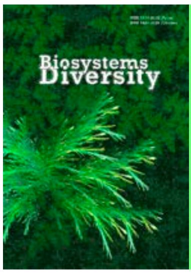

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The interpolation of cadmium in soils of an urbanized territory of the steppe Dnieper region using geoinformation modeling methods

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We collected data on the content of gross and mobile forms of cadmium in the genetic horizons of the main types of soils of the steppe Dnieper region in anthropogenically contaminated landscapes (for instance, the city of Kamianske). The content and distribution of gross and mobile forms of cadmium are shown laterally and radially. The highest concentration of cadmium content is noted for profiles 1 to 6, in particular for a root-saturated ground horizon (up to 50 cm). For soil horizons located at a depth of 50–150 cm, there is a slight excess (4–6 mg/kg) of the mean (2–4 mg/kg) for all urban systems. Minimal concentrations of gross forms of cadmium are observed along the soil profile of 25–29 (up to 1 mg/kg), but anomalous excesses are noted at intersections of major highways, which is characteristic for all arranged profiles. The distribution of mobile forms of cadmium for each araigned profile usually duplicates the situation of distribution of gross forms of heavy metal content. The ArcGIS Spatial Analyst's software capabilities in assessing the ecological status of the Kamianske soil according to the content of cadmium are demonstrated in the study. The results of interpolation of cadmium concentration (gross and mobile forms) on the territory of the city for the corresponding soil horizons are given. According to the conducted simulation, it has been established that the soils of almost the entire eastern part of the city (east of the soil profile of 1 to 6) are characterized by the content of the gross form of cadmium in the range of 3 to 4 mg/kg, except for the wooded ravine Vodyana, within the territorial boundaries of which the values of 2 to 3 mg/kg are forecast, as well as in the soils of the southern and central parts of the city. The interpolation of the results of measurements of cadmium content indicates that the abnormal zone is gradually decreasing by area, however, it maintains the maximum values for the city's territory.

Keywords: soil horizon; heavy metal; concentration; accumulation; program module

Introduction

In Ukraine, pollution with heavy metals in the biosphere is decreasing. This is due to the closing of factories with old equipment and the opening of ecologically clean plants. Currently, the greatest danger is posed by localized contamination of soils, which in a number of cases forms a technogenic geochemical anomaly. Special attention should be paid to cadmium as one of the most dangerous toxins in the environment (Bobyliov et al., 2014; Bigalke et al., 2017; Khan et al., 2017).

The most significant criteria on the extent of anthropogenic load on the natural environment within an urbanized territory are the sizes of the city, the density of built structures and the economic profile of the urbanization. Ecological characteristics of an urbanized area at high extent of closeness between the agglomerations are much worse than in a certain agglomeration due to the effect of antropogenic load overlay on a single territory. The agglomeration of the cities Dnipro and Kamianske forms a large industrial center of Ukraine. It is a zone of ecological crisis, which is characterized by the significant effect of the ecologically hazardous factors on health of the population. The problem of healthcare of the population and measures for preserving and improving health requires constant attention of the state (Yu & Tsunoda, 2004; Godt et al., 2006; Gun'ko, 2011). The main problem which requires constant attention and resolution is an integrated ecological study on the extent of pollution with heavy metals, particularly cadmium, deposited components of Kamianske.

Similarly to other industrial cities, Kamianske is an extremely unstable but an integral system created of natural, artificial and technogenic components. Currently, this system has lost the ability of self-recovery and is not able to resist the negative ecological environmenttal factors, including anthropogenic effects which are in continuous action (Tsvetkova et al., 2016).

There is a large amount of data on the content of cadmium in different types of soil in Kamianske, but until now, there has been a lack of complete information on the geochemical behaviour of cadmium in them and on the priority impact of one or the other soil property on its concentration in particular soils – natural and anthropogenically transformed. The soil cover accumulates information about the processes and changes which occur in it, i. e. the soil is a specific indicator of not only the current condition of the environment, but reflects the processes in the past (Tsvetkova & Gun'ko, 2015). Kamianske is not only a large industrial center of Ukraine. The interrelation of potentially hazardous industries (metallurgical, chemical, mechanical engineering, energy enterprises, etc.) with the natural environment and population create dangerous regional structural-ecological zones which require appropriate corresponding regulation.

The sources of environmental pollution can be divided into two groups. The first group includes industrial and municipal waste. The second group is chemicalized preparations (Chavezetal., 2015; Lu et al., 2017; Radojčić et al., 2017). The regime of their introduction to the environment can be constant, regular, spontaneous (involuntary). During the constant regime, mine waste water of fossil extraction sites and gaseous products of thermal electric power plants, for example, are introduced to the soil. Catastrophic oil spills, non-organized aerial emissions of industrial plants are sources of spontaneous soil pollution. By character of the territorial distribution of the pollutants, the pollution sources are divided into local spot pollution (thermal electric power plants), areal (large industrial zones), linear (transport) (Davydova et al., 2014; Kumpiene et al., 2016). In an urbanized territory, a second large source of soil pollution is municipal waste. By the content of chemical elements in municipal waste and concentration, municipal waste is equivalent to waste of industrial plants. The products of combustion contain an excessive content of plumbum, cadmium, bismuth, argentum that is a hundred times in excess of their content in the lithospere, and the dust involved in burning municipal waste has a concentration of these metals thousands of times higher than in the lithosphere (Bielská et al., 2006; Borah et al., 2018). Transport is a source of environmental pollution with plumbum, zinc, cobalt, and benzo[a]pyrene. Exhaust fumes from autotransport bring to the earth surface 260 thousand t/year of Pb, which is three times higher than its amount which is introduced by metallurgical plants. Gasoeos-dusty emissions of industries and autotransport create powerful technogenic currents of toxic substances, including cadmium, which enter and pollute the soil cover soil and plants (Seshadri et al., 2017; Liu et al., 2018).

