Bioindication of atmospheric trace metals – With special references to megacities

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Abstract

After considering the particular problems of atmospheric pollution in megacities, i.e. agglomerations larger than 5 mio. inhabitants, with urbanization of World’s population going on steadily, possibilities of active biomonitoring by means of green plants are discussed. Based on specific definitions of active and passive bioindication the chances of monitoring heavy metals in Sao Paulo megacity were demonstrated (first results published before). This is to show that there is need for increased use of bioindication to tackle the particular problems of megacities concerning environmental “health”, the data to be processed according to the Multi-Markered-Bioindication-Concept (MMBC). Comparison to other work shows this approach to be reasonable.

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1. Introduction

Numbers of towns steadily increase globally. Some 200 years ago (in 1800) just 25% of German population lived in cities, as opposed to 75% in rural environments, while in 2005 the population share of German towns had increased to 85%. Similar developments are observed in all industrialized countries: as of 2005, the corresponding shares of urban populations were 61% in Eire, a stunning 97% in Belgium, 77% in France, 90% in UK, 66% in Japan, 73% in Russia and 81% in USA. The increase in number and average population was largest in megacities (megacities are not subject to an unequivocal definition but usually the minimum is taken to be 3 mio. inhabitants [about the size of Rome, Chicago, Kiev, Montreal, Berlin, or Sydney], but sometimes higher limits of five, eight, or even ten mio. inhabitants are taken). Anyway, we will count Mexico City (23 millions), São Paulo (20 millions), Beijing (17 millions), Buenos Aires (15 millions) Rio de Janeiro (11 millions), and Santiago de Chile (5 millions) among the megacities.

Atmospheric burdens are enormous in megacities. If pregnant women are exposed to CO, the fetus will be harmed. Likewise, experts agree that car exhaust gases strongly damage children’s health, including effects on behaviour and psycho-social development (Chelala, 2010).

In Mexico City, which is notorious for air pollution (at a total of >4.5 mio tons/a of hazardous substance inputs), also children are exposed, with authorities keeping them from attending school if the extent of pollution in town is particularly high. Mexico City is not an exception; about the same holds for almost all large cities in the Western hemisphere but also in Chinese cities, Lagos in Nigeria, or in Tehran the capital of Iran and others.

Due to high levels of atmospheric pollutants, inhabitants of Santiago de Chile struggle with chronical respiratory diseases. There, pollutants stay airborne longer than elsewhere and hence
accumulate due to topographical and climate peculiarities, with Santiago “sandwiched” in between the (Pacific) ocean and nearby Andean mountains.

Neither, Buenos Aires will escape these problems. Due to both pollutant and noise emissions, it became one of the most polluted cities in the World (Chelala, 2010).

In terms of extent and hazards, air pollution does compete against other forms of pollution coming from waste materials, including pesticide residues and toxic industrial wastes. In Santiago de Chile, some 300 million cubic meters of untreated sewage water are estimated to be poured into the two rivers and the main watering (1) channel of this metropolis (Chelala, 2010).

All the environmental compartments air, water, soil and the biocoenoses associated with them are considerably influenced by a larger number of both biotic and abiotic factors (Ellenberg et al., 1986; WHO, 1996; Haber, 2009; Zhu and Jones, 2010). Owing to an increasing extent of anthropogenic activities, the environment is especially influenced by chemical pollutants (Lee and Tallis, 1973; Adriano, 1992; Loppi and Bonini, 2000; Freitas et al., 2006; Franca et al., 2007). This diverse group of potentially hazardous substances contains a larger number of organic compounds and chemical elements as well as “heavy” metals (e.g. mercury and tin), so-called semi-metals (e.g., arsenic and antimony), and organo-metal compounds (like tributyl tin). Once they get accumulated in soil, ground water or organisms, drawbacks for certain members of a trophic chain may become unpredictable yet grave (Markert et al., 2003; Marcovecchio and Ferrer, 2005; Rauch, 2010; Wolterbeek, 2002; Wolterbeek et al., 2003, 2010; Zhu and Jones, 2010).

