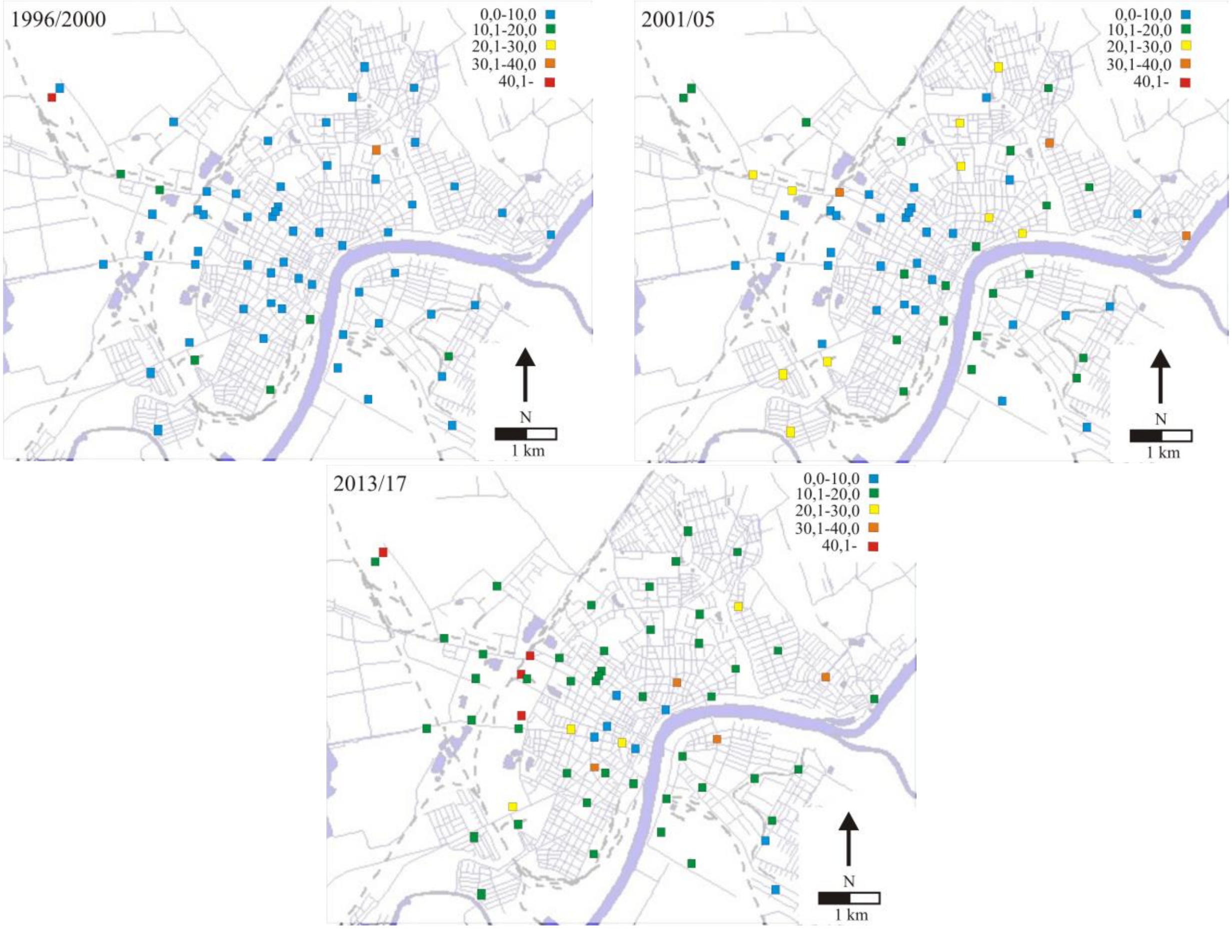

Fig. 10 Spatial distribution of Zn content (ppm) in tree-rings at Szeged in the periods of 1996/2000, 2001/05 and 2013/2017

DISCUSSION

Spatial and temporal changes in heavy metal bio-accumulation

In general, the living conditions of the urban trees (and other organisms as well) at Szeged was the worst in 2001/05, when the heavy metal pollution was the greatest, therefore the biomass production of the sampled trees decreased (-28%). It is parallel to the results of Fischer et al. (2002), who found negative correlation between tree-ring width and its lead content. However, the living conditions of the trees in Szeged did not become more favourable ever since, nor it became worse, as the biomass of the tree-rings remained the same. This reflects that despite of the decline in heavy metal pollution some other stress factors became stronger, creating unfavourable urban environment for the trees. Probably the low wood-biomass is connected to the hotter and drier summers (Ladányi and Blanka-Végi, 2015), as Szeged is the hottest city in Hungary.