The content of heavy metals in soils is the total of the output content and technogenic contribution over entire period of the soil's existence for the chemical properties of heavy metals determine their low mobility in the soil profile. They create poorly soluble compounds in soils, and also irrevocably are absorbed by mineral and organic components of soils, making the pollution with heavy metals especially dangerous. In big cities, the maximum amount of heavy metals in precipitations is observed in the winter months, for as result of temperature inversions, industrial pollutions accumulate surface layer of air, and in winter, in addition the content of heavy metals in the emissions of thermal electric power plants increases. However, in summer, currents related to the autotransport and total dust load are significantly higher (Eichler et al., 2014; Zohar et al., 2014).

Metallurgical plants are among the main industrial sources of soil pollution with heavy metals, including cadmium. As a result of prolonged industrial activity, geochemical anomalies form around them, bringing an increased content of polluting elements into the soil. Configuration of a polluted territory around the sources of emissions is incredibly close to the form of the wind rose in the area. The introduction of dust from the atmosphere to the soil is a necessary but insufficient condition for creating a geochemical anomaly. The level of soil pollution and further share of heavy metals is in many ways related to the qualitative composition of the industrial emissions (Kabata-Pendias, 2004).

The formation and development of local soils have peculiarities which have an effect on the content and the form of heavy metals present within them (An et al., 2014; Willgoose, 2018), they include: 1) erosion or elimination of plant cover and the upper humus horizon (this causes decrease in the resistance of soils to the pollution with heavy metals, such phenomena are observed on construction sites, landfills, roadsides); 2) transportation and addition of soil (properties of soil in this case will be determined by the properties of the imported soil); 3) using sand and salt against glazed frost (this causes not only clear salinization and change towards more light granulometric composition of the upper layer of soil, not only of soil near the roads, but also of soil at large distances from roads); 4) annual rejection of the plants` leaves fallen in the autumn (as a result, many chemical elements become excluded from the biological circulation, and the content of organic compounds in the soil decreases).

The relevance of the research presented here is conditioned, first of all, by the necessity of decreasing the hazardous ecological consequences of soil pollution with cadmium and optimizing the living conditions of the population of Kamianske. The assessment of the technogenic impact on the soil cover of the city is relevant in terms of monitoring and corresponds to ongoing tasks of monitoring the condition of the environment (Mu'azu et al., 2018).

Nowadays, the municipality faces new problems which by degree of severity and urgency are equivalent and even more serious than the ones earlier. The main reason for this is certainly the redistribution of functions of power, rights and duties between the central and local authorities. Administrations of cities, districts and oblasts receive a large list of inquiries related to the work of their services. In addition to regular inquiries related to public transport, trading and services, public safety, construction and repair works, water supply and sewers, healthcare and education, local authorities and executive institutions must pay more and more attention to the tasks of strategic and tactical planning of the economic development of their regions, development of infrastructure, rational usage of nature and ecological safety. The municipalities have to manage the increase in the load on their institutions and services. To a high extent, the success of their work in the new conditions will be facilitated by using advanced computer technologies. Global experience demonstrates that the efficiency of the intellectual work of the staff of municipalities and city administrations, and, closely related to this, the level of social-economic development of cities greatly increases when it is possible to combine and quickly analyze large amounts of information of various nature about the complex of a city's economy and management (or a certain branch of it, for example the economic situation), without increasing the investments or the number of workers at the same time.

The ArcGIS software family is a powerful tool for creating and editing geographic data bases for the purposes of spatial analysis, search, providing and managing data. These tools can be used for helping various municipal functions such as, for example: city land registration, permission for emissions and wastes, measures in critical situations, planning, development strategy, decision making, assessment of the level of pollution of the components of the environment, etc. (Sarzhanov, 2012). Using GIS technologies radically increases and improves the quality of the work with usual maps and plans. ArcGIS software is used all around the world as a tool for solving the typical tasks which institutions of local government deal with. ArcGIS Spatial Analyst provides a broad range of functions of spatial analysis and modeling on the base of the raster data model, including cartographic algebra, and also functions of integrated vector-raster analysis – in total includes over 200 instruments of processing and analyzing geodata. ArcGIS Spatial Analyst module provides a wide spectrum of functions for working with raster, which allows creation and analysis of raster data. ArcGIS Spatial Analyst also allows joint raster-vector analysis to be conducted. Using SpatialAnalyst module, one can obtain information about available data, determine their spatial relationship, determine locations according to the given criteria. ArcGIS Spatial Analyst provides a high number of tools, which significantly enlarges the ArcGIS Desktop working media (Kevin et al., 2001; Ha et al., 2014). To solve tasks in a particular sphere, the head of a project organizes the GIS content of relevant geographic and topical information (Konovalova et al., 2010; Tsvetkova et al., 2015). In our case, the topic is the content of total and mobile forms of cadmium in the 0–150 cm soil horizon in Kamianske. Detailed information, especially new, to a different extent is relevant for all directions of activity without exception in the territory and, according to the experience of advanced countries, is important and used for improving the quality of life.

