Urban ecological risk assessment using the sediment quality triad

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Abstract

Rapid urbanization has occurred all over the world in recent years. It has both provided reliable infrastructures and better living conditions, as well as resulted in numerous urban ecological and environmental problems. Ecological risk assessment has been proposed and applied in many cities. The sediment quality triad, consisting of different lines of evidence, comprises a weight-of-evidence framework for regional risk assessment. As a preliminary study, this paper measures the concentration of Polycyclic Aromatic Hydrocarbons in five dust samples collected in Nanjing via chemical tests. Our results demonstrate that dust from different functional areas contains different compositions and concentrations of PAHs.

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Keywords: Urban ecological risk assessment; Sediment quality triad; aggregate risk

1. Introduction

Rapid urbanization has taken place worldwide in recent years. Indeed, cities in China have also undergone fast industrialization and urbanization processes. With population aggregation, land use change, and industrialization, urbanization produces a series of ecological and environmental effects. As the main driving force of urbanization, the industrialization process both provides reliable infrastructure and better living conditions but also causes numerous urban ecological and environmental problems. Within the industrialization process, complex chemical substances generated during production or waste disposal procedures inevitably enter the environment, and these compounds may pose a grave threat to the health
of both humans and other organisms. Increasingly adverse effects may appear in the subsequent years, especially in situations where the industrialization process occurs without effective regulation and management.

Commonly used laboratory monitoring methods have become increasingly unsuited to the needs of environmental management. Additionally, many contaminants are negligible due to the minute quantities released from industry processes. However, these chemicals can distribute, transfer, and then accumulate both in the environment and in vivo, and their harmful effects may take years to appear. Thus, an effective method is required to assess potential sources of ecological risk and their aggregate effects.

In most cases, air pollution, water pollution, and noise pollution in urban areas have already been studied. Increasingly serious air pollution is found in more and more cities. For instance, 522 cities in China were monitored in 2005, 56.1% of which did not meet the national ambient air quality second standard and 39.7% of which suffered moderate or severe pollution. The inhalable particles (e.g., PM_{10} and PM_{2.5}) remain as the primary pollutants affecting air quality in most cities. The majority of urban populations have lived in situations in which inhalable particles exceed air quality standards over the long term. High levels of toxic metals and organic contaminants (e.g., PAHs Polycyclic Aromatic Hydrocarbons) are contained in these inhalable particles. Such contaminants may cause several types of health hazards, such as genotoxicity [1]. The inhalable particles’ negative effect on urban ecosystems is hidden, potential, and long-term, while the threat to creatures’ health is direct and sometimes even fatal.

In this context, a method to assess the aggregate urban ecological risk of inhalable particles is proposed and preliminarily studied.

2. Method

2.1. The sediment quality triad (SQT)

The SQT was originally developed to examine the sediments in marine environments and consists of three components: chemical analyses, bioassay tests, and in fauna observation [2,3]. Based on measures of each component (chemistry to determine chemical contamination, bioassays to determine toxicity, and benthic community structure to determine the status of in fauna arguably exposed to the sediment), the sediment quality determines the correspondence among measures of these three components [4]. When integrated together, the data from measurements provide information regarding the possible biological significance of chemical aggregations in sediments. Since the SQT was initially proposed, the approach has subsequently been refined to meet the requirements of research [5-7]. This method has been widely used to assess the effects of both chemical and non-chemical factors.

The three original components of the SQT (sediment chemistry, sediment toxicity, and benthic community structure) are proposed as three line of evidence (LOEs). Although these three LOEs serve as the primary basis for the SQT, there is no limitation that only three specific LOEs can be used [6]. The first two LOEs (i.e., sediment chemistry and sediment toxicity) have been consistently used in all research. The possibility of different LOEs focuses on the third LOE. A variety of LOE replacements, modifications, and additions to the third LOE (e.g., alterations to resident communities) has been proposed and applied [3,8-12].

Effectively, each LOE provides an independent assessment of hazards, with the combination and integration of these hazards providing a screening-level ecological risk assessment (ERA), which results in a weight of evidence (WOE) framework determination related to the risk possibly posed by contaminated sediments [4].
It is obvious that the SQT approach was explicitly derived for use with contaminated aquatic sediments. However, its use is not restricted to aquatic sediments; it can also be adapted for any sediment type or other media [10,13-15].

