LAND USE IN URBAN ECOSYSTEMS AS SUPPORT OF ECOSYSTEM SERVICES. CASE STUDY: THE URBAN ECOSYSTEM OF BĂLȚI (REPUBLIC OF MOLDOVA)

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Abstract. The urban ecosystem is the ecological system located inside a city and which is composed of ecological infrastructure (green infrastructure + blue infrastructure) and built infrastructure (grey infrastructure). The green infrastructure consists of natural and anthropogenic elements, such as parks in urban areas, grass roofs and walls, farmland with high natural value, or forests with high conservation value. Green infrastructure can preserve and create landscape features that ensure ecosystems will continue to provide services such as clean water, clean air, productive soils, and attractive recreation areas. The municipality of Bălți, of 7798.54 ha according to the Land Registry, mostly includes agricultural land - 51% (4001.44 ha), followed by constructions and courtyards – 28% (2138.25 ha), forests -9% (722.75 ha), lands occupied by water and lands for streets and markets with 4% each, roads – 3% and other lands including degraded. In the rural area, agricultural land predominates, and in the urban area – buildings and yards. Urban ecosystems are considered to be in "good condition" if living conditions for people and urban biodiversity are good. This means, among other things, good air and water quality, a sustainable provision of ecosystem services, good conservation status of species and habitats, and a high level of urban species diversity. Another criterion concerns the balance between built and green infrastructure within the ecosystem.

Keywords: urban ecosystem, land use, ecosystem services.

Rezumat. Utilizarea terenului în ecosistemele urbane ca suport al serviciilor ecosistemice. Studiu de caz: Ecosistemul urban Bălți (Republica Moldova). Ecosistemul urban este sistemul ecologic situat în interiorul unui oraș și care este compus din infrastructură ecologică (infrastructură verde + infrastructură albastră) și infrastructură construită (infrastructură gri). Infrastructura verde constă din elemente naturale şi antropice, cum ar fi parcurile din zonele urbane, acoperişurile şi pereţii înierbaţi, terenurile agricole cu valoare naturală ridicată sau pădurile cu valoare ridicată de conservare. Infrastructura verde poate păstra şi crea caracteristici peisagistice care ne garantează că ecosistemele vor asigura în continuare servicii cum ar fi apă curată, aer curat, soluri productive şi zone de recreere atractive. În Municipiul Bălți, din cei 7798,54 ha conform Cadastrului funciar, predomină terenurile cu destinație agricolă – 51 % (4001,44 ha), urmate de cele de construcții și curți – 28% (2138,25 ha), pădurile -9% (722,75 ha), terenurile ocupate de apă și terenurile pentru străzi și piețe cu câte 4%, drumuri - 3%, și alte terenuri inclusiv degradate. În mediul rural predomină terenurile cu destinație agricolă, iar în cel urban – construcțiile și curțile. Ecosistemele urbane sunt considerate în „stare bună" dacă condițiile de viață pentru oameni și biodiversitatea urbană sunt prielnice. Aceasta înseamnă, printre altele, calitate bună a aerului și apei, o furnizare durabilă de servicii ecosistemice, o stare bună de conservare a speciilor și habitatelor și un nivel ridicat de diversitate urbană. Un alt criteriu se referă la echilibrul din interiorul ecosistemului între infrastructura construită și cea verde.

Cuvinte cheie: ecosistem urban, utilizarea terenurilor, servicii ecosistemice.

INTRODUCTION

Urban green space (UGS) in urban ecosystems plays an increasingly important role in the well-being of the inhabitants of these highly modified landscapes (CHIESURA, 2004; GÓMEZ-BAGGETHUN & BARTON, 2013, PINHO et al., 2016). Although their ecological value has often been considered limited due to their size and degree of artificiality (DAVIES et al., 2011), USG can provide various ecosystem services (ES), i.e. the benefits that humans receive from them. These ES are the basis for their use as a nature-based solution to the multiple environmental problems in the cities.