The objective of the article is to demonstrate the content and distribution of gross forms of cadmium by landscape and depth of soil profile (0–150 cm), to create a map of interpolation of the soil pollution with cadmium (total and mobile forms) in Kamianske, demonstrating the capacities of ArcGIS Spatial Analyst for assessing the condition of the soils by content of cadmium.

Materials and metods

For creating a complex characteristic of the cadmium content in edaphotopes of Kamianske, we used a system approach to assessing the ecological problems in the urbanecosystems with different extenst of technogenic load. Experimental studies included conducting field surveys using geobotanical methods. Selecting the soil samples for determining the cadmium content was made according to the generally accepted methods. Previous processing of the samples for determining the total forms of cadmium used incineration and dilution of ash with HNO_3. Chemical analysis of soils in the laboratory was conducted using the certified methods with the following mathematical processing of the data at $P > 0.05$ (Statistica 7.0). The total forms of heavy metals were determined using the atomic absorption method on an atomic absorption micrometer C-115 with atomization in air-acetylene flame, the mobile forms were identified in ammonium acetate buffer solution (pH = 4,8) (Alekseev, 1987; Obuhov & Plehanova, 1991). The results presented in the article are arithmetic mean of 10 values.

For assessment of cadmium distribution in the soils within Kamianske, we conducted a detailed soil examination, selected 29 sample locations (Fig. 1) arranged from the south to the north according to the wind rose and change in the high points of the city. Kamianske is located at the border of the Ukrainian crystalline massif and the Dnipro-Donetsk rift. The right bank part of the city is situated on the flood plain and above flood plain terraces of the Dnipro and also on the forest water divide plain and its slopes on the north-east edge of the Dnipro-Bug water divide. The left bank is situated on the flood plain and the first above flood plain terrace of the Dnipro and is a plain. The western part of the city is characterized by steeper relief. Minimum height is 51 m, maximum – 180 m, therefore, the amplitude of the height fluctuations is 129 m. The zonal type of soil in the right bank part of the city is common low-humus chernozem, in the left bank – sod-sandy and clay-sandy soils in the complex with low-humus sands and sandy chernozem, and also alkaline soils in the reed bed.

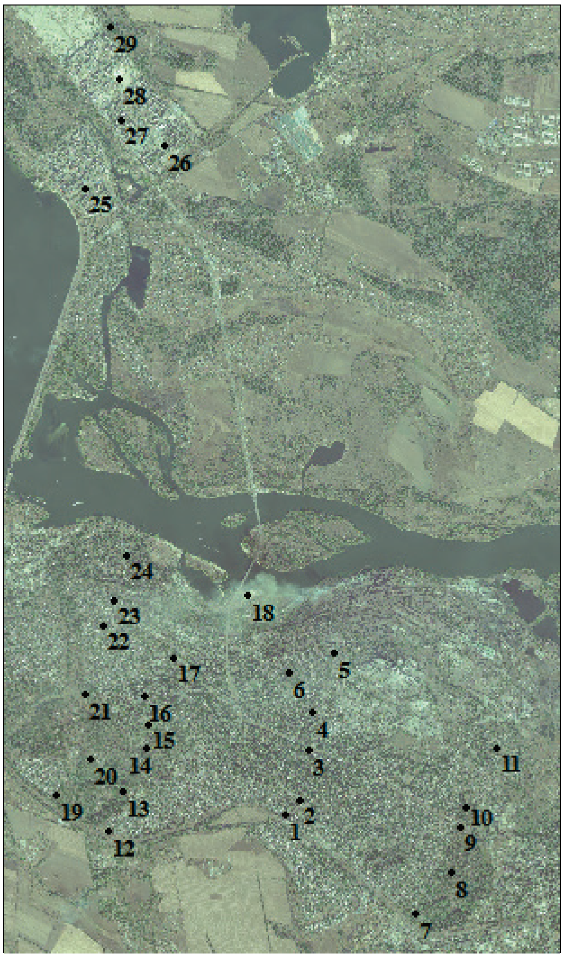

Fig. 1. Sampling locations in Kamianske, where the samples were taken

Each of the profiles has a significant amplitude of height differences, though all of the five are close to permanent sources of anthropogenic pollution, which are, first of all, industrial plants within the city. The exception is the profile 1–6, which is established along the central road of the city, and profile 25–29 established in the built up left bank part of the city remote from the industrial complex and located in the windy part compared to the others.

