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Geoinformation Modelling of Heavy Metals Spatial Distribution in Soils of Polyfunctional Towns

[1]Fedor Lisetskii, [2]Alexander Matsibora, [3]Iryna Kuraieva and [3]Yuliia Voitiuk
[1]Faculty of Mining and Natural Resource Management,
Belgorod State National Research University, 308015 Belgorod, Russian Federation
[2]Institute of Geography of the National Academy of Sciences of Ukraine, 01030 Kyiv, Ukraine
[3]M.P. Semenenko Institute of Geochemistry, Mineralogy and Ore Formation,
National Academy of Sciences of Ukraine, 03680 Kyiv-142, Ukraine

Abstract: Factors of anthropogenic load and heavy metals pollution of soils of polyfunctional town's urban-ecology systems are considered in the study. Geoinformation modelling of heavy metals spatial distribution has been performed within urban soils. Insight has been provided into a connection between functioning of anthropogenic objects and heavy metals gross content characteristic on the adjacent areas.

Key words: Urban soils, heavy metals, road transport, soil pollution, geochemical, assessment

INTRODUCTION

Among the geocomponents of the environment, the soil differs by a rather high sensing and possesses a pedomemory allowing it to register an action of pedogenesis natural factors as well as results of direct and indirect effect of human activity.

In the course of natural and especially during natural-anthropogenic evolution, the soils accumulate specific biogeochemical outputs of pedogenesis in its material composition. These peculiarities are determined by various environments: under natural reproduction renaturation (Lisetskii, 2012) in a subsurface state up to industrial epoch (Lisetskii *et al*., 2016), under prolonged exposure to different land use practice (Lisetskii *et al*., 2015). However, urban soils are mostly subjected to physical-chemical and sanitary properties. Soil cover of urbanized terrain in a result of industry facilities, transport infrastructure functioning amasses chemical elements in accumulative horizon in an amount different to its natural geochemical background.

The significance of soil pollution problem within urbanized terrain by heavy metals becomes apparent in number growth of scientific researches associated with various aspects of the issue in question regardless of the town's size, their functional characteristics and territorial allegiance. For certain urban-ecology systems with distinct predominant factors of anthropogenic load, the following issues become important: Fe, Cr, Co, Ni high concentration (Rizo *et al*., 2011), migration of chemical elements into a vegetable cover (Douay *et al*., 2007), mobility of heavy metals in urban areas, allocation of areas which can be considered as polluted (Giusti, 2011), determination of correlation relationships between soil characteristics and heavy metals content (Guo *et al*., 2004), distribution of elements along the profile (Korchagina *et al*., 2014), formation of geochemical barriers (Kosheleva *et al*., 2014), pollution peculiarities in different functional zones of towns (Linde e*t al*., 2001), impact of granulometric soil composition on chemical elements accumulation (Kaminski and Landsberger, 2011), toxic impact of heavy metals upon human physiology (Sialelli *et al*., 2011), estimation of anthropogenic load level through soil chemical composition (Thuy *et al*., 2000), ecological risk computation (Wang and Qin, 2008), contamination by steelworks and chemical plants (Lysychenko *et al*., 2017).

Evaluation of heavy metals supply by air to the soil surface with subsequent attachment and migration along the profile requires a special attention. Intensive technogenic burden upon the soil cover in the towns, a strong concentration of industry facilities generates a need for ecological factor consideration within development of urbanized territories and application of modern technological solutions in order to raise efficiency of urban-ecologic monitoring. Using of GIS technologies and database management in soil science is prospective and modern approach for storage and modeling of spatial information (Lysychenko *et al*., 2017). Formation of Spatial Data Bases (SDB) of geochemical indexes on

Corresponding Author: Fedor Lisetskii, Faculty of Mining and Natural Resource Management,
Belgorod State National Research University, 308015 Belgorod, Russian Federation

urban soils and modelling by means of GIS shall be the efficient tool in monitoring and evaluation of urban-ecology system ecological state.

MATERIALS AND METHODS

Study area: The investigation is concerned with the soils of urban-ecology system of Gayvoron town with a total area of 8.75 km^2 located in the central part of Ukraine (48°20'26" N, 29°51'59" E) within forest-steppe zone (average temperature of January -5 to -6°C, July +19 to +20°C, annual precipitation 600 mm) at a height of 126 m above sea level. Background soils of suburb are presented by Podzol Chernozem soils, though within the composition of urbanized terrain they suffered sufficient changes in morphological structure and physical-chemical composition.