Already ancient high cultures used metals to an extent emissions from which can be detected globally by corresponding depositions in e.g. Greenlandic ice cores. During the last 150 years, however, anthropogenic emissions got that large that negative effects on man and his environment were no longer restricted to the regional surroundings of emission sites (Markert et al., 1994; Fraenzle and Markert, 2007). Accumulation being a slow, unconspicious process which, however causes a likewise slow damage to living organisms requires a meticulous and constant surveillance of deposition of chemical elements (and likewise organic compounds, also) and of their impacts to living nature (Baker and Brooks, 1989; Wuenschmann et al., 2008). Emissions into the atmosphere are often monitored by means of (technical) deposition collectors whereas in aquatic monitoring a running a deposition sampler. Hence bioindicators can be means of measuring emissions, doing bioindication takes much less expenditures in both personnel and apparatus than e.g. running a deposition sampler. Hence bioindicators can be employed throughout large areas provided the organisms are sufficiently far-spread and abundant, enabling investigations which cover entire countries or even continents which could be done otherwise only if accepting very high demands of work and money. Using one or several (different) organismic species for purposes of estimating environmental burdens brings about yet another advantage: beyond statements on the very organism which is embedded in some ecological niche within an ecosystem, hence analytical data obtained on it can be integrated into a more comprehensive biological system. Thus beyond the very bioindicator ecologically relevant statements are possible on larger parts of the biocoenosis due to the biotic interactions which interconnect them, unlike when using direct physico-chemical methods.

The aim of this study is, to demonstrate that bioindication methods can be used effectively in so called megacities. Here especially active bioindication methods are of importance, because the bioindicational organisms are not simply available in the megacity, they have to being exposed for a time.

Fig. 1. Distribution map of Zn in the metropolitan region of São Paulo (June/July 2003).

<table>
<thead>
<tr>
<th>Stations</th>
<th>City Region</th>
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<tr>
<td>ST</td>
<td>Santana</td>
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<td>IB</td>
<td>Ibirapuera</td>
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<td>CG</td>
<td>Congonhas</td>
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<tr>
<td>SA</td>
<td>Santo Andre</td>
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<td>SC</td>
<td>Sao Caetano</td>
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<td>MA</td>
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<td>CC</td>
<td>Cerqueira Cesar</td>
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<td>PI</td>
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<td>DP</td>
<td>Parque D. Pedro</td>
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<tr>
<td>SM</td>
<td>Sao Miguel</td>
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</tbody>
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1. Zn
2. São Paulo
3. São Paulo metropolitan region
4. São Paulo extended city
5. Ibirapuera
6. Congonhas
7. Santo Andre
8. Sao Caetano
9. Maua
10. Cerqueira Cesar
11. Pinheiros
12. Parque D. Pedro
13. Sao Miguel


Because bioindicators do integrate environmental burdens (by chemicals) over time of experiment at their sites, (very) short-term variations are cancelled out. As compared to “conventional” methods of measuring emissions, doing bioindication takes much less expenditures in both personnel and apparatus than e.g. running a deposition sampler. Hence bioindicators can be employed throughout large areas provided the organisms are sufficiently far-spread and abundant, enabling investigations which cover entire countries or even continents which could be done otherwise only if accepting very high demands of work and money. Using one or several (different) organismic species for purposes of estimating environmental burdens brings about yet another advantage: beyond statements on the very organism which is embedded in some ecological niche within an ecosystem, hence analytical data obtained on it can be integrated into a more comprehensive biological system. Thus beyond the very bioindicator ecologically relevant statements are possible on larger parts of the biocoenosis due to the biotic interactions which interconnect them, unlike when using direct physico-chemical methods.
2. Transferring the method of bioindication to megacities

In the past 10 years more and more activities were undertaken to transfer the bioindication method into the pollution control observations of so-called megacities. In the following, we would like to report on results of São Paulo (Figueiredo et al., 2001, 2007), the biggest megacity of Brazil having around 20 million inhabitants. For this reason, *Tillandsia usneoides* L., an epiphytic bromeliad plant, was chosen, because this plant is able to absorb water and nutrients directly from the air (Vutchkov, 2001; Vianna et al., 2010). Five consecutive transplantation experiments (8 weeks each) were performed in 10 sites of the city, submitted to different sources of air pollution (industrial, vehicular), using plants collected from an unpolluted area. After exposure, trace metals were analyzed in the plant by instrumental neutron activation analysis. Distribution maps (Fig. 1) were drawn, which demonstrate that traffic related

Fig. 2. Enrichment of the element Zn (%) in *Tillandsia usneoides* to the exposure period and exposure site (Figueiredo et al., 2007). Exposure period: A – April–May/2000; B – June–July/2002; C – Nov./2002–Jan./2003; D – Feb.–April/2003; E – April–May/2003. Stations: ST – Santana; IB – Ibirapuera; CG – Congonhas; SA – Santo Andre; SC – Sao Caetano; MA – Masa; CC – Cerqueira Cesar; PI – Pinheiros; DP – Parque D. Pedro; SM – Sao Miguel (Figueiredo et al., 2007).

