SOIL QUALITY ASPECTS IN THE URBAN ECOSYSTEM OF BĂLȚI (REPUBLIC OF MOLDOVA)

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Abstract. Soil quality is determined by agrophysical, agrochemical and agrobiological indicators. This paper evaluates the level of soil supply in the urban ecosystem of Bălți with organic matter and the main nutrients – nitrogen, phosphorus, potassium. The accumulation of heavy metals in the city's soil cover under the action of anthropogenic factors was also investigated. The soil samples taken and analyzed (30 samples) belong to weakly alkaline (pH – 7.3-7.8), neutral (pH – 6.7-7.2) soils. In terms of organic matter supply, they vary from very low (1.56%) to high (5.5%). The total nitrogen content recorded values of 0.06% to 1.63%, i.e. from a low to optimal supply level. The values of the macroelement P_2O_5 varied between 1.46 and 63.64 mg/100 g, and K_2O from 29.1 to 187.9 mg/100 g, which constitutes a very low to very high supply level. Exchangeable cations (Ca^{2+} and Mg^{2+}) varied for Ca^{2+} from 8.81 to 27.94 mg/eq/100 g soil, and for Mg^{2+} from 1.31 to 15.06 mg/eq/100 g soil. The content of heavy metals analyzed (Zn, Cu, Ni, Pb, Cr) fell into the level categories from very low for Cr to very high for Pb. High values of Pb and Zn concentrations were recorded in the northern part of the Bălți urban ecosystem, near the railway.

Keywords: urban ecosystem, soil quality, macroelements, heavy metals.

Rezumat. Aspecte privind calitatea solului în ecosistemul urban Bălți (Republica Moldova). Calitatea solului este determinată de indicatorii agrofizici, agrochimici și agrobiologici. În această lucrare este evaluat nivelul de aprovizionare a solului din ecosistemul urban Bălți cu substanță organică și principalii nutrienți – azotul, fosforul, potasiul. A fost cercetată de asemenea acumularea unor metale grele în învelișul edafic al orașului sub acțiunea factorilor antropici. Probele de sol prelevate și analizate (30 probe) aparțin solurilor slab alcaline (pH – 7,3-7,8), neutre (pH – 6,7-7,2). Aprovizionarea cu substanțe organice variază de la foarte scăzut (1,56%) la ridicat (5,5%). Conținutul de azot total a înregistrat valori de 0,06% la 1,63%, adică de la un nivel scăzut de aprovizionare la optim. Valorile macroelementelor P_2O_5 au variat între 1,46 și 63,64 mg/100 g, iar K_2O de la 29,1 la 187,9 mg/100 g, ceea ce constituie un nivel de aprovizionare de la foarte scăzut la foarte ridicat. Cationii schimbabili (Ca^{2+} și Mg^{2+}) au variat pentru Ca^{2+} de la 8,81 la 27,94 mg/ech/100 g sol, iar Mg^{2+} de la 1,31 la 15,06 mg/ech/100 g sol. Conținutul de metale grele analizat (Zn, Cu, Ni, Pb, Cr) s-a încadrat în categoriile de nivel de la foarte scăzt pentru Cr pînă la foarte mare pentru Pb. Valorile ridicate ale concentrațiilor de Pb și Zn au fost înregistrate în partea de Nord a ecosistemului urban Bălți, în apropiere de calea ferată.

Cuvinte cheie: ecosistem urban, calitatea solului, macroelemente, metale grele.

INTRODUCTION

Urban ecosystems are characterized by the built environment – buildings, roads and other access routes that form the communities in which people live and work. Soils in urban ecosystems are subject to a range of anthropogenic effects, from low influence (urban forests, pastures, etc.) to those affected by urban activity (sealed lands, impermeable surfaces, etc.) (POUYAT et al., 2009; MOREL et al., 2017). Human activity leads to soil manipulation for a wide variety of purposes ranging from stormwater management, lawn maintenance, landscaping, urban agriculture, as well as pollution with industrial waste, solid household waste, wastewater, etc.