In recent years, methods have been developed for quantifying (WILLEMEN et al., 2008; GÓMEZ-BAGGETHUN & BARTON, 2013) and evaluating ES (BOYD & BANZHAF, 2007; JOHNSTON & RUSSELL, 2011). Most publications aim to quantify ES at a regional or national scale, with a focus on natural and rural landscapes. Less than 10% of all publications refer to urban ecosystems (GÓMEZ-BAGGETHUN & BARTON, 2013; HUBACEK & KRONENBERG, 2013). The change in land use and ecosystems is due to urbanization (LARONDELLE & HAASE, 2013) causing typical city problems such as air pollution, noise, heat stress, etc. which can be regulated by USG. Most researchers who study one or more USG or land cover modes in detail usually focus only on a single ES.

Carbon storage was studied by BAE & RYU, (2015) and GRATANI et al., (2016) while SPEAK et al., (2015) focused on biodiversity, and DERKZEN et al., (2015) went a step further and studied the ES provided by the entire green space.

In this study, we aim to analyze the way of land use in a residential area with houses on the ground, where the built infrastructure (BI) (roads, houses, paved yards, etc.) and USG (forests, gardens, trees, shrubs, grassy vegetation), but also ES quantification (air purification, carbon storage and runoff retention).

MATERIALS AND METHODS

The Bălți urban ecosystem with its peri-urban areas – the villages of Sadovoe and Elizaveta (Fig. 1) served as the object of study. The green, blue and built infrastructure was quantified and the relationships between these infrastructures were established. The initial data source served the Land Registry (***. AGENȚIA RELAȚII FUNCIARE ȘI CADASTRU, 2004–2019). The gray infrastructure included the land under roads, streets and squares, buildings and yards. Green infrastructure includes agricultural land (arable land, fallow land, perennial plantations, hayfields and pastures), forest plantations – green spaces (forest lands, shrubbery and shrub plantations, protective forest strips), and blue infrastructure sums up lands under water (swamps, ponds, lakes, segments of rivers, streams and streams).

The total surfaces of the respective infrastructures were identified and calculated and the correlation between them was analyzed. The research was carried out at the level of the central city and the Functional Urban Area (UFA) as a unified spatial unit for the delimitation of cities in Europe taking into account population density. A functional urban area is made up of an urban center and the economically integrated area close to the central city (eg: labor pool, commuting area) (ROȘU & BLĂGEANU, 2012). A peripheral area of the expanding urban ecosystem was identified to establish the influence of habitat change on ES. In the pilot area (Fig. 1), the establishment of infrastructure types was made based on the data obtained from the interpretation of Sentinel-2 images with a resolution of 10 m using QGIS 3.16 software. The classification of the map was carried out by the FAO Land Cover Classification System - Corine Land Cover Land Use, at the II classification level and includes 7 categories of land - arable, pastures, perennial plantations, forests, waters and urban areas.

Figure 1. Schematic plan of the pilot research area (original).

To quantify the ecosystem services (Table 1), the coefficients of 3 types of ES (air purification, carbon storage, leakage retention) were used according to DERKZEN et al. (2015).

Table 1. The role of some types of green infrastructure in the provision of different ecosystem services (DERKZEN et al., 2015).

The type of UGS	Air purification*, g/m^2/years	Carbon storage, kg/m^2	Run-off retention, l/m^2
Woodland	2,69	15,62	8,7
Trees	3,97	10,64	8,4
Short shrubs	2,05	5,51	7,3
Herbaceous	0,9	0,17	8
Cultivated lands	0,82	1,07	6
Gardens	0,82	1,07	6
Water	0	0	10
Other	0,82	1,07	6

* The indicator depends on the location of the IV (the air purification rate is doubled for the IV on a buffer zone of 50 m from the road.

Air purification is calculated for PM 10 particles because they are the most harmful to health and the most efficiently captured by UGS. In quantifying carbon storage, two factors are important, the first being the volume of biomass, which is proportional to the carbon storage capacity of the trees, and the second factor is the type of vegetation. Runoff retention is calculated for a 10 mm rain event.

RESULTS AND DISCUSSION

The municipality of Balti, including the communes of Sadovoe and Elizaveta, according to the Land Registry, occupies an area of 7800.57 ha (***. AGENȚIA RELAȚII FUNCIARE ȘI CADASTRU, 2004–2019; ȚUGULEA et al., 2022). Arable land is cultivated with cereals, technical crops, vegetables and some fodder crops. They represent the main form of land use in peri-urban areas, currently owning 4001,442 ha (or 50% of the municipality) (Table 2).

Table 2. Distribution of infrastructure according to land use in urban and peri-urban areas.

