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URBAN GREENING FOR LEAD SOILS POLLUTION CONTROL: THE USE ISOTOPE SIGNATURES ANALYSIS AND REMOTE SENSING

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ABSTRACT: This study aims to understand the assessment using NDVI analysis and lead isotopic ratio for helping informed decision-making process in the urban soil pollution aspects for Chelyabinsk, Russia. We used new combination of two modern approaches to study of industrial city urban greening such as (1) Pb-isotope approach for identification of pollution sources; (2) remote sensing-based analysis of urban landscape and urban forest using Normalized Difference Vegetation Index (NDVI). We observed spatial variations in the NDVI calculated from Landsat satellite-observed data. The study was conducted in Chelyabinsk urban areas with different anthropogenic pressures. We used several new criteria for assessing the degree of geochemical transformation and pollution of the urban environment, and for identification of Pb pollution sources. Our results reveal that the polluted sites had a lower NDVI than the intact sites. We have identified typical mistakes in the urban areas greening and proposed modern strategies for increasing green cover in Chelyabinsk.

Keywords: Normalized Difference Vegetation Index (NDVI), Lead isotopes, Urban forest, Urban greening, Soils

1. INTRODUCTION

Cities currently occupy less than 2 percent of the world's land area, but they account for 80 percent of the world's gross domestic product (GDP) and more than 70 percent of carbon emissions. Until the 1950s, Russia remained a country with a predominantly rural population. The 1959 census showed that more than half of all residents lived in cities. Today 74% of Russians live in cities. Currently, there are over 1,000 cities in Russia. Most of them have a population of up to 50,000 people. The population of 16 cities exceeds 1 million people. Urbanization requires effective governance by national and local authorities. One of the modern solutions for the sustainability of the urban space is the use of urban greening. The value of urban green spaces has evolved over the years into an indispensable component of green infrastructure, incorporated into urban planning and design as an investment to improve the well-being of residents. Urban forests and urban greening play a significant role in the cultural, health-improving, sanitary-hygienic, and ecological state of the urban area. In connection with the ecosystem function of urban greening, modern approaches to the study of the state of urban greening are required.

Russian industrial cities are unique urban ecosystems. A range of production sites are located in a small area, but there are fewer people living in comparison with, for example, China, and there is less transport than in Asian megacities. Most modern Russian cities were built in the Soviet Union. Urban greening was taken into account in Soviet urban planning practices. Landscaping issues were associated with a whole range of planning and development issues in populated areas. The general planning structure of cities included the creation of the landscaping system. In part, these traditions have been lost. Recently, due to the rapid expansion of urban areas, an increase in the pace of urban construction, and the modernization of urban spaces (the expansion of roads due to the increase in the number of vehicles), the optimal greening of urban areas has been lost.

Modern tools, including remote sensing, can be used to develop effective strategies for the urban greening of Russian industrial cities. The open archive of the NASA/USGS Landsat Program can be used to build long-term models of urbanization. Landsat provides the longest continuous space-based record of Earth's land in existence. Landsat data can give information essential for making informed decisions about Earth's resources and environment. The unique combination of the fine spatial detail and high temporal resolution of Landsat images allows temporal assessments of individual urban areas at relatively low cost. It is possible to quickly understand the long-term changes in urban vegetation using Normalized Difference Vegetation Index (NDVI). NDVI generally represents the total amount of surrounding greenness (e.g., street trees and general vegetation in public and private spaces).

NDVI levels range between 0 and 1, with higher values indicating more greenness [1]. WHO suggests two main indicators of urban greenness: NDVI and the percentage of green area identified from land cover and land use maps.

Chelyabinsk is a typical industrial city. Its urban area is characterized by the concentration in a relatively small space of a large number of ferrous and non-ferrous metallurgical industries, a developed transport network, and rapid growth in urban construction. All this has led to residents of the city worrying about “black sky regimes” and the uncontrolled removal of green spaces. Despite the clear contribution of urban greening to improving urban quality of life and the existence of demands for urban sustainability, there is a methodological gap in evaluating the effectiveness of urban greening in Russian industrial cities. There is no protocol or methodology for assessing changes in urban greening and developing strategies for the development of urban greening. As a result, urban planning can be described as disorganized, deficient, and unrealized which means an increase in the effects of industrial activities, among which are increasing air pollution.

The Pb isotope ratio does not change in industrial or environmental processing, and retained its characteristic ratio from its sources. The Pb isotope ratios can be used to identify the sources and transport pathways of Pb in pollution studies [2-3]. The study addresses the following research questions:

RQ1 Does NDVI relate with Pb concentrations and sources in urban environment?