Soils have the capacity to sequester various nutrients, such as phosphorus (P) and nitrogen (N) which, if transported to surface waters, can cause algal blooms. They also store significant levels of heavy metals such as lead (Pb), zinc (Zn), chromium (Cr), etc., which, if the intervention threshold is exceeded and certain environmental conditions are met, can affect the activity of microorganisms and plants, causing health effects on the population (ROSSITER, 2007).

In addition, urban soils, as parts of the urban environment, have a great impact on the way people live and work. Therefore, the study of urban soils is of critical importance. Nitrogen and phosphorus are the most important nutrients for organisms; however, their excess in urban soil can lead to pollution of lakes and rivers in or around the city (JARVIE et al., 2006; NYENJE et al., 2010), and this transport would enormously influence the quality of urban water (MAJUMDAR et al., 2008; CHEONG et al., 2012).

In previous research (ȚUGULEA et al., 2021; 2023) an analysis of the content of some nutrients and some heavy metals in the soils of the Bălți urban ecosystem was carried out. A high content of humus supply was determined, and for mobile phosphorus and potassium, in the 0-10 cm layer, the optimal levels were very high. In the case of heavy metals, sites exceeding the intervention threshold for Pb were recorded in four analyzed sites. The research given in this paper complements the results previously obtained in the aforementioned works.

MATERIALS AND METHODS

Soil samples (30 samples) were collected throughout the territory of the urban ecosystem (EU) of Bălți (table 1). The average sample collection consists of 5 samples collected by the envelope method and individually packed in polyethylene bags. The depth to which the samples were taken is 30 cm.

For the selection/placement of the measurement/collection points of the soil samples, the systematic network (grid) combined with the random one (stratified systematic network) was used, which involves dividing the studied territory into homogeneous units (2×2 km) and randomly placing, within each homogeneous unit, at least one measurement/collection point (WATTS & HALLIWELL, 1996). For urban soils of the municipality of Bălți, an uneven profile, excessive compaction, mixed horizon with solid inclusions (construction and household waste, fragments of natural horizons, industrial waste) are typical. In urban soils, the same processes take place as in natural soils: the formation and accumulation of humus, the mobilization and precipitation of carbonates, the formation of structure, salinization. The intensity of these processes depends on the age and conditions of land use, the specifics of the natural area. Natural soil types are preserved in parks and forest areas, the floodplains of the Răut and Răuțel rivers in the Bălți urban ecosystem.

Table 1. Identification of soil sample sampling sites.

Sampling point	Geographic coordinates		Soil type
	x	y	
1	47°44'08,8" N	27°51'49,7" E	Carbonate chernozem
2	47°44′26.9″ N	27°52′51.7″ E	Hydrous alluvial soil
3	47°44′46.4″ N	27°54′11.9″ E	Hydrous alluvial soil
4	47°45′21.1″ N	27°55′21.3″ E	Hydrous alluvial soil
5	47°45′41.7″ N	27°55′48.9″ E	Hydrous alluvial soil
6	47°46′55.6″ N	27°56′13.9″ E	Carbonate chernozem
7	47°46′06.6″ N	27°56′44.6″ E	Typical alluvial solonetized salinized soil
8	47°45′43.7″ N	27°52′42.3″ E	Typical weakly humiferous chernozem
9	47°45′34.7″ N	27°57′45.3″ E	Typical alluvial soil
10	47°44′42.2″ N	27°57′10.3″ E	Typical weakly humiferous chernozem
11	47°45′19.4″ N	27°56′33.7″ E	Typical alluvial solonetized salinized soil
12	47°44′52.0″ N	27°55′24.3″ E	Typical moderately humiferous chernozem
13	47°44′35.1″ N	27°55′12.3″ E	Typical moderately humiferous chernozem
14	47°44′28.0″ N	27°54′39.7″ E	Soft deluvial soil
15	47°44′15.9″ N	27°53′55.0″ E	Typical moderately humiferous chernozem
16	47°44′24.8″ N	27°53′02.5″ E	Hydrous alluvial soil
17	47°45′27.5″ N	27°53′46.9″ E	Typical weakly humiferous chernozem
18	47°45′11.8″ N	27°52′45.6″ E	Typical weakly humiferous chernozem
19	47°45′53.4″ N	27°53′53.6″ E	Typical weakly humiferous chernozem
20	47°46′50.9″ N	27°53′26.5″ E	Solonetized chernozem
21	47°46′46.6″ N	27°52′51.8″ E	Typical weakly humiferous chernozem
22	47°47′38.3″ N	27°53′51.4″ E	Salinized hydric alluvial soil
23	47°47′30.9″ N	27°54′51.1″ E	Typical moderately humiferous chernozem
24	47°46′59.0″ N	27°54′46.2″ E	Carbonate chernozem
25	47°46′32.4″ N	27°55′03.3″ E	Carbonate chernozem
26	47°46′43.8″ N	27°55′38.0″ E	Salinized hydric alluvial soil
27	47°46′59.4″ N	27°56′39.0″ E	Soft deluvial soil
28	47°46′47.3″ N	27°57′20.6″ E	Typical weakly humiferous chernozem
29	47°47′07.9″ N	27°58′43.7″ E	Carbonate chernozem
30	47°43′55.2″ N	27°51′10.9″ E	Hydrous alluvial soil