2. MMBC: Multi-Marked-Bioindication-Concept, an integrative approach on human health care which draws upon a multidisciplinary input organized along several integrated and functional “windows”. MMBC is one way how bioindicative toolboxes may be organized in a hierarchical framework for purposes of human and ecotoxicology. In toolboxes MED and ECO, respectively, there are single sets of tests for functional combination in order to obtain an integrated approach towards some specified scientific problem. Toolboxes HSB (Human Specimen Banking) and ESB (environmental specimen banking) derive from years of research using sample banks for both human and environmental toxicology; thus they can complement MED and ECO by important information on toxicological and ecotoxicological features of environmental chemicals. This integrated approach is not only to link all the results but to corroborate them by data already available from (eco-)systems research, toxicology, environmental monitoring and specimen banks. Toolboxes TRE and DAT provide parameters required to accomplish this (Markert et al., 2003).

Fig. 3. MMBC: Multi-Marked-Bioindication-Concept, an integrative approach on human health care which draws upon a multidisciplinary input organized along several integrated and functional “windows”. MMBC is one way how bioindicative toolboxes may be organized in a hierarchical framework for purposes of human and ecotoxicology. In toolboxes MED and ECO, respectively, there are single sets of tests for functional combination in order to obtain an integrated approach towards some specified scientific problem. Toolboxes HSB (Human Specimen Banking) and ESB (environmental specimen banking) derive from years of research using sample banks for both human and environmental toxicology; thus they can complement MED and ECO by important information on toxicological and ecotoxicological features of environmental chemicals. This integrated approach is not only to link all the results but to corroborate them by data already available from (eco-)systems research, toxicology, environmental monitoring and specimen banks. Toolboxes TRE and DAT provide parameters required to accomplish this (Markert et al., 2003).
elements such as Zn (and Ba, not given in Fig. 1) presented high concentrations in exposure sites near to heavy traffic avenues (cars, buses and trucks) and may associated to vehicular sources (Ribeiro et al., submitted for publication).

For Zn (and Co) the highest contents were related to industrial zones and can be associated to the presence of anthropogenic emission sources. The rare earth elements, Fe and Rb probably have soil particles as main source.

In Fig. 2 the enrichment in concentration for Zn in T. usneoides exposed in the monitoring sites in relation to the concentrations measured in plants from the control site during the monitoring period is represented. In many cases, the highest increase in concentration occurred in winter time (Exposure B: June–July/2002), in opposition of a period of lower enrichment in relation to the control sample observed in summer (Exposure C: Nov/2002–Jan/2003). These seasonal changes in relation to a summer/winter oscillation is already well know to other epiphytic plants, as mosses (Markert and Weckert, 1993).

Highly promising “starter projects”, to introduce bioindicative methods into other megacities were already done f.e. in Beijing by Wang et al., 2010, 2011. In these investigations special interests were focused on the pollution status of soils.

3. Discussion – construction of a setup for preventive healthcare and conclusions/outlook

With bioindicative methods being used for monitoring release, distribution, effects and control of pollutants an integrative approach towards monitoring on larger spatial scales – as well as including quite diverse sets and sources of information – is suggested (Multi-Markered-Bioindication-Concept, MMBC), meant to be eventually used for preventive healthcare on the scale of counties (Fig. 3). Fig. 3 represents only one proposal of a complete dynamics environmental monitoring system supported by bioindication to integrate human and ecotoxicological approaches. It can be recembe its measurements parameters according to the particular system to be monitored or the scientific frame of reference. Therefore it seems to have good chances to being transferred into use for the pollution control observation in megacities.

To come closer to a prophylactic healthcare system (independent of in megacities or in smaller cities or rural areas) we should come to a more integrated thinking on an international, interdisciplinary and intercultural level (Simeonow and Simeonova, 2009). For overcoming existing gaps during the international cooperation we are working in different fields assisting us in understanding problematic issues in use of bioindicative and biomonitoring methods for dealing with the status of our environment. Without their strong advices, discussions and assistance during the past 25 years, a development in the form described in this paper would never been possible.

For sure we are thankful to Prof. Bill Manning and the local organizers of the Urban Environmental Pollution (UEP) conference in Boston for opening the first author the possibility to giving his thoughts to an international audience, and Elsevier, especially to Gert-Jan Geraeds and an independent reviewing committee, to accepting this talk as an invited paper for Environmental Pollution. Kay Russell and her team of Elsevier is deeply thanked for the perfect logistically organisation during the exciting days in Boston.

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