RQ2 What strategies are there for increasing green cover in Chelyabinsk?

2. RESEARCH SIGNIFICANCE

The novelty of this study is that this is the first time remote sensing has been used as tool for the analysis of the urban greening of a typical Russian industrial city. We used Landsat NDVI satellite data and physical and chemical analysis to search for solutions and recommendations for the modern organization of urban greening for city authorities. It is also useful because urban greenery shows positive associations with human health [4]. Green spaces play an important role in preserving the health of the population in cities. This is connected with the ability of trees to capture metalloids, which has a serious impact on human health [5]. Urban dust, ambient particulate matter (PM_{10} and $PM_{2.5}$) and rural surface soils are good indictors of the accumulation of metalloids contamination from human activities in urban environment [6-8].

3. MATERIALS AND METHODS

3.1 Study Area and Selection of Research Sites

Chelyabinsk is one of the largest industrial cities in Russia, with a population of more than 1 million people. The city has an unfavourable situation with urban pollution and is included in the national “Ecology” project, initiated by the decree of the President of Russia in 2018. The task of this federal project is to implement comprehensive action plans to reduce the emissions of pollutants into the atmosphere in 12 large industrial cities.

The Chelyabinsk urban and suburban area covers 501 km^2. The climate is temperate continental, the average temperatures in January and July are −16.4°C and 18.1°C respectively. There is 436 mm of annual precipitation. The prevailing wind directions are southwest and west. The average wind speed is 3 m/s.

The concentration of metallurgical enterprises in the Chelyabinsk urban area and a lack of effective planning have made it the centre of environmental problems. In particular, construction in Chelyabinsk which appeared after the implementation of a new city development plan. As a result, there have been significant changes in the environment and the landscape in recent years. The city’s green infrastructure suffered when hundreds of trees were cut down from wide roadside green spaces under the pretext of improving road safety, and with the modernization of the engineering network. An additional loss of trees was due to changing climatic conditions − abnormally cold winters and prolonged periods of heat and drought led to the death of many trees. As a result, there are numerous environmental and health problems in the city associated with damage to the urban ecosystem. There is a high level of public dissatisfaction in the city with the recent development and its impact on the green landscape, especially the clearing of trees.

A hierarchical typology of urban nature based on population density is often used for site selection. Most cities follow common patterns in terms of density. There are cities with high population density in the centre and a negative density gradient moving outwards, others have a lower population density in the centre and positive gradient moving outwards. Usually highly urbanized, moderately urbanized, and less urbanized areas located at different distances from the city centre are selected for urban research. However, we decided to take a different approach to site selection. The morphology of Russian cities is different from other cities around the world. In Chelyabinsk, the population density does not decline for some distance from the centre. High population density is typical for residential areas, which are usually located at a distance from the centre.