The temporal change in lead pollution (considerable decline in 2013/17) could be explained by the obligatory usage of lead-free petrol. In Hungary it is used since 1999, but no data exists for the neighbouring countries (Romania and Serbia), though the international traffic through the city was high until 2011, when a circular highway was built to divert the through-traffic from the town., though some years had to be passed to eliminate from the air. Thus, the first period (1996/2000) was characterised by intensive lead emission, and during the second period (2001/05) its amount was supposed to decrease. However, the comparison of the periods suggests, that the introduction of unleaded petrol had delayed favourable results, as by 2001/05 the lead content of the tree-rings increased by 3-4 times, and it decreased just later, in the third period. This could be explained by the fact, that lead is connected to small dust particles (Pasinszki, 1996), these particles just gradually became fixed in the soil or they were washed out from the town during heavy rains, thus these particles probably circulated in the air for a while. The extended presence of the lead in the air was also proven in 2005 (Csemete Association, unpublished report, 2006). This temporal lag of lead output from the city suggests, that the lead (and also other heavy metals) could be-mobilised repeatedly in the city, thus it was repetitively available for foliage up-take for the trees much longer, then it was expected. The cadmium pollution also declined in 2013/17, after the international traffic was diverted from the city. The cadmium pollution is connected to the usage of brake-linings (Grigoratos and Martini, 2015), thus as the transit-traffic decreased after the construction of the M43 highway in 2011, much less cadmium could get in the air.

Along the studied busy roads, the bio-accumulation of lead in tree-rings was twice as much as along less busy roads during the first and second period, fitting to former European studies (Watmough, 1999). In the third period the differences in lead content was smaller, however its spatial trend was the same. Along the quite busy Bajai road and Kossuth road the lead concentration gradually increased towards the city centre, though at Kossuth road it decreased at a large junction (Fig. 8.). This phenomenon reveals, that the outer ring-roads, which divert the traffic, play important role in decreasing the environmental load of a city. This phenomenon points on the importance of road diversions, which could be applied to decrease the environmental load of the heavily built-in areas, as in these cases the narrow and badly ventilated streets enclosed by high houses trap the dust particles containing lead. This idea is supported by the measurement of Pasinszki (1996), who found positive linear correlation between the rate of deposited dust and the lead pollution of the air.

In our case the pollutants were dispersed further from the busy road, then it was reported in the literature, as according to Kardell and Larsson (1978) the busy roads effect the pollution of the side roads just within 20-25 m buffer zone, while at Szeged the effective distance is ca. 30-40 m.

Whilst the lead and cadmium content of the tree-rings decreased during the studied decades, the trees accumulated increasing amount of zinc throughout the studied periods. Nor the zinc, neither the copper content of the tree-rings reflects any spatial tendency along the main roads, thus they are not related to traffic. According to the data their concentrations are proportional to the age of the tree, the size of the canopy and root system. Thus these elements either could be deposited from the air and in this way they got onto the leaves and into the tissues, or could be up-taken from the ground-water, as the larger the canopy of a tree the denser and deeper its root system is. Unfortunately, no data exists on the air pollution of the city, but presumably the copper pollution originated from an agricultural activity, as copper is often used in pesticides. The greatest zinc pollution characterised the trees growing at the outskirts, along the Tisza River and an ox-bow-lake of the Maros River. Thus, probably the zinc was transported to the town by wind or by ground water. The root-uptake could be verified by the fact, that the water and the sediment of the Maros River contains large amount of zinc (Waijandt and Bancsi, 1989; Kiss and Sipos, 2001), and also the ground water has high zinc content (Fejes 2014).