The determination of heavy metals (MG) was carried out in the Reference Laboratory of the Environmental Agency. The content of heavy metals (Zn, Cu, Ni, Pb, Cr - total forms) was determined by analyzing ash solutions using the atomic absorption spectrometry method with thermal atomization of the elements in a graphite atomizer (Analytik Jena GmbH - ZEEnit 650 P) (SM SR ISO 11047-2006).

The cartographic representation of the results obtained was developed using the software Qgis.

RESULTS AND DISCUSSION

Soil samples taken from the Bălți urban ecosystem mostly belong to weakly alkaline soils (pH – 7.3-7.8) and only 4 samples – to neutral soils (pH – 6.7-7.2) (Fig. 1).

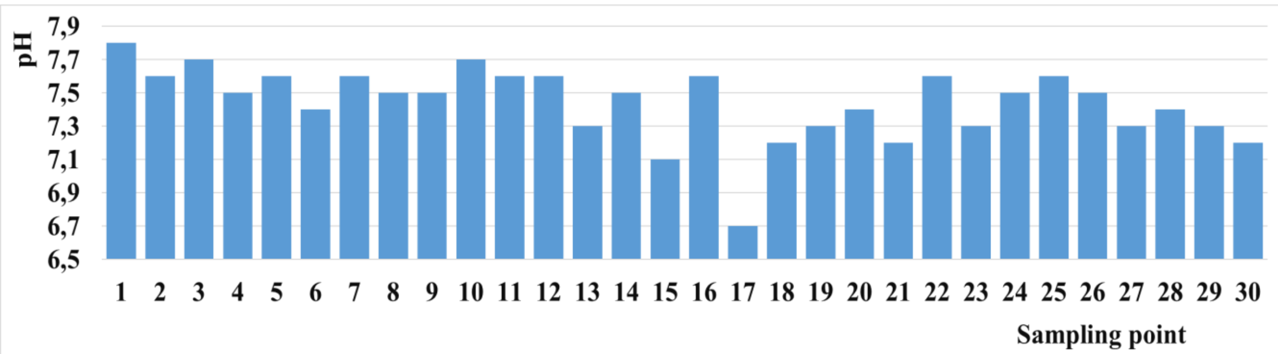

Figure 1. pH variation in soil from experimental sites for EU Bălți (original).

Organic matter is a major source of plant nutrients and plays a key role in the cycling of elements in the soil-plant system. It conditions the texture and porosity of soils, thereby improving water and nutrient retention, as well as their resistance to mechanical stress (LAL, 2004). Therefore, the quantity and quality of organic matter is a vital indicator of soil quality and functioning (BROCK et al., 2017). Soils in the Bălți urban ecosystem have a level of organic matter supply from very low (1.56%) to high (5.5%) (Table 2). The coefficient of variation of the values recorded for this element was 25%, which represents a relatively homogeneous dispersion and can also be observed from figure 2.