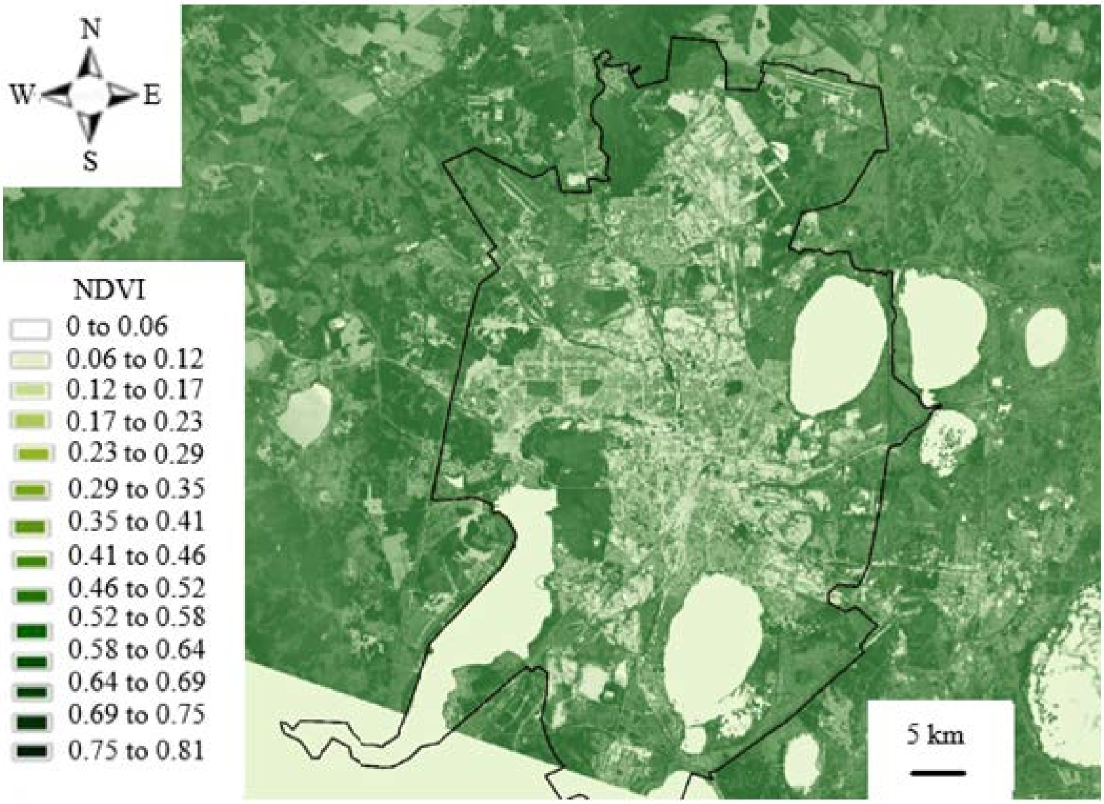

Fig. 1 NDVI image the Chelyabinsk urban area

Dense building in the centre of Chelyabinsk has led to a high population density there and near industrial enterprises, which are located in various parts of the city.

Despite the obvious ecological disadvantage of areas near industrial enterprises, people choose to live there because of the accessibility if they work at such an enterprise. Therefore, we used a different approach to select the studied green areas which were characterized by different ecological conditions and pollution sources. We chose three types of green area: urban forest, residential areas, and sites near industrial plants.

As urban forest we understood the forests which were present in Chelyabinsk urban areas. They were spring up naturally, and they have area not more than 1000 ha. This classification was chosen taking into account the peculiarities of landscaping in Russian cities. Each of the selected research sites were evaluated by NDVI (Fig. 1) in summer 2020.

3.2 Remote Sensing Data

In this study, Chelyabinsk’s urban green cover were monitored in July 2020 using satellite images. Landsat 8 OLI data for Chelyabinsk were downloaded from USGS. Landsat 8 was the most recent Landsat satellite and Landsat 8 OLI captures images with narrower spectral bands compared to Landsat 7 ETM+, but with an improved radiometric precision over a 12-bit dynamic range and higher signal-to-noise ratio. The OLI collects data in eight bands at 30 m resolution and one panchromatic band at 15 m resolution [9]. Thus, we used Landsat 8 OLI data in this study analyze the urban vegetation. In this study, four multispectral LANDSAT 8 OLI surface reflectance calibrated georeferenced images were acquired from July 03, 2020, July 10, 2020, 19 July 2020, 26 July 2020.

Data processing was carried out on ENVI 5.3 Software (Exelis Visual Information Solutions, Inc.; Boulder, CO, USA). The images were pre-processing, NDVI was threshold and after that we made classification of urban vegetation types. The imagery was already corrected for ortho-systematic and processed for pan-sharpening [10].

In this study we examine vegetation productivity in Chelyabinsk using NDVI, which is a well-established proxy for gross photosynthesis at different spatial scales [11, 12] and an index of vegetation greening, density, and development. NDVI was derived from Landsat 8 OLI band 5 (NIR, 0.851–0.879 µm) and band 4 (Red, 0.636–0.673 µm) as shown in Eq. (1) [13]. We define NDVI as a ratio of reflectance factors in the near infrared (NIR) and red spectral radiation bands:

Fig. 2 Sanitary felling in the urban pine forest

Fig. 3 Photos of studied area 2 in 2020

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}, \quad (1)$$

where ρ_{nir} and ρ_{red} are the surface bidirectional reflectance factors in their respective bands. NDVI sets on the contrast between the red and NIR vegetation reflectance, with chlorophyll being a strong absorber of red light, as far as leaves reflect highly in the NIR [14].

To assess the accuracy of the thematic mapping of urban greenery, data from test plots were used, which were established during field studies in summer 2020 of Areas 1–3 (Fig. 2–4). GPS-based field mapping was taken for them together with remote sensing data. We used Garmin® GPS/GLONASS receivers, they provide location accuracy up to 15 meters (49 feet) in 95% of cases.