Relationship between the type of built-in areas and heavy metal content

The spatial distribution of the studied heavy metals was compared to the built-in types of the city, referring to the environmental load of a given area, thus to the life conditions of the citizens. Some heavy metals were deposited from the air and were built into the tree-rings through leaf-uptake, probably similar rate of heavy metals could get into the human body through inhalation. It is especially valid for the lead and cadmium pollution, which are both closely related to the traffic and its dust production.

The mean heavy metal pollution of the *densely built-in city center* was relatively low in 1995/2000 and 2013/17 (Fig. 11). It could be probably explained by the shading effect of the tall, densely built detached houses, thus the pollution could not spread far from the sources. However, in the period of 2001/05 this area became polluted. Until 2005 the lead-born environmental risk of this area was closely related to traffic and to the usage of leaded petrol, but only those areas and living organisms were closely affected, which located in 50-60 m distance from the main roads, or at local or regional bus stations.

The environmental status of the *northern living areas with block-of-flats* is relatively good, except along the busy roads, where the data of the first two measurement periods refer to medium of moderately bad pollution. However, the environmental status of these areas also improved.

Some parts of the *suburban* areas are the most polluted. Toward the industrial area and the city centre (Rókus, Alsóváros suburbs) the environmental load increased until 2001/05, but since that time these areas became less polluted. In general, the south-eastern part of the town (Újszeged) is the less polluted. Relatively large concentrations were built only along the roads or at some points, where previous waste disposals or traffic junctions were located.

The northern *industrial area* is the most polluted, though the other small industrial centres are also characterised by high values. These are such a places of the town, where though the absolute heavy metal concentrations in tree-rings is decreasing, but these concentrations compared to the other parts of the city are still high. In these neighbourhoods housing is rare, thus these areas are responsible for relatively low environmental risk for humans.

It could be stated, that the tissues of urban trees, as living organisms, reflect considerable changes in spatial and temporal dispersal of pollutants. In the first period (1995/2000) the city of Szeged was characterised by low heavy-metal load, but during the next period (2001/2005) the situation considerably became worse, as heavy metals appeared in all studied trees all over the city, and even worse than that, their amount was multiplied. Fortunately, the environmental conditions became better, only there are some points in the industrial area, where the heavy metal pollution of the environment is gradually increases.

CONCLUSIONS

According to former researches (Lepp, 1975, Kardell and Larsson, 1978; Temminghoff et al., 1998) the copper, cadmium and lead uptake of trees is the greatest through the foliage. Some metals could be relatively mobile in the soil, however, only at low pH values (Csathó, 1994), but the soils in Szeged city are slightly basic or basic (Fejes, 2014). Therefore, at Szeged the heavy metals above probably originated from air pollution, and they got into the tree-rings through foliage uptake. This is also supported by the spatial distribution of pollutants within the city, and their temporal changes.

The heavy metal content of tree-rings considerably increased in the second period, in 2001/05, compared to the previous and subsequent periods. While in the first period only some sampling points were considered as polluted, in 2001/05 the urban environment of Szeged was affected by higher and more uniform heavy metal