Gayvoron is a town of regional subordinance with population of 14 960 residents (as of 01.01.2016). It is a typical small polyfunctional town, in which economic activity and life support are presented in various kinds.

Data used: Aiming to model heavy metals spatial distribution and to evaluate the level of urban soils pollution, the sampling was performed in the layer directly contacting the surface (0-10 cm). Heavy metals composition was ascertained by atomic emission analysis at STE-1 spectrograph of large dispersion (4.7 A^0/mm) where elemental composition analysis had been performed by optical linear spectra of atoms and ions emission in the decomposed. Some data were verified by means of Inductively Coupled Plasma Mass Spectrometry (ICP-MS) in order to measurement accuracy increase. Opportunity to determine the content of large amount of chemical elements with feasible accuracy under insignificant mass of the sample shall be one of the advantages in this approach in comparison with other physical-chemical analysis. Selection of chemical elements for the analysis is based on the consideration of toxicity and potential hazard for living organisms being directly or indirectly associated with soils within urban environment. Proceeding from these criteria, analysis and spatial modelling was performed for Pb, Zn, Cu, Cr, Co, Sn. Since, the background content of some chemical elements can vary widely for different natural zone and types of soils and concentration of mentioned heavy metals has been compared with their background indexes which to be commonly believed as corresponding values beyond the urban area where anthropogenic load is minimal.

Aggregate coefficient (Z_c) calculated by the formula has been used for complex evaluation of urban soils technogenic pollution:

$$Z_c = \sum_{i=1}^{n} \frac{C_i}{C_{bg}} - (n-1) \quad (1)$$

Where:

Z_c = A coefficient of aggregate technogenic pollution
C_i = Concentration of i element
C_{bg} = Background concentration of i element
n = Number of investigated chemical elements

When calculating Zc, a degree of all chemical elements toxicity is conditionally considered to be similar as well as extreme indexes of individual elements may be levelled out if remaining ones do not exceed the background values. Offers on applied computation scheme improvement are known which consider variations in elements toxicity. In spite of certain restrictions in application of this index, the coefficient Zc allows to evaluate a total soils pollution considering the content of investigated heavy metals Pb, Zn, Cu, C r, Co, Sn and in common features it reflects the degree of ecologic-geochemical tension of the territory under study.

In a result of on-site and laboratory researches a data array has been obtained becoming a base for formation of spatial data base on geochemical features of the soil's urban-ecology system. Organization of obtained data as well as creation of continual distribution surfaces of heave metals concentration has been performed by means of polyfunctional system QGIS 2.14 "Essen". The software product QGIS possesses a source code and is spread freely under the licence terms GNU General Public License. Considering the number of discrete values and character of their distribution, method Inverse Distance Weighting (IDW) has been used for spatial interpolation. Realization of this algorithm provides for loss in values of interpolated index in the direction from the point with known value to the points where instrumental surveys have not been intimately performed. Method IDW allows to model to a reasonably high precision the spatial distribution of heavy metals content and provides opportunity to detect the factors influencing upon the overall territorial picture even under the small array of point data.

RESULTS AND DISCUSSION

We have determined factors of the most intensive anthropogenic load which can be considered as significant according to the impact on ecologic-geochemical peculiarities of soil cover within the framework of small town. These are: plant facilities, automobile transport, mining industry, application of chemical agents at small holdings.

The territory of Gayvoron town has a very long history of anthropogenic transformation. The first plant facility was launched in 1897 and operates with different intensity up to the present day "Gayvoron Locomotive Rebuilder" in the area of 0.07 km^2.

Since, 1938 "Gayvoron Specialized Quarry" has been actively operated, the activity of which associated with granites and migmatites mining, processing, transportation. The mining area of active quarry is 0.47 km^2. Intensive extraction volumes of building granite connected with deep-seated ancient mineral's lifting on the surface and distribution by aerial way which are not peculiar to any land surface, supposedly shall precondition occurrence of geochemical anomalies, including relatively heavy metals.