2.2. ERA

ERA is a flexible process for organizing and analyzing data, assumptions, and uncertainties to evaluate the probability of adverse ecological effects that may have occurred or occur as a result of exposure to one or more stressors related to sources of ecological risk. The concept of ERA was first proposed by the U.S. Environmental Protection Agency (US EPA) in its Framework for Ecological Risk Assessment [16]. Then, the Guidelines for Ecological Risk Assessment [17] presented an ERA framework consisting of three primary phases: problem formulation, analysis, and risk characterization. The objective of ERA is to provide reliable quantitative evidence for ecological environment risk management and decision making.

It is challenging to determine whether an ecosystem is impaired. The complexity of direct and indirect interactions between physical, biological, and chemical components with their varying temporal and spatial scales generally renders the use of multiple assessment approaches mandatory, with a consequent need to integrate different LOEs. Integration generally involves some form of weight-of-evidence (WOE). In regional ecological risk assessment, relative risk assessments based on WOE are widely used [18]. WOE approaches reported in the literature broadly vary from subjective and qualitative to quantitative. The categories of WOE include qualitative combinations, expert ranking, consensus ranking, semi-quantitative ranking, and the SQT. WOE approaches can be used in retrospect assessments, causation assessments, and the entire ERA process.

In term of the generally accepted risk assessment framework [17], the SQT provides the basis for contaminated sediment risk assessment (Figure 1). Sampling and analysis plans identify the problem formulation, sediment chemistry is used to assess exposure, and sediment toxicity tests assess any alterations to resident communities to determine the effects. Furthermore, with specific additional LOEs, such as in situ sediment toxicity, the SQT can determine the causation of risk, which is beneficial for risk management decisions [19].

For less restriction in LOEs, the future application of the SQT allows direct measurements for all components of a risk assessment as long as the appropriate LOEs are chosen. Chemical and non-chemical stressors can be considered according to the receptors of potential concern. With causation LOEs, the SQT provides both a screening-level risk assessment and a more detailed risk assessment, which can directly indicate what is causing impacts to inform risk management and decision making.
2.3. Aggregate urban ecological risk of inhalable particles

The contaminants in inhalable particles are transported and accumulate in the environment, and urban dust has been a focus in this context. Urban dust is defined as surface solid particles that are < 20 mesh size (0.841 mm), scattered in different areas of the city, and composed of dust from the street, regional dust, and atmospheric dust [20]. Urban dust is also expressed as surface (road) sediment in research on contaminant distribution and aggregation [15]. The dust acts as a sink and source of pollutants in urban environments [21], especially atmospheric aerosols, and there are complex genesis and evolution relationships between them. Specifically sized particles of urban dust can gain access to the human body by respiration, ingestion, and skin absorption. Urban dust is a valuable archive of environmental information and can act as a useful indicator of local air pollutant transport and deposition [22]. Hence, urban dust can be used to indicate the accumulation of atmospheric inhalable particles such as PM$_{10}$ and PM$_{2.5}$ in the environment.

In developing countries, especially in some areas with congregate large population that are experiencing rapid urbanization and industrialization processes, a more in-depth ERA of to exposure to industrial pollutants is required.

The SQT meets the demands of urban ERA within types of risk stressors and receptors. Additionally, in the assessment of risks posed by industrial pollutants, the SQT minimizes uncertainties and provides
information to address primary objectives: 1) providing direct measurements of exposure and the effects of contaminants, 2) identification of problem areas where contamination is causing adverse ecological effects, 3) prioritization and ranking of such areas according to their risk degrees, and 4) providing risk-based information for decision-making in risk management.

3. Sampling

3.1. Sample sites selection

Downtown Nanjing City was chosen as the study area, with the Nanjing Chemical Industry Park as the pollution source. To avoid the influence of the rainy season, sampling occurred in autumn (November). In autumn, the dominant wind direction in Nanjing is northeast. Considered the position of the urban zone and the Nanjing Chemical Industry Park, a northeast wind was considered the main wind direction when choosing the sampling sites.

One of Nanjing City’s leading industries is the petrochemical industry, which is a main source of PAHs. PAHs are a typical kind of persistent organic pollutant and are the most investigated organic environmental contaminants as objects of aggregate risk assessments. Main factories of the petrochemical industry, such as the Sinopec Yangzi Petrochemical Company Limited and the BASF-YPC Company Limited, are located in the Nanjing Chemical Industry Park. Nanjing Chemical Industry Park has three main areas: phase I, phase II, and an ecological green space between them, marked in Figure 2 as areas A, C, and B, respectively. We choose one of the areas as the center to draw concentric circles, spaced every 2 km, with eight equally spaced radials in the area that covers the urban zone to divide it into sampling units.

Using area A as the risk resource center, it can best represent the effect of petrochemical industries on contaminants in inhalable particles because the main factories are concentrated in phase I. Using area C as the risk resource center, it can best represent the influence of the main wind direction on the transfer of inhalable particles. Using area B as the risk resource center, it can represent the effect of the entire Nanjing Chemical Industry Park because it is the center of the park.