Table 2. Descriptive soil statistics for some nutrients.

Ingredients	**Minimum**	**Maximum**	**Mean**	**Standard deviation**	**CV %**
Organic matter, %	1.56	5.5	3.70	0.92	25
N tot, %	0.06	1.63	1.10	0.02	21
P_2O_5, mg/100 g soil	1.46	63.64	17.70	13.59	77
K_2O, mg/100 g soil	29.1	187.9	76.22	29.88	39
Ca^{2+}, mg/eq/100 g soil	8.81	27.94	19.67	3.29	17
Mg^{2+}, mg/eq/100 g soil	1.31	15.06	4.59	1.80	39
Ca^{2+} + Mg^{2+}, mg/ech/100 g soil	11.87	36.12	24.26	4.55	19

Total nitrogen content is an important indicator of soil fertility and one of the limiting factors of vegetation development. This is one of the macronutrients of essential importance for plant nutrition. The concentration of this element varied from 0.06% to 1.63%, with the average value being 1.10% and with a coefficient of variation of 21%. Analyzing figure 3, a moderate level of nitrogen supply is observed, with some sites recording low levels and only in four cases an optimal level. The optimal level was recorded on the outskirts of the city.

Figure 2. Schematic map of the distribution of organic matter in soil (original).

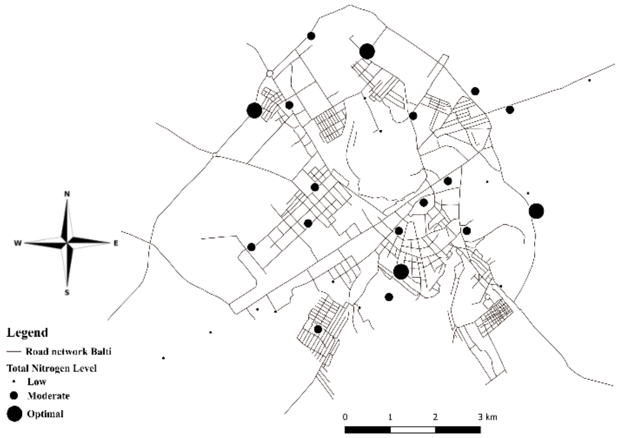

Figure 3. Schematic map of N_{tot} distribution in soil (original).

Mobile phosphorus (P_2O_5) is a limiting macroelement of major importance for plant biodiversity. Its low content can show a nutritional stress for most plants. In the soils of the urban ecosystem of Bălți, values of this indicator from 1.46 mg/100 g to 63.64 mg/100 g were recorded. The variation of the content of mobile phosphorus in the soils of the analyzed sites was 77%, which represents a heterogeneous structure.

The soil of the ecosystem studied in most of the researched sites, according to the scale of nutrient levels in soils of the Republic of Moldova, according to CERBARI (2010), showed moderate-very high levels of phosphorus supply (figure 4). Only one site recorded a low level. In this site, the soil is anthropized, determined by increased compaction, contaminated with construction waste, etc.

Potassium (K_2O), along with nitrogen and phosphorus, is one of the macronutrients of major importance for plant nutrition. Potassium is found in the soil in much larger quantities than nitrogen and phosphorus, except in saline and alkaline soils, but about 98% is in an unchanged form CHIRIŢĂ (1974).

The K_2O content in the soils of the analyzed sites varied from 29.1 to 187.90 mg/100 g, with an average value of 76,22 mg/100 g. The degree of homogeneity of the values recorded for this macronutrient is high (CV-39%) (table 2). The level of vegetation supply with K_2O varies from optimal (1 site) to very high (27 sites) (Fig. 5). This macronutrient does not present a risk phenomenon, as a limiting factor for the plant diversity in the urban ecosystem of Bălți.