A special mention should be made of automobile transport impact assessment being characterised by high-rate flow due to the highway T 0207 of territorial importance passing through the town. Traffic flow of different carrying capacity through the town and roundabout routes generates accumulation of volatile gas mixtures in the atmospheric boundary layer enabling concentration of specific elements and compounds in the surface soil.

Content of six heavy metals in the Gayvoron soils is characterised by relatively moderate indexes (Table 1). The minimal concentration (min in table) is marked within the town boundaries for Pb, Cr, Co, Sn among the investigated chemical elements which is lower the background values corresponding to the soils not being subjected to anthropogenic loading. Simultaneously, the average content of each metal exceeds the respective backgrounds indexes in some case twice and in more times (Table 1).

The soil samples were obtained at 41 key areas being relatively uniformly distributed along the town territory (Fig. 1a). Pb content in the Gayvoron soils reaches the maximal values 500 mg/kg, though, this element has not been detected at some key areas. In the course of spatial analysis, it has been revealed (i.e., areas of notable increase in concentration in the central part nearby the town park and southern suburb (close to granite quarry) up to 400 mg/kg (Fig. 1c).

Maximum Zn content in the soils is observed within north-western microdistricts of the town and reaches values of 650-750 mg/kg. Local concentration increases are assigned on the rest territory which correspond to automobile transport travel lines along the road T 0207. Minimum Zn concentration on the level 300-450 mg/kg is peculiar for the southern microdistricts (Fig. 1 d).

Table 1: Statistic indexes of geochemical research findings as to the Gayvoron urban-ecology system's soils (number of definitions 41)

	Content (mg/kg)			
Chemical element	Max.	Min.	Average	Background
Pb	500	0	76.34	40
Zn	800	300	546.34	200
Cu	600	30	131.22	20
Cr	300	40	140.61	50
Co	10	4	5.80	5
Sn	20	0	5.10	2

The average value of Cu in the urban soils is 131 mg/kg. Local geographical ranges with content up to 330-550 mg/kg are set in the nature of spatial distribution which are dispersed along the territory and correspond to key areas where selection is attributed to the sites of agricultural designation (Fig.1e).

An area with increased concentration in the northern and north-western town parts is established in the Cr spatial distribution. Maximal values of Cr reach 200-250 mg/kg. The aggressive reduction of Cr content in the soils is observed in the eastern and southern Gayvoron's microdistricts where this index does not reach 50 mg/kg (Fig.1f).

Concentration of Co within urban soils is characterised by a common trend in values rising up to 6.5-9.5 mg/kg in the north-western direction. Individual local anomalies with 6.5-7.5 mg/kg values are disseminated in the central and western parts of Gayvoron. Minimum values of Co 4.5-5 mg/kg are observed in the south-eastern part of the town (Fig.1g).

Sn concentration reaches 20 mg/kg. Three geographical ranges with increased values of Sr are marked in the soils of the area under investigation in the central part of the town up to 7.5 mg/kg in the northern one up to 10 mg/kg, in the western up to 20 mg/kg. The general background of Gayvoron soils is 2.5-3 mg/kg (Fig.1h).

The aggregate index of heavy metals (Zc) content considering values of each chemical element allows to perform an evaluation of total urban soils pollution. Maximal concentration of heavy metals is observed in the northern and central Gayvoron parts where the values of given coefficient reach 90-110. Minimally polluted areas by heavy metals are the southern and south-western town districts (Fig.1 b).

The concentration of heavy metals content in the northern and western parts of the town are explained by the presence of industrial production facilities there on the peripheral passageways.