After surveying the three areas, it was obvious that the most polluted areas are area A and the towns near area A. Our objective was to determine the aggregate ERA for PAHs, so the effect of petrochemical industries on contaminants was the most important factor. Thus, we chose area A as the risk resource center and, taking the different functional areas into account, chose 18 of them to collect dust samples, of which eight units are vertical and eight units are horizontal.
Figure 2. Sample sites selection schematic diagram.
3.2. Sample collection

We used the plum-shaped distribution method to select three to five appropriate parallel sample points to collect dust samples at each sampling unit (central points to take the center of the sampling unit), mixed the dust sample from each sample unit equally, and took the mixed sample as the surface dust sample of the sample unit. To avoid interference from soil and vehicle exhaust, dust samples were collected from the windowsills of residential buildings located away from traffic arteries. Dust samples were collected with Ziplock plastic bags and brushes. To guarantee thorough sampling, only \( \geq 10 \text{-g} \) samples were valid. Fresh samples were loaded into storage bags and quickly delivered to the laboratory. There, the dust samples were freeze dried with a vacuum freeze dryer, filtered with a 200-mesh sieve, and refrigerated. For our preliminary study, we analyzed five sample collection units (N1-N5 in Figure 2).

Table 1. Sample collection list.

| Sample unit no. | Sample collection site                  | Site type        | Total sample weight (g) |
|-----------------|-----------------------------------------|------------------|-------------------------|
| N1              | Zhongshan scenic area                   | Clean area       | 34.44                   |
| N2              | Nanjing Chemical Industry Park phase I area | Pollution area  | 192.25                  |
| N3              | Ming Palace residential area            | Residential area | 97.74                   |
| N4              | Hunanlu business district area          | Business district area | 217.54                |
| N5              | Xinjiekou business district area        | Business district area | 151.87                |

3.3. Sample pre-treatment and analysis

N-hexane and acetone (1:1, 120ml) were used to extract a 1-g mixture dust sample at 100°C and 1500 psi by the accelerated solvent extraction process. After extraction, a chromatography tube filled with 2 g silicone and 1 g anhydrous sodium sulfate was used to purify the sample solution. Then, we used methanol to solvent exchange the sample solution and concentrated it to 2 ml.

In our research, we used HPLC with methanol and pure water (75:25) gradient elution to analyze the chemical concentration of PAHs in dust samples.

4. Results

The chemistry analysis results revealed that:

- The concentration of PAHs in a clean area (N1) dust sample was much less than other areas (i.e., 40.26% of a pollution area (N2), 44.15% of a residential area (N3), and 34.04% of a business district area (N4)). The clean area is in the Zhongshan scenic area; the high elevation and forest of this area prevent particulate matter from aggregating there.
- The composition and concentration of PAHs in a pollution area (N2) dust sample were similar to the business district area (N5). This indicates that the chemicals can distribute, transfer, and then aggregate at a long distance from the pollution resource area.
- The concentrations of PAHs in the business district area (N4 and N5) dust samples were much higher than the residential area (N3). Indeed, N4 is 29.69% higher than N3, and N5 is 9.95% higher than N3. This phenomenon is due to the fact that the business district area is more bustling than the residential area. However, even though we collected samples from the windowsills of residential buildings that are located away from traffic arteries, the influence of vehicle exhaust pollution still cannot be ignored.
5. Conclusions and outlook

According to the results of our preliminary research, we concluded that: 1) different functional areas contain different compositions and concentrations of PAHs in dust samples; and 2) vehicle exhaust pollution plays an important role in PAH emissions and should be further evaluated.

In our future research, the following problems must be resolved: 1) will the ecological risk be different according to the distance and the main wind direction’s influence; 2) how to integrate the chemical analysis data with the eco-toxicity data from the bioassay tests; 3) the dust sample quality is indicative of the long-term aggregation of contaminants of inhalable particles, but the exposure levels of humans and other organisms cannot be directly represented by the dust samples (i.e., data acquisition for exposure assessment is our next task); and 4) for effect assessment, the laboratory toxicity tests (cytotoxicity test) and in situ questionnaire for cancer incidence of the people who live around the sample sites are in progress to measure the ecological effect of the aggregation of inhalable particles.

Acknowledgements

This research was funded by the National Ministry of Science and Technology (No. 2007BAC28B03), the project “Research of ecological risk in fast urbanization region” (the National Natural Science Foundation of China, No. 40871262) and "the Fundamental Research Funds for the Central Universities".

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