Exchangeable cations (Ca^{2+}/Mg^{2+}) registered relatively varied values from 8.81 to 27.94 mg/eq/100 g soil for Ca^{2+}, and Mg^{2+} values between 1.31 and 15.06 mg/eq/100 g soil. The average values of these indicators were 19.67 mg/eq/100 g soil for Ca^{2+} and 4.59 mg/eq/100 g soil for Mg^{2+}. The variation of the content of these cations represents a high homogeneity (Table 2).

Analyzing the distribution of the content of Ca^{2+} + Mg^{2+} in the soil of the analyzed sites, we observe that the highest values were recorded in the southern part of the city (Fig. 6). The higher content in these sites is due to the alkaline dust coming from the gravel roads.

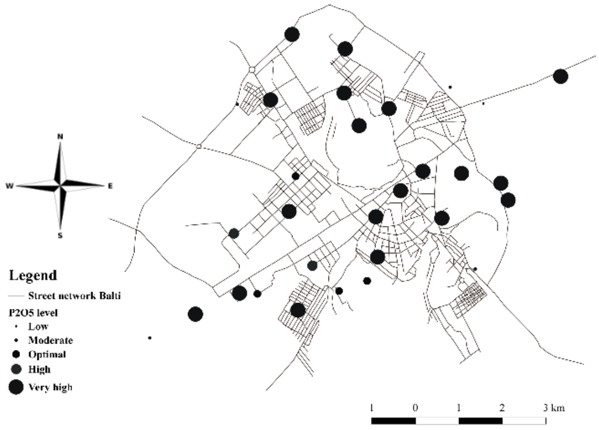

Figure 4. Schematic map of P_2O_5 distribution in soil (original).

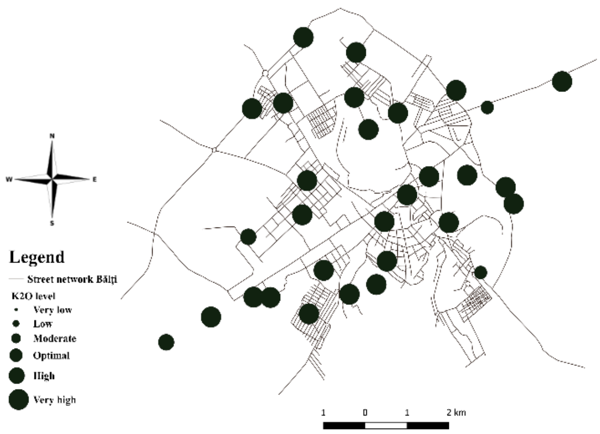

Figure 5. Schematic map of K_2O distribution in soil (original).

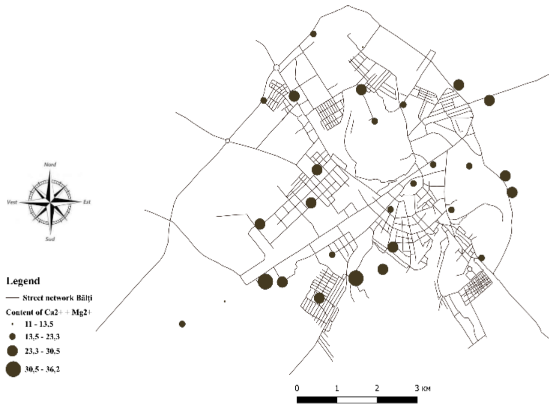

Figure 6. Schematic map of the distribution of Ca^{2+} + Mg^{2+} content in soil (original).

The ecological status of the soil component in the urban ecosystem of Bălți was also assessed based on some metals. Most of these have a bivalent role in nature, depending on their concentration they can be micronutrients or toxins for plant development (SMIDT S. et al., 2012).