The type of infrastructure	Bălți		Sadovoe		Elizaveta	
	ha	%	ha	%	ha	%
Woodland	376	9	2,7	0	0	0
Trees	7	0	15,56	2	4	0
Short shrubs	312,021	8	5,38	1	0	0
Herbaceous	83,46	2	105,4996	11	513,4824	19
Cultivated lands	585,2402	14	562,3411	57	1880,789	70
Gardens	117,35	3	141,87	15	11,41	1
Water	178	4	42,43	4	78,13	3
Built infrastructure	2434,93	59	100,98	10	189,21	7
Other	49	1	3,7	0	0	0
Total	**4143,0**	**100**	**980,46**	**100**	**2677,02**	**100**

Perennial plantations are areas cultivated with fruit trees, vines and other perennial crops. In the municipality of Bălți, this category occupies only 3% of the land (249.63 ha). Of these, 120.87 ha are in Sadovoe village, 117.35 ha in Bălți and only 11.41 ha in Elizaveta village. Orchards (234.28 ha), vineyards (19 ha), fruit nurseries (10 ha) and 1.79 ha of land occupied by other crops predominate.

In the Bălți municipality, the area of forests is 722.75 ha (including 312 ha of young forests), which constitutes 17% of the land. Most of the forests are located on the outskirts of Bălți (Fig. 2, Table 2). Forest resources are fragmented and spread mainly on degraded lands.

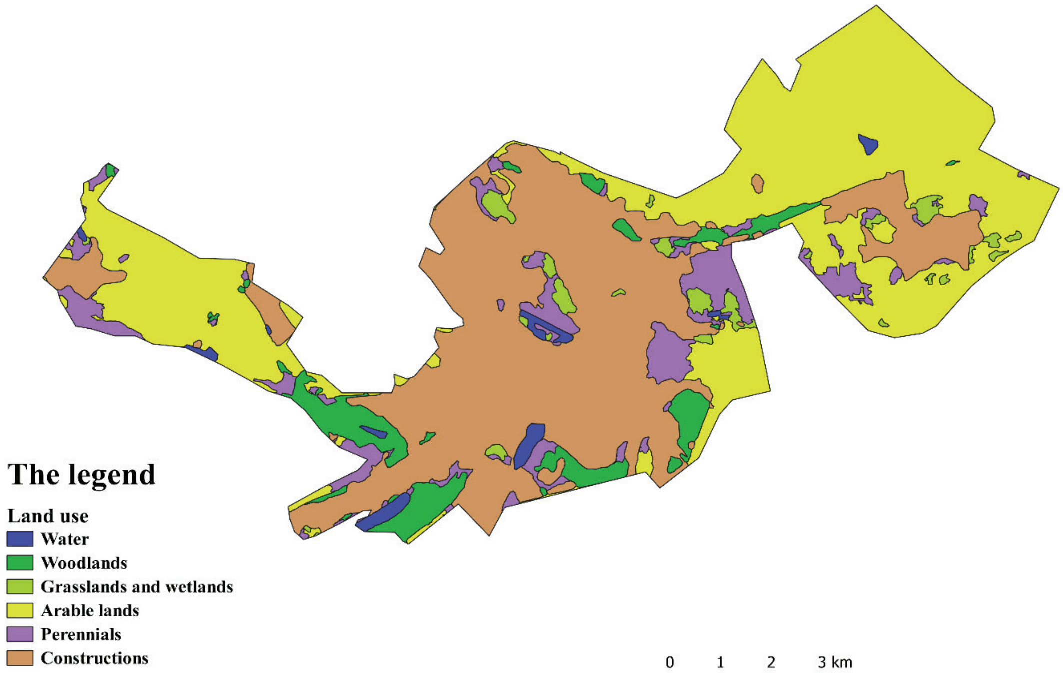

Figure 2. Land use in the Bălți Municipality (ȚUGULEA et al., 2022).

The lands of the aquatic background include in its composition the beds of water courses, the basins of lakes, ponds and water reservoirs, and swamps. The share of these lands in the municipality of Balti is 4% (298.56 ha) – 178 ha in the city Bălți and 120.6 ha in rural areas.