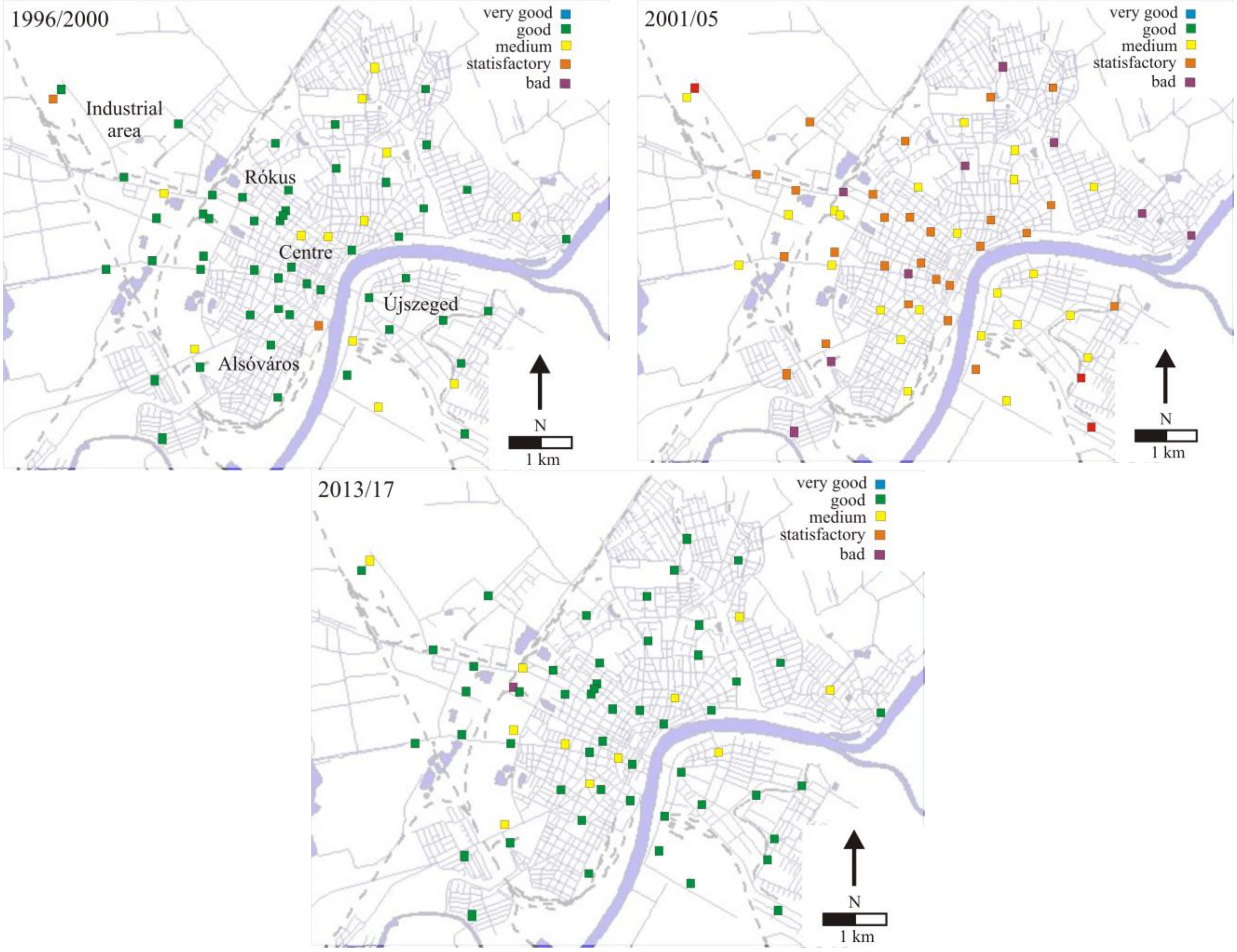

Fig. 11 Changes in environmental status of the sapling points based on the summarised heavy metal load of the tree-rings

pollution. The deteriorating life conditions are also shown by the declining biomass. Though the environmental hazard due to heavy metal pollution seems to be reduced, other factors (e.g. drought, heat-stress) increase the exposure of urban trees to environmental stress, thus the tree-ring width and biomass production remained low.

The spatiality of heavy metal concentrations in tree-rings refers to the variations in environmental load of the various parts of the city. The greatest amount of pollutants was measured in trees along the busy main roads and in the north-western part of the city. Some parts of the heavy metal pollution (lead and cadmium) is undoubtedly originates from traffic, while other parts (copper and zinc) originates from other (yet unknown sources) and the trees can accumulate them through the root-system (from groundwater) or the leaves (from air). As the lead and cadmium pollution mainly appear along within 30-40 m buffer zone of main roads and busy junctions, the environmental status of these areas improved since the usage of unleaded petrol and the diversion of international through traffic. The spatial pattern of some heavy metals (copper and zinc) is changing by time, and in case of zinc more and more sampling sites are polluted, and the degree of pollution also increases.

This researched proved, that a long-term bio-monitoring study is a useful tool to analyse the spatial and temporal changes of the environmental risk, which does not only determine the living conditions of urban trees, but also influences the quality of the human environment.

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