The Cu content in the 30 investigated sites ranged from 12.79 to 89.55 mg/kg (Table 3). Based on the gradation scale of soils in the Republic of Moldova, according to KIRILYUK (2006), the Cu concentration fell into different levels of content, from low to high. Of these, in 22 sites the concentration fell into the low level, 7 - medium and only one site the high level (89.55 mg/kg). (Fig. 7). The predominance of the medium level (26 - 50 mg/kg) of the concentration of this microelement can also be observed from Table 2, the average Cu concentration in the soil is 23.11 mg/kg. The coefficient of variation of the values recorded for Cu, presents a high degree of homogeneity (30%). The average level of Cu content was recorded in the N part of the Bălți urban ecosystem (Fig. 7). This site is in close proximity to the railway. The results obtained for Cu are within the limits of the average values for the soils of the Republic of Moldova (KIRILYUK, 2006).

Copper is in the category of microelements with an important biological role for ecosystems. The vegetation of these sites is provided with the microelement Cu. Insufficiency of this metal in the soil (< 10 mg/kg) or exceeding the alert threshold (> 100 mg/kg) can cause reduced growth of roots and shoots, inhibition of enzymes (ADRIANO, 2001), which was not recorded in the researched sites.

Sources of pollution with this metal may come from the excessive use of Cu compounds in agriculture, sludge from wastewater especially from pig farming, the plastics industry, etc.

Table 3. Descriptive soil statistics for some heavy metals.

Ingredients	**Minimum**	**Maximum**	**Mean**	**Standard deviation**	**CV %**
Cu, mg/kg	12.79	89.55	23.11	6.83	30
Ni, mg/kg	16.73	74.35	42.17	5.84	14
Pb, mg/kg	10.89	241.20	50.23	35.01	70
Zn, mg/kg	37.43	322.05	110.11	32.04	29
Cr, mg/kg	20.18	32.05	26.16	3.23	12

Nickel in the 0-30 cm soil layer recorded concentration values ranging between 16.73 and 74.35 mg/kg (Table 3), which according to KIRILYUK (2006) corresponds to levels from medium to high. Values in the medium level predominate (27 sites) and only one site in the high level. The coefficient of variation of the values recorded for Ni shows a high degree of homogeneity (14 %). According to the same source, the Ni concentration in most of the researched sites does not differ from the limits of soils in the Republic of Moldova (5-75 kg/ha), only one site approaches the alert threshold (AT) (75 mg/kg) according to KLOKE (1980). This is attested in the central-southern part of the city (Fig. 8).

Figure 7. Schematic map of the distribution of Cu content in soil (original).

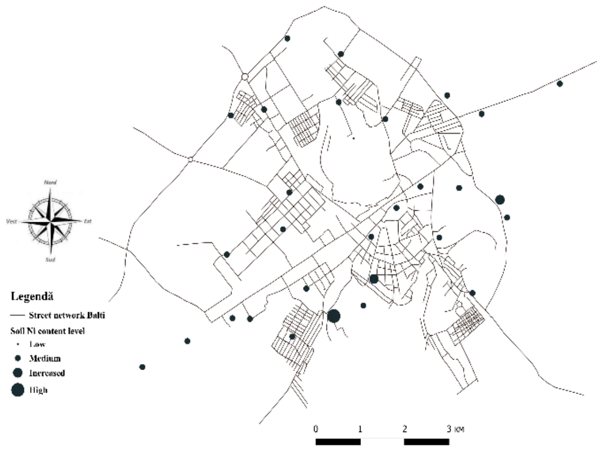

Figure 8. Schematic map of the distribution of Ni content in soil (original).

The values of Pb content in the soils of the Bălți urban ecosystem ranged between 10.89 and 241.2 mg/kg (Table 3). Based on the gradation scale of soils in the Republic of Moldova, according to KIRILYUK (2006), the Pb concentration fell into different levels of content, from low to very high. Thus, the distribution of the values obtained for this chemical element by levels is: 8 sites with very high levels; 8 – medium; 7 – low; 5 – increased; 2 – high. The coefficient of variation of the values recorded for Pb represents a heterogeneous structure. The concentration of Pb in the soil exceeds the alert threshold (50 mg/kg) according to KLOKE (1980) in 8 sites, and the intervention threshold (100 mg/kg) in 4 cases. The 8 sites with very high levels of Pb are distributed in the immediate vicinity of Ștefan cel Mare Street and the sixth ring road of the city of Bălți (Fig. 9). The sources of Pb pollution in urban ecosystems are diverse: from motor transport (leaded fuels that are no longer used, batteries, etc.) to some industrial activities (paints, wiring coatings, etc.), as well as from anthropogenic activities (fertilizers, etc.). Some studies demonstrate negative effects of increased Pb concentration in soil on the morphology, growth and photosynthetic processes of plants (HLIHOR et al., 2022). Getting into the food chain, it affects the neurological, gastrointestinal, hematological, renal and cardiovascular systems, especially in children.