Studied area 1 is urban pine forest. This site is located at a distance from industrial enterprises and transport interchanges. The total area of the Chelyabinsk urban pine forest is 12 square kilometres. It is a protected area. Pine (*P. sylvestris L.*) is the dominant tree species (91.4% of total). Poplar, maple, mountain ash and some other species were artificially planted. The natural regeneration of pine along the outskirts of the forest is difficult due to the large anthropogenic pollution load. Recently, trees have been cut down in the urban pine forest. The administration explains this by planned sanitary clearance work (Fig. 2).

Residents of Chelyabinsk believe that this will lead to the development of the territory and are actively protesting against this.

Studied area 2 is the landscaping of city center. In the Soviet Union, green dividing strips were located on the main avenues of the city and there was landscaping along the roadsides. A striking example is the main avenue of Chelyabinsk, Lenin Avenue (Studied area 2). At present, shrubs and apple trees are planted on the dividing strip (Fig. 3).

Fig. 4 Photo of an established park

Studied area 3 is the park in the metallurgical district. The metallurgical district is relatively green compared to other areas of the city. There is a park and a lot of green spaces (Fig. 4). The park has not only a recreational and aesthetic function, trees remove air pollution in the area located around the largest metallurgical plant. For a long time the park was not well maintained, but it is currently being reconstructed without the cutting down of large trees.

3.3 Sampling and Analysis of Topsoils

Topsoils (0–15 cm layer) were collected in 32 selected research sites and mixed in order to obtain a homogeneous sample. The soil samples were dried in an oven at 60°C for 3 d. Then they were crashed and sieved through a 1 mm polyethylene sieve to remove stones, coarse materials, and other debris. Samples were digested into 10 ml of aqua-regia solution (HNO_3: HCl v/v 3:1). The solution was incubated at room temperature for 24 h. Afterward, the solutions were heated to reflux for 15 min and set aside to cool. After digestion, the solution was filtered through a blue ribbon filter and made up to 50 ml with distilled water. The digested solutions of soils were analyzed for Pb content by mass spectrometry with inductively coupled plasma ICP-MS using Perkin Elmer ELAN 9000. The analyses were performed in triplicates. The Russian national state standard samples of soils GSO 10413-2014 CO of soil was used for checking the accuracy of the determination. Recovery of Pb was 108%.

3.4 Pb Isotopic Analysis

Lead isotope ratios ($^{206}Pb/^{207}Pb$, $^{206}Pb/^{208}Pb$) were determined by inductively-coupled plasma mass spectrometry (ICP-MS) using an Agilent 7700x equipment Agilent Technologies (Tokyo, Japan) an Isotope analysis mode. Equipment with nickel cones, employing an RF forward power of 1550 W and reflected power of 2 W, with argon gas flows of 1.10 L min^{-1} and 0.20 L min^{-1} for carrier and makeup flows, respectively, and peristaltic pumping or free aspiration rates into the Micro Mist nebulizer.

The solutions prepared for ICP-MS analysis were used for the chromatographic lead isolation. The lead isolation was carried out in accordance with conventional HBr–HCl procedure described by Seleznev [15]. Pre-cleaned polypropylene funnels (Vitlab, Germany) were filled with Bio-Rad AG 1 × 8 resin (100–200 mesh). Chemically resistant 11 μm glass wool (Carl Roth, Germany) was applied as a fitting to retain the resin in the column.

Isotope analysis acquisition mode was employed, with three points per unit mass and integration times of 1 s per point for all isotopes.

Sample solutions were diluted to 10 μg L^{-1}, where necessary, to ensure that they fell into the pulse count mode. A common lead isotopic reference material (NIST SRM 981) was used for mass bias correction. The mean analytical precision for the three lead isotopic ratios, $^{206}Pb/^{207}Pb$ and $^{206}Pb/^{208}Pb$, for the 18 duplicate soil samples, was ±4% and ±7%, respectively, for the soil digests.

4. RESULTS AND DISCUSSION

4.1 Overall Chelyabinsk Urban Greening and Pb Soils Analysis

NDVI image of the Chelyabinsk urban area (Fig. 1) depicts the areas under the study: city forest, tree planting along the roads, parks and landscaped areas in new districts.

NDVI value is low (0.3 or lower) in downtown supposedly due to the fact that greening is mainly represented by grass and bushes. The central part of the city lacks big trees with spreading crowns. On the outskirts of the city, the value of NDVI is much higher mainly due to the forests of tall trees surrounding the city. The NDVI values are given in Table 1 for each type of green area.