We determined the relationship between the content of heavy metals by the established soil profiles from the sources of technogenic load and geomorphic peculiarities using the Microsoft Excel program module. The interpolation maps of the cadmium content in the soils were created using ArcGIS Spatial Analyst program module. Using the analytical capacities of ArcGIS Spatial Analyst (Kevin et al., 2001) through interpolation, it is possible to determine the location of intermediate values by the available discrete set of determined values. Using Interpolation tool of the supplement to ArcGIS Spatial Analyst, using the method of ordinate kriging, we developed maps which interpolate the results of measuring the total and mobile forms of cadmium, including those beyond the studied urban system. The mean-square error in map development using an ordinate kriging has the lowest value compared to the other kriging methods, i.e. simple, disjunctive, probability universal, indicatory, and the method of ordinate kriging allows interpolation of the studied parameter over the entire territory of the city, at the same time obtaining the most accurate territorial distribution. Therefore we used this particular method.

Results

The highest concentrations of cadmium were observed for the profile 1–6, particularly for the root-rich soil horizon (to 50 cm), which indicates short term or non-continuous technogenic impact at presence of cadmium. For soil horizons at the depth of 50–150 cm, we observed insignificant excess (4–6 mg/kg) compared to the average (2–4 mg/kg) for all urban ecosystems. For the profile 12–18, we found uniform increase in the concentration along the established profile from the south to the north; and at intersections of major roads and railway lines (sampling locations 15, 17) it increased in the upper soil horizons. Also there was an intermittent decrease to minimum value at the location 18, which possibly occurred due to careful maintenance (cleaning, watering, etc) of a private territory within the restaurant-hotel complex, taking to account its location close to the industrial zone. For the profile 7–11, we saw a reverse tendency – decrease in the content of heavy metal from the south to the north. This could be explained by the fact that the location of selecting soil samples 7 is within a coke-chemical complex, and the next location of the profile follows the thalweg of the Vodiana bairak (ravine) (point 8) and crossing of the busy road with Praspekt Anoshkin (points 9–10). Minimum concentrations of the total forms of cadmium were observed along the established soil profile 25–29 (to 1 mg/kg), though anomalous increases were recorded at crossing of the sections with major roads, which is typical for all established profiles. The following tables demonstrate the content of total and mobile forms of cadmium along the established soil profiles of Kamianske (Fig. 2, 3).

The results of the conducted studies prove the formation of the zones with increased content of cadmium within Kamianske, though we found an insufficient number of the established profiles, taking to account the colour diversity of the obtained results for each of them, which does not allow full indication of the formation of anomalies with heightened content of heavy metal. Therefore, the next stage of the research was determining the anomalies of the zones not only within the established profiles, but at a distance from them. Geoinformational processing of the data was performed using geoinformational technologies which create electronic maps of the set parameters, and also their modeling and predicting.

Using the tools of the ArcGIS Spatial Analyst program module, we proved the interpolation of the obtained results of ranging of the cadmium concentration in the corresponding soils, which allows us to determine the anomalous zones of cadmium content (Fig. 4).

According to the conducted modeling, we determined that the soils of almost the entire east part of the city (to the east from the soil profile 1–6) are characterized by the content of total form of cadmium in the range of 3 to 4 mg/kg, except the Vodiana bairak, in the territorial borders of which, 2 to 3 mg/kg was predicted, similarly to the soils of the south and central part of the city. Due to the moderate technogenic load on the western part of the city, in the soil horizon to 150 cm, we observed minimum content of the total form of the heavy metal – 2 to 0.5 mg/kg. At the same time, its content decreases, and the zones of pollution change their configuration due to decrease in the content in depth at the widening of the borders from the Samyshyna and Vovche Hyrlo bairaks. Within the scope of the scientific study, using the method of the ordinary kriging, we conducted an interpolation of the content of the mobile cadmium form in the corresponding soil horizons (Fig. 5).