The land under construction has a weight of 33%. This includes built surfaces, spaces and access links between them within the city and villages. The largest built-up area is owned by Bălți, here there are 131.44 ha of roads, 286.34 ha of streets and squares and 2017.12 ha of buildings and yards. The urban green infrastructure in the urban (Bălți city) and peri-urban ecosystems produces different amounts of ES (Table 3).

Table 3. The amount of ES provided by USG in the localities of Bălți Municipality.

The type of ES	Town		
	Bălți	Sadovoe	Elizaveta
Air purification, kg/year	23702.91	7555.019	20296.17
Carbon storage, t	84852.25	10127.76	21545.05
Run-off retention, t	125649.7	1383.153	162759.5

In the Bălți urban ecosystem, the largest amount of particles is retained by forest plantations (Fig. 3).

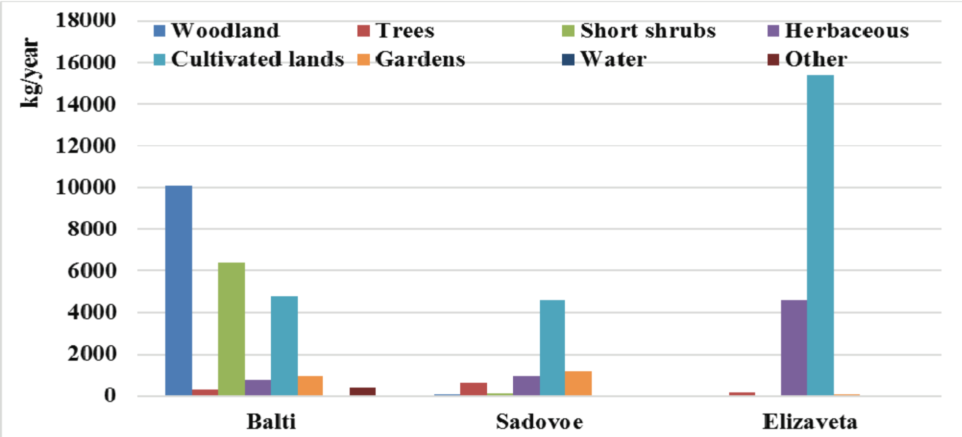

Figure 3. Air purification by green infrastructure in urban and peri-urban ecosystems.

Likewise, carbon storage is determined by the amount of biomass synthesized in the forests in the city area (Fig. 4), and the retention of atmospheric precipitation is determined by cultivated land (Fig. 5).

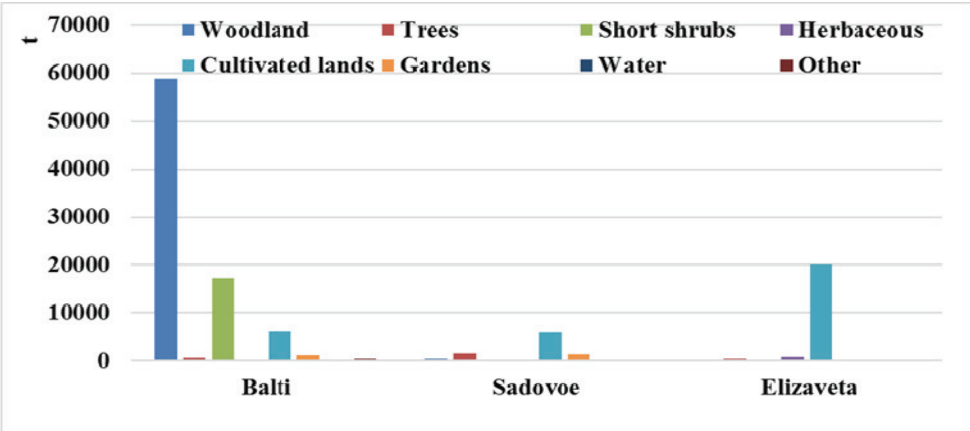

Figure 4. Carbon storage by green infrastructure in urban and peri-urban ecosystems.