The zinc content in the soil of the analyzed sites recorded values between 37.43 and 322.2 mg/kg (table 3), from low to very high levels. Of these, one site exceeded the alert threshold according to KLOKE (1980), and in 25 sites the Zn concentration is above the average of this element in the soils of the Republic of Moldova (71 mg/kg). The coefficient of variation of the values recorded for Zn shows a high degree of homogeneity (39%). The site with the Zn concentration value exceeding the Zn range in the soils of the Republic of Moldova, but also falling within the very high level of this metal content, is located in the northern part of the city of Bălți (Fig. 10).

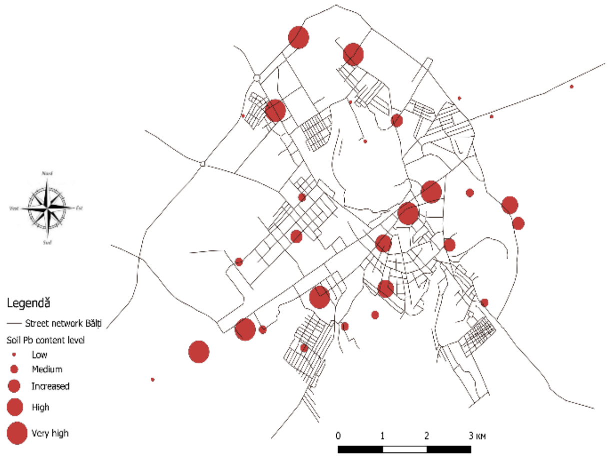

Figure 9. Schematic map of the distribution of Pb content in soil (original)

Figure 10. Schematic map of the distribution of Zn content in soil (original)

The sources of Zn pollution in these sites with very high, high and increased levels are of anthropogenic origin, located in close proximity to the railway section, and road routes with heavy traffic. Zinc is an essential nutrient for most plants but also toxic when present in excess quantities in soils (***. ATLASUL GEOCHIMIC AL METALELOR GRELE DIN SOLURILE MUNICIPIULUI IAŞI ŞI ÎMPREJURIMI, 2008).

The chromium (Cr) content in the soil of the researched sites varied from 20.18 to 32.05 mg/kg, which falls within the very low level according to KIRILYUK (2006). The average concentration values of this element were 26.16 mg/kg. The coefficient of variation of the values recorded for Cr shows a high degree of homogeneity (12%) (Table 3).

The statistical analysis (minimum, average, median, maximum) of some macro and microelements from the soils of the Bălți urban ecosystem reveals a deviation from the average for K_2O, Zn and Pb (Fig. 11). This deviation is also observed in tables 2 and 3.