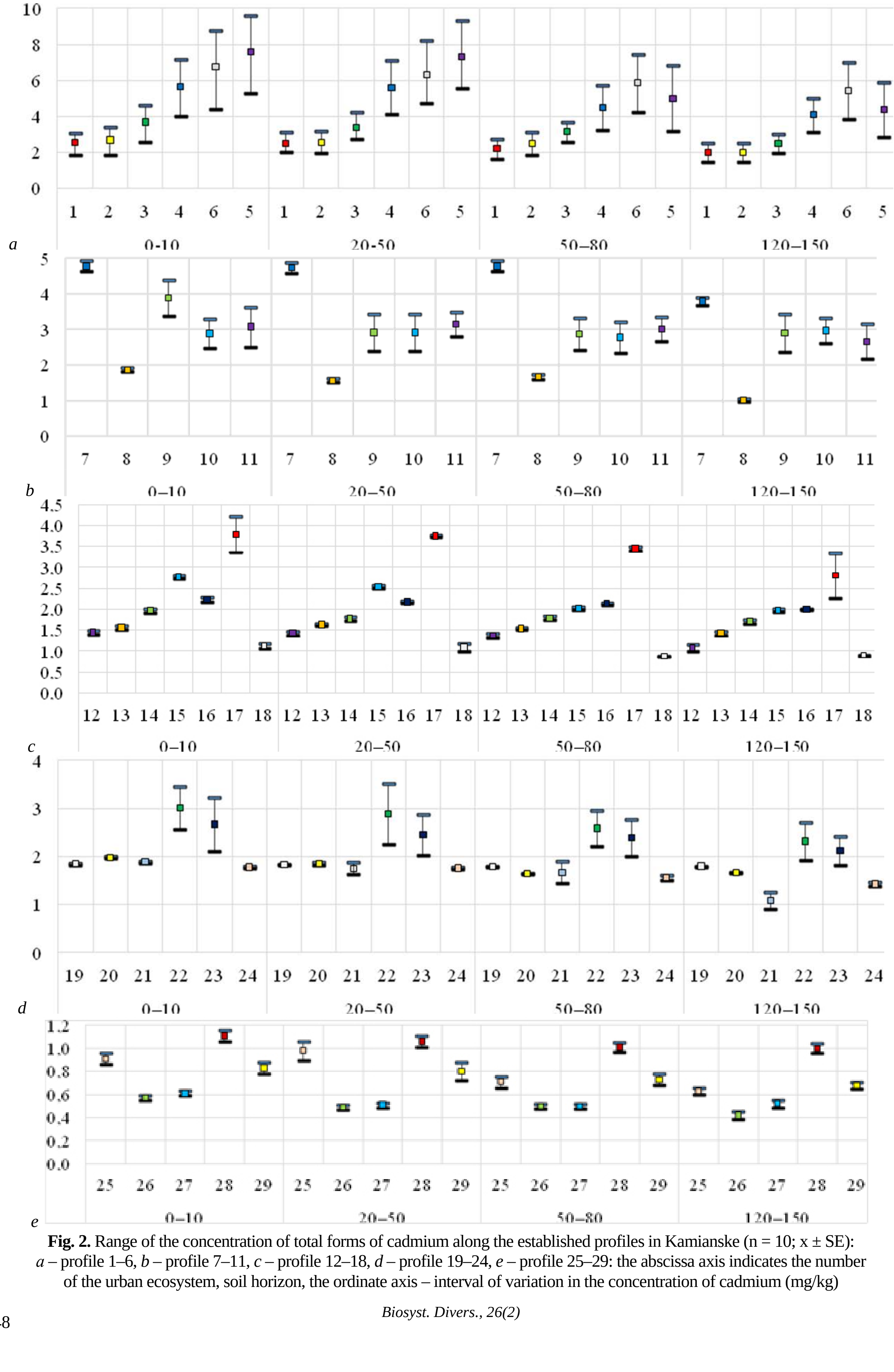

Fig. 2. Range of the concentration of total forms of cadmium along the established profiles in Kamianske (n = 10; x ± SE): *a* – profile 1–6, *b* – profile 7–11, *c* – profile 12–18, *d* – profile 19–24, *e* – profile 25–29: the abscissa axis indicates the number of the urban ecosystem, soil horizon, the ordinate axis – interval of variation in the concentration of cadmium (mg/kg)