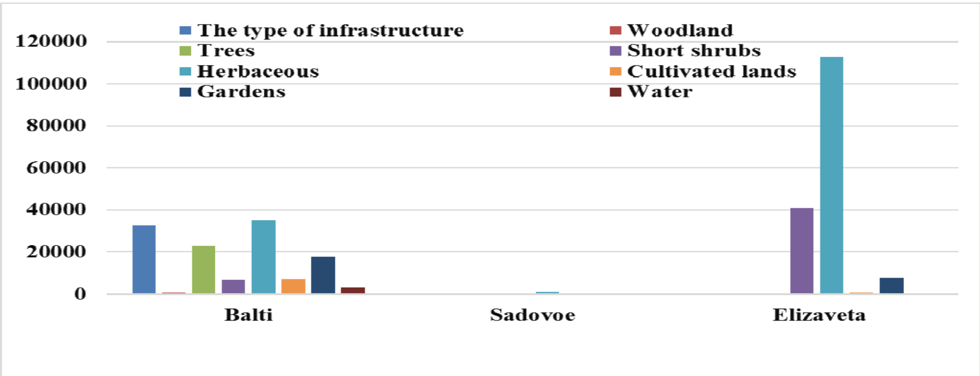

Figure 5. Runoff retention by green infrastructure in urban and peri-urban ecosystems.

Air purification is defined as lowering the background concentration of air pollution. UGS improves air quality by filtering the atmosphere from particles such as nitrogen dioxide (NO2), particulate matter (PM10) and sulphur dioxide (SO2) (TALLIS et al., 2011).

Even if the share of land covered by the infrastructure built in Balti is quite high 59% (Table 2), the amount of retained pollutants is higher compared to the Sadovoe and Elizaveta villages (Fig. 3). This is determined by forest vegetation and shrubs that have a purification coefficient greater than 2 compared to 0.8 for cultivated land (Table 1). The village of Sadovoe has a small area, and the share of cultivated land and grassy vegetation is the majority. In this case, the ES offered by this locality is reduced.

The contribution of UGS regarding carbon storage is determined by two essential factors such as the volume of biomass which is proportional to the carbon storage capacity, as well as the type of vegetation. Most of the amount of stored carbon is carried out by the canopy of trees in forests, but also solitary ones and less by shrubs and herbaceous vegetation (JO & MCPHERSON, 1995; ESCOBEDO et al., 2012). The high volume of carbon sequestered by the city compared to the other localities in Balti municipality is determined by the area occupied by forest, solitary trees and shrubs (Table 2).

The factors that influence the regulation of runoff are the intensity and duration of precipitations, the climate, the slope and the characteristics of the vegetation. Trees contribute mostly through interception, while herbaceous vegetation contributes to soil water infiltration (ARMSON et al., 2013).

For the Elizaveta village, the share of cultivated lands and those covered with grassy vegetation is relevant (about 90), namely, these two types of UGS retain the runoff to the greatest extent (Fig. 5).

In the pilot area, an area subject to urbanization expansion, land use (Figs. 6-7) is characterized by areas covered with herbaceous vegetation (42% of the total of 37.73 ha), built-up areas – 31%, cultivated land – 18%, forest – 6%, shrubs – 2% and associations of trees – 1%.

Figure 6. The spatial configuration of land use in the pilot area (original).

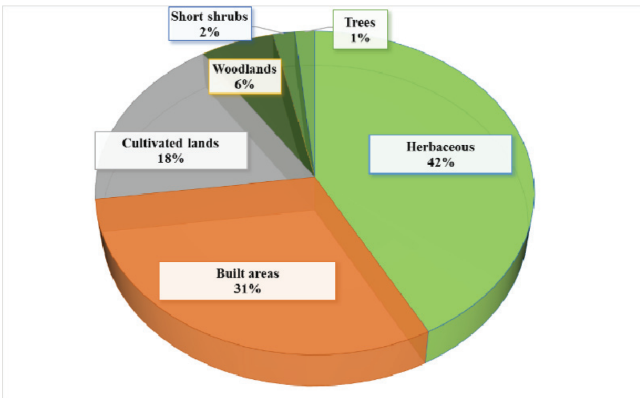

Figure 7. The use of land in the pilot area.

The area covered by herbaceous vegetation corresponds to the original state of the habitat and consists of ruderal flora with a low ecological value. The arable land is characterized by a strong fragmentation by the owners and, in most cases, it is represented by small plots used as gardens, where vegetables are grown. The built-up area is occupied by buildings and roads, followed by paving in private yards, roads and sidewalks.

The urban green infrastructure (USG) in the researched area comprises 69% (grassland, cultivated land, forests, trees and shrubs) and fulfils various roles in the provision of ecosystem services.