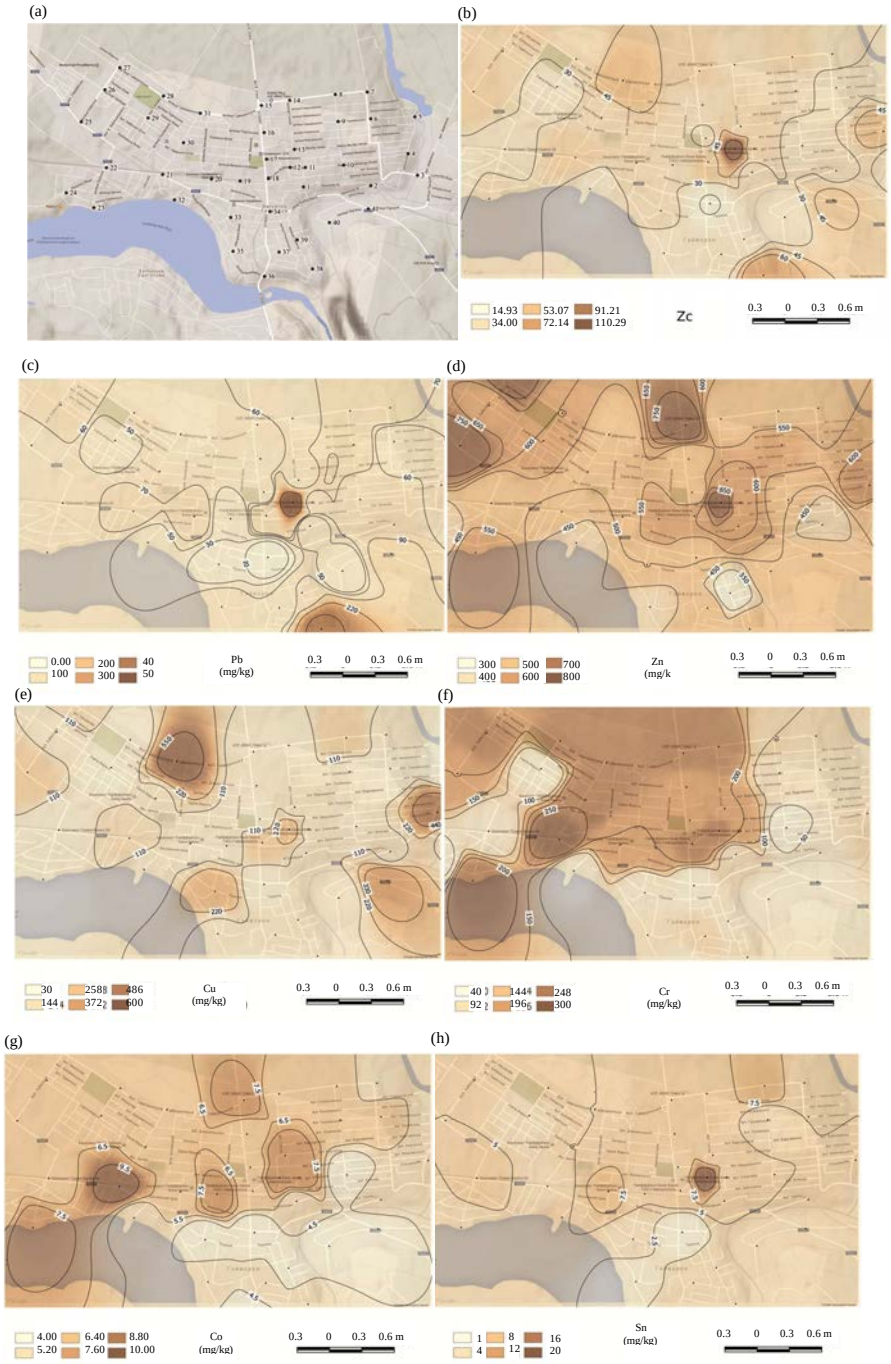

Fig. 1: The key investigation areas of urban soils and spatial distribution of heavy metals content in the soils: a) Sampling places; b) Integral pollution index; c) Pb; d) Zn; e) Cu; f) Cr; g) Co and h) Sn

CONCLUSION

The automobile transport is one of the key aspects in formation of spatial distribution of heavy metals (Pb) in the soils for small towns with population of up to 50 thousand persons located in the transport hubs, causing increase in the common background of territory pollution background. The industry facilities are able to develop local anomalies of heavy metals (Co, Cu, Cr) in the soil cover on the territories located in the contact zones which is associated with air emissions of chemical agents-waste products of machine-building industry functioning. It is worth mentioning that by no means physical proximity to the town boundary of granite quarry has found any

reflection in spatial distribution of heavy metals which has been actively operating, since, 30's of 20th century. An application of inorganic chemical agents at the personal small holdings may also be the reasons of raise in the content of some chemical agents (Cu).

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