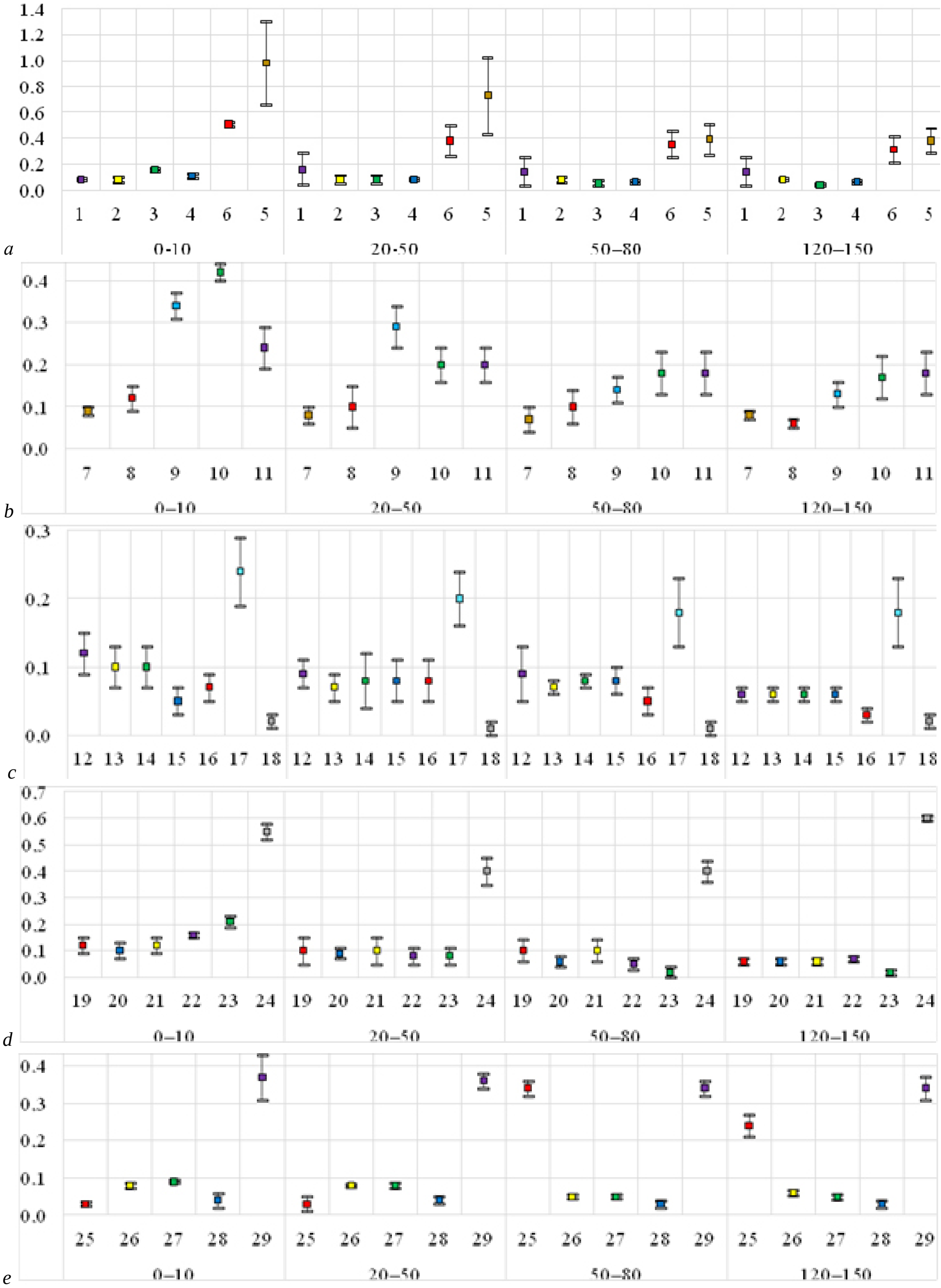

Fig. 3. Range of the concentration of mobile forms of cadmium along the established profiles in Kamianske (n = 10; x ± SE): *a* – profile 1–6, *b* – profile 7–11, *c* – profile 12–18, *d* – profile 19–24, *e* – profile 25–29: the abcissa axis indicates the number of the urban ecosystem, soil horizon, the ordinate axis – interval of cadmium concentration variation (mg/kg)

We determined the areas with maximum content of the mobile form of the metal (over 0.7 mg/kg). We should mention that these areas are located separately one from another at the depth to 10 cm, they connect before the depth of 50 cm, and at greater depth disappear.

Discussion

One of the most important components of biogeocenoses (urban ecosystems) is soil, which absorbs the greater part of the pollutants from the aerial currents. At the same time, soil not only connects the polluting compounds, but is also a natural buffer which controls the movement of chemical elements and their compounds to the atmosphere, hydrosphere and, living organisms. Around the sources of industrial aerosol emissions to the atmosphere, a local zone of increased (compared to the natural factors) concentration of pollutants in soil occurs (Tsvetkova et al., 2016). The determination of the borders of a local pollution zone is quite conditional for it depends on the ability to distinguish the background content of the metals in the soil from the anthropogenic addition from a given source. The length of the zone of local soil pollution reaches 10–20 km. At the same time, the highest levels of pollution were determined in the zone of 3–5 km from the source. The greatest length of the local pollution zone corresponds to the main direction of the wind. It also depends on the height of the dispersive composition of the emissions, wind speed, the amount of precipitation and its distribution in relation to the wind rose and some other factors. The obtained results prove that the presented data demonstrate the tendency towards increase in the content of total form of cadmium from the south to the north on approach to the industrial zone located in the northern part of the right bank part of Kamianske.

Soil horizon, cm

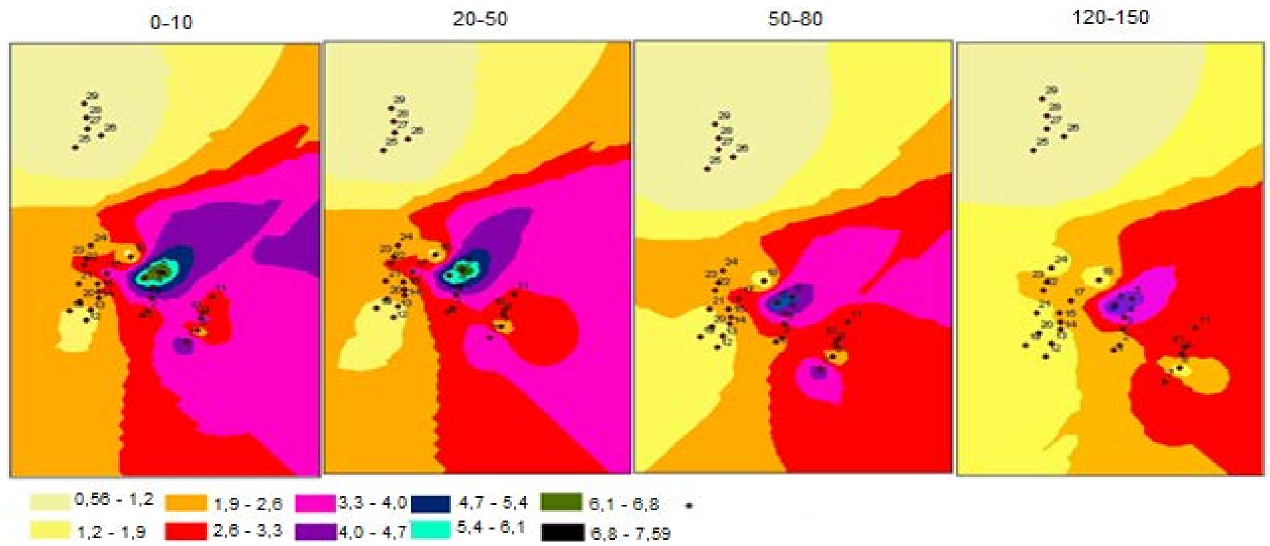

Fig. 4. Interpolation of the content of total forms of cadmium in the soils of Kamianske: 1–29 – points of soil selection