The quantification of ecosystem services (Table 3) highlights the role of each type of green infrastructure in this area. Both the forest and the solitary trees have the highest air purification coefficient, surge retention, and carbon sequestration. Trees absorb gaseous pollutants such as nitrogen oxides, sulphur oxides, ozone, etc. in the process of photosynthesis, and PM 2.5, PM10, etc. are captured on the surface of the leaves (NOWAK et al., 2013). Lands covered with grassy vegetation contribute to runoff retention and less to air purification (ESCOBEDO et al., 2008). Almost all above-ground carbon storage occurs in trees and only a small percentage is stored in shrubs and herbaceous vegetation. Carbon storage expresses the gross amount of carbon stored at a given time and does not take into account its dynamics over time (NOWAK & CRANE, 2002).

Different land cover types influence surface runoff. Lands covered with constructions are not capable of infiltrating water into the soil, thus investments in rainwater drainage systems are necessary. The factors that influence the runoff regulation function are the intensity and duration of precipitation, climate, slope and vegetation characteristics. Trees contribute largely through interception, while grass absorbs most rainwater through infiltration (ARMSON et al., 2012).

Table 4. Provision of ecosystem services (SE) by different types of UGS in the pilot area.

The type of UGS	Air purification, kg/years	Carbon storage, t	Run-off retention, t
Woodland	60,525	351,45	195,75
Trees	23,82	63,84	189,00
Short shrubs	13,735	37,587	164,25
Herbaceous	143,01	27,013	180,00
Cultivated lands	55,186	72,011	135,00
Total	**296,276**	**551,901**	**864,00**

Resulting from the structure of UGS in the researched area, it was established that they store 551.9 t of carbon, retain 864.0 t of precipitations at a 10 mm rain event and have a significant contribution to air purification (Table 4). In pasture conditions (until the change of destination) the land had the potential to retain more than 3000 t of runoff, and in urban conditions, this indicator decreased by 3.5 times (Fig. 8).

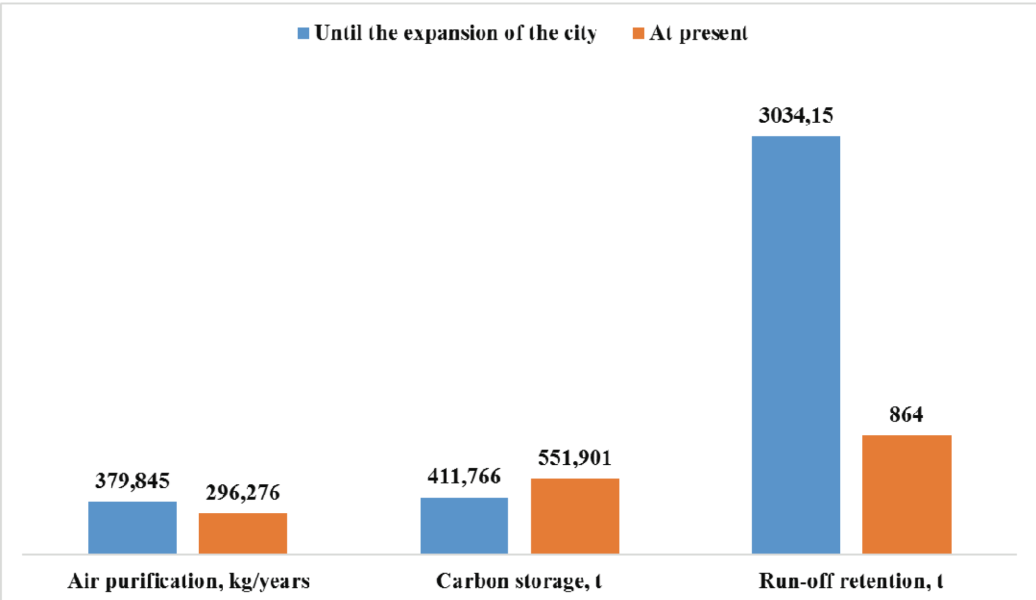

Figure 8. The evolution of the amount of ES as a result of the change of land destination in the pilot area.

Comparing the ES value per surface unit under the conditions of the pilot area (calculated on the basis of Sentinel-2 image interpretation data with 10 m resolution using QGIS 3.16 software) and per hour, for Balti in general (based on the Land Register data), we note that the size of the data is comparable (Fig. 9).