Table 1 NDVI and Pb concentration in soils average values of different type of urban greening

Green area type	Average NDVI	Pb concentration in soils, mg/kg
Urban forests	0.81	11.7
Residential areas	0.51	31.4
Industrial areas	0.24	112.9

The NDVI values range from 0 (lack of plants) to 1 (green areas), the NDVI value of 0.5 shows that the area is covered with bush and semi-dense forests, providing medium photosynthesis.

The city forest showed the best mean value (0.81), indicating vigorous trees; plants are of high density providing favourable photosynthetic activity. Landscaping near industrial plant marked low NDVI mean values (0.24). It means that this area almost lacks grass and bushes. The mean value of NDVI in residential areas was 0.51, indicating bush cover and lower level forest density with a medium level of photosynthesis.

It can be seen that the closer to industrial plants, the more lead contaminated soils. Soil pollution leads to inhibition of vegetation and a decrease in the average NDVI. We used the isotope ratio method to better understand the sources of lead in urban soils. Figure 5 shows that soil pollution occurs mainly with industrial dust.

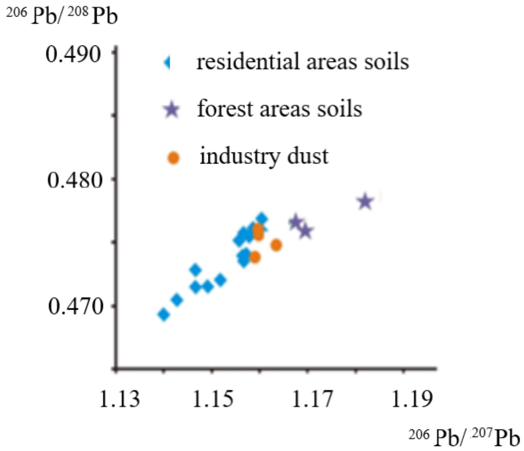

Fig. 5 2D-diagrams of Pb isotope ratios

4.2 Recommendations

4.2.1 Tree inventory

Urban green spaces are an example of man-made ecosystems that have an impact on the city's microclimate. Competent landscaping is an effective method for improving air quality. It must begin with an inventory of existing plantings (the number of trees and shrubs, and their condition). Such an inventory can be carried out using modern geoinformation technologies, as is done, for example, in Melbourne (Urban Forest project).

In Chelyabinsk, it is possible to simplify the identification of trees not to a species, but to a family, since the definition of a species is difficult and special knowledge is needed. The public, schools, and universities can be involved in the inventory as the amount of public funds is limited. A mobile application that, when the camera scans a tree leaf, determines whether it belongs to a family can be used. Such a method can become an element of environmental education, attracting young people to scientific work.

A public organization could be created which collects membership fees, and private donations and funds from enterprises whose budget includes the environmental activities. These contributions can be used for specialists – botanists and programmers – to create a database.

4.2.2 Planting trees with spreading crowns and creating green corridors

It is recommended to plant trees with spreading crowns along the sidewalks, as they shading the space and on a hot day reduce the temperature and make outdoor walks more comfortable. Such green pedestrian zones should be interconnected, creating continuous green corridors.

In Chelyabinsk there is a problem with poplar fluff, which is released in large quantities in early summer and leads allergic reactions. In addition, this fluff is highly flammable and can lead to fires causing significant damage (Fig. 6).

Fig. 6. The consequences of the wrong type of plant for landscaping-poplar fluff

Fig. 7 An example of unsatisfactory landscaping

For the winter period, when temperatures can be as low as −30ºC, and while minimizing the use of anti-icing agents, which have been shown to clog stomata. It would be useful to plant evergreens as most deciduous trees lose their leaves for the winter season. However, growth conditions must be taken into account − for successful growth, they need moist shaded territory, the absence of direct sunlight, which leads to the burnout of the needles, killing the trees (Fig. 7).

4.2.3 Modern non-standard solutions for landscaping

Rooftop gardens can improve the quality of life of urban settlers by lowering the air temperature. It is important to choose plants that are resistant to soil freezing in winter. The most reliable and winter-hardy plants were planted on the experimental plots: femoral-leaved rose, birch-leaved spirea, brilliant cotoneaster, rowan-leaved fieldfare, which endured the winter well.

5. CONCLUSIONS

Environmental lead contamination is prevalent in urban areas where soil represents a significant sink and pathway of exposure. This study characterizes the speciation of lead that is relevant to urban greening of Chelyabinsk, Russia. It is the first time when remote sensing and lead stable isotopes have been used as tool for the analysis of the urban environment. The follow strategies for increasing green cover in Chelyabinsk were proposed: making tree inventory database, planting trees with spreading crowns and creating green corridors, rooftop gardens.

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