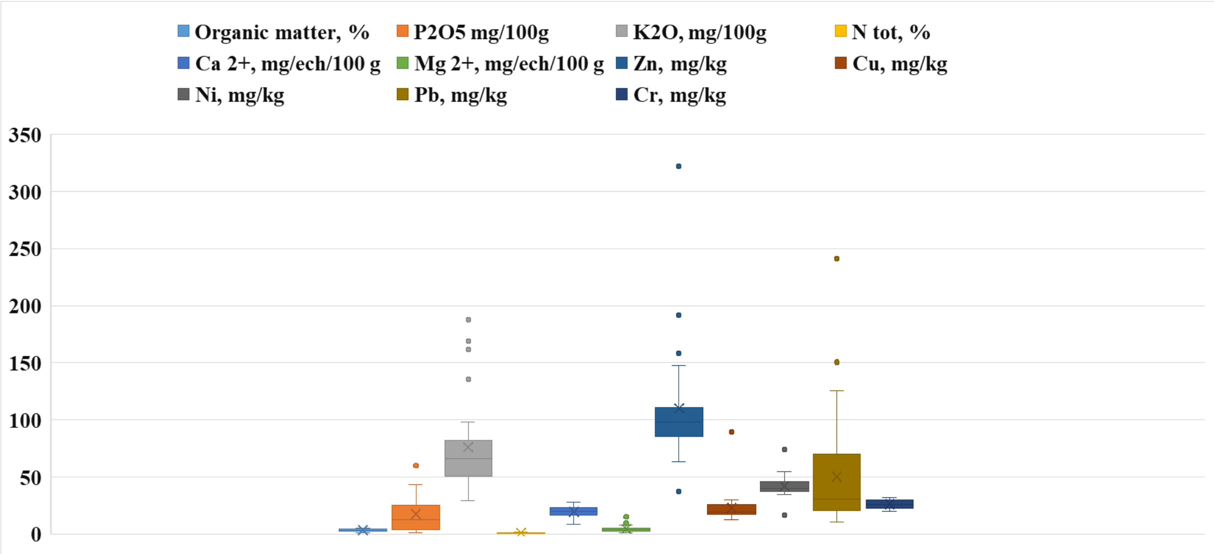

Figure 11. Boxplot of the content of some macro and microelements in the soils of Bălți city (original).

Soil contamination with these heavy metals causes their transfer and accumulation by plants and some invertebrates that live in the soil (HEIKENS et al., 2001). Considering that plants are at the base of terrestrial food chains, there remains a risk that these heavy metals will reach higher trophic levels, including humans (GALL et al., 2015)

Soil decontamination of these heavy metals can be carried out by conventional (chemical or physical) or biological methods (plants, algae, microorganisms, etc.). Conventional methods produce various pollutants and are not profitable. Biological methods, such as phytoremediation, are considered environmentally friendly, but also cost-effective (YADAV et al., 2017).

Among the plants effective for decontaminating soil with heavy metals, especially Pb and Zn, can be enumerated species such as: *Brassica juncea* L. (TURAN & ESRINGU, 2007; KOPTSIK, 2014; SHARMA et al., 2018.), *Brassica napus* L. (TURAN & ESRINGU, 2007; PARK et al., 2012.), *Cardaminopsis halleri* (L.) Hayek (SHARMA et al., 2018.), *Euphorbia cheiradenia* Boiss. & Hohen. (CHEHREGANI & MALAYERI, 2007), and *Trifolium alexandrinum* L. (HAZRAT et al., 2013).

CONCLUSIONS

The assessment of the quality of the soil component of the urban ecosystem of Bălți (0 – 30 cm) was highlighted by a weakly alkaline – neutral pH, and the level of organic matter supply from very low to high, for Ntot very *low – optimal*; P_2O_5 levels from *moderate* to very high and K_2O from *optimal* to *very high*.

The content of exchangeable cations Ca^{2+} and Mg^{2+} varied from 8.81 to 27.94 mg/eq/100 g soil for Ca^{2+}, and for Mg^{2+} values between 1.31 and 15.06 mg/eq/100 g soil.

The content of heavy metals analyzed varied from very low for Cr to very high for Pb. The alert threshold was recorded for Zn in one site and for Pb in eight sites. The latter exceeded the intervention threshold in four sites.

The only site where very high levels of Zn (322.05 mg/kg), Pb (241.2 mg/kg) and high levels of Cu (89.55 mg/kg) were recorded is in the northern part of the Bălți urban ecosystem, in the immediate vicinity of the railway section. The origin of these metals is assumed to be from railway transport, coal burning, etc. The reaction (pH) of the soil in this site being weakly alkaline, relatively reduces the very high level of heavy metals, reducing the risk for phytocenoses.

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