Soil horizon, cm

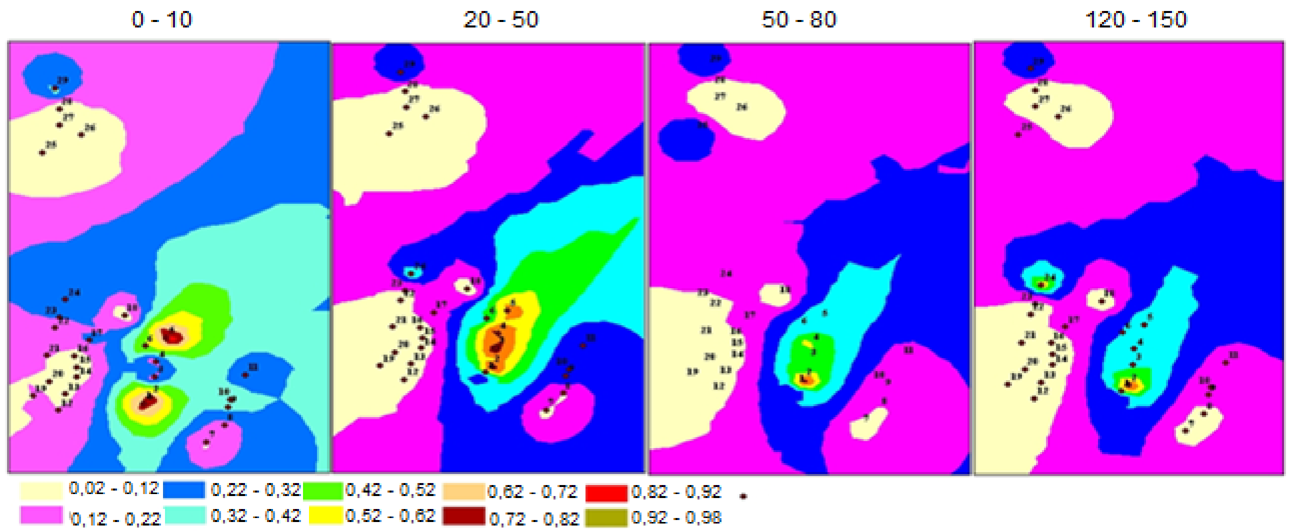

Fig. 5. Interpolation of the content of mobile forms of cadmium in the soils of Kamianske: 1–29 – locations where the samples were taken

The results coincide with the data of the researchers who studied the total content, peculiarities of distribution, pattern of distribution, assessed the mobility and bioavailibility of cadmium in the soils of the world. Scientists of the Department of Soil Science in the University of Saskatchewan, Canada (Onyatta & Huang, 1999) studied the soils in Kenya and the content of cadmium and provided an assessment of its mobility and bioavailibility. Decrease in the cadmium content depending on the depth of soil profile was demonstrated, which fully coincides with the results we obtained. It was mentioned that the information obtained during their study could be the main basis for creating data bases on the cadmium content in tropical soils. A study by Kookana & Naidy (1998) focused on the distribution of cadmium in the soil profile in the context of existence of geochemical barriers (they measured absorption and migration of cadmium in presence of cadmium and natrium salts). The results of our studies demonstrate the presence of humus horizon in the edaphotopes of urban landscapes. Scientists at the Scotland Agricultural College, Great Britain (Hooda & Alloway, 1998) conducted a comparative analysis of the sorption property of soils in England and India. The results demonstrated that the English soils sorbed more cadmium more and at greater intensity compared to the Indian soils. The researchers suggested using mud from waste water for increasing the sorption ability of the soils and presented a conclusion about the most appropriate physical-chemical characteristics of soils for utilization of wastes which contain cadmium. Spanish scientists from the Institute of Natural Resources and Agrobiology (Sanchez-Camazano et al., 1998) focused on determining the total content of cadmium in natural soils of Valladolid province, the range of the total cadmium content equaled 0.05–4.44 µg/g.

Our results also coincide with the data of other researchers who studied the peculiarities of the distribution and the level of the content of heavy metals, including cadmium, in the soils of Ukraine and Dnipropetrovsk oblast. N. M. Tsvietkova studied the background levels of the content of total and mobile forms of Pb, Ti, Mn, Cr, Ni, V, Cu, Mo heavy metals in the profile of soils, correlation relationship between heavy metals and physical-chemical properties, intensity of biological circulation of microelements, distribution of metals in the organs of plants. Especially interesting is the work of I. I. Saranenko devoted to the impact of heavy metals on the"soil – plant" subsystem in the forest cultures in biogeocenoses in Kremenchuh. S. M. Serdiuk and H. V. Pasichny studied pollution with heavy metals in the urbanized territories of the Dnipro agglomeration, analyzed the geoecological situation in the city, determined the content of heavy metals in the soil cover of the main industrial enterprises of Dnipro. In Kamianske, fragmentary studies of heavy metals` content, including cadmium, in the root-occupied layer of soil have been carried out. The study by T. K. Klymenko presents the results of the study on the total content of mobile forms of heavy metals, including cadmium, in the root-rich layer of soils of recreational, built-up and industrial zones of the city, analyzed the problem of pollution of the soil cover in Kamianske (Gun'ko, 2010). The work by S. O. Gunko includes a correlational analysis of relationship between the content of cadmium in the soil of Kamianske with selected characteristics of soil (humus content, sulphate-ions, dry remains, total alkalinity, pH of the aqueous solution, volumetric weight). It was determined that the cadmium concentration in the natural soils of steppe Prydniprovia (on the example of Kamianske) depends first of all on the amount of pH, humus and hygroscopic moisture (Tsvetkova & Gun'ko, 2015).

Greek scientists (Sarris et al., 2009) monitored the pollution of soils caused by a stationary source (electric power plant). It is relevant that in their work the researchers used GIS methods for demonstrating the content of pollutants by different topographic and geological peculiarities of the area, the maps were created using the algorithms of interpolation, which indicate the spatial distribution of the measurements. The interpolation of data of the cadmium distribution in an edaphotopic urban ecosystem by vertical soil profile (0–150 cm) and interpolation of the results using GIS technologies in Kamianske was conducted for the first time. The highest concentrations of cadmium were observed for the profile 1–6, particularly for the root-occupied soil horizon (to 50 cm). Therefore, the humus horizon in the city soils is a technogenic and organosorption barrier (Qi et al., 2017). Distribution of mobile forms of cadmium by every established profile in general duplicates the situation of distribution of total forms of heavy metal content. Thus, minimum value of the content of mobile forms of cadmium at the locations 1–4, 7–8, 12–16, 18–23, 26–28 indicates the presence of developed plant cover, unlike the locations 5–6, 9–11, 17, 24–25, where powerful and prolonged technogenic impacts are present, which cause inhibition of the plant cover, particularly along the roads.

During prolonged introduction of pollutants to soil, a large amount of heavy metals can accumulate, which can coincide with their content in natural geochemical anomalies. However, the significant difference between the content and distribution of heavy metals in soils of technogenically polluted territories and soils of geochemical anomalies is that in the first case, they concentrate in the upper layer of the soil, whereas in the second case, they concentrate in the lower layer following insignificant accumulation in the humus layer (Volesky & Holan, 1995). Buffer ability of soils and resistance of tree plantations to industrial pollution are limited (Yang et al., 1995; Wyszkowska et al., 2013; Pizzol et al., 2014). As a result of anthropogenic changes, soil can become a toxic environment for growth and development of plants, a source of additional pollution of urban ecosystem (Salmanzadeh et al., 2017; Raiesi et al., 2018).

According to the conducted spatial analysis, we determined the anomalous zones at the corner of Prospekts Svoboda, Shevchenko and Himnazychny (spots 4–6), which is proved by the studies of the soil profiles. Geoinformational methods allowed us to develop a model of a particular territorial zone on the northern border of the profile 1–6, where, very likely, not only does a large content of the heavy metal concentrate, but it also accumulates constantly in the upper soil horizons (0–10 cm). Also, within this horizon, there were modeled the zones where possible accumulation of total form of cadmium can take place, for example, in the range of 4.7–5.4 mg/kg, not only within the location 3, but around the locations 5–6 as a stretched circle as demonstrated in Figure 4. The interpolation of the results of measurements of all the horizons indicates a gradual decrease in the area of the zone with high concentration of the heavy metal. According to the results of interpolation of the mobile form of cadmium, we can indicate quite poor soils and plant cover in the left bank of the city, where we observed a gradual decrease in the content of cadmium mobile forms along the depth. The amount of mobile form of cadmium in the soil horizons of the right bank part of the city indicates the stability of the condition of the influence of technogenic pollution and adaptation of local biogeocenoses to the environmental conditions.

Conclusions

We obtained data on the content of total and mobile forms of cadmium in genetic horizons of edaphotopes of steppe Prydniprovia (on the example of Kamianske). We demonstrated the content and distribution of total and mobile forms of cadmium in relation to landscape and depth of soil profile (0–150 cm). Using the ArcGIS Spatial Analyst software, we conducted an ecological assessment of the edaphotopes of Kamianske by the content of cadmium. Using the method of ordinary kriging, we obtained results of interpolation of the distribution of cadmium content (total and mobile forms) in the territory of the city for the corresponding soil horizons, which allowed us to determine anomalous zones of its content. According to the conducted spatial analysis, we identified the anomalous zones at the corner of Prospekts Svoboda, Shevchenko and Himnazychny (locations 4–6), which is proved by the results of the studies on the soil profiles. We found a tendency towards increase in the content of total form of cadmium from the south to the north on approach to the industrial zone located in the northern right bank part of Kamianske. We determined the territories with maximum content of mobile form of the metal (over 0.7 mg/kg). The obtained data can be used by the ecological services of cities with high level of anthropogenic load for monitoring the components of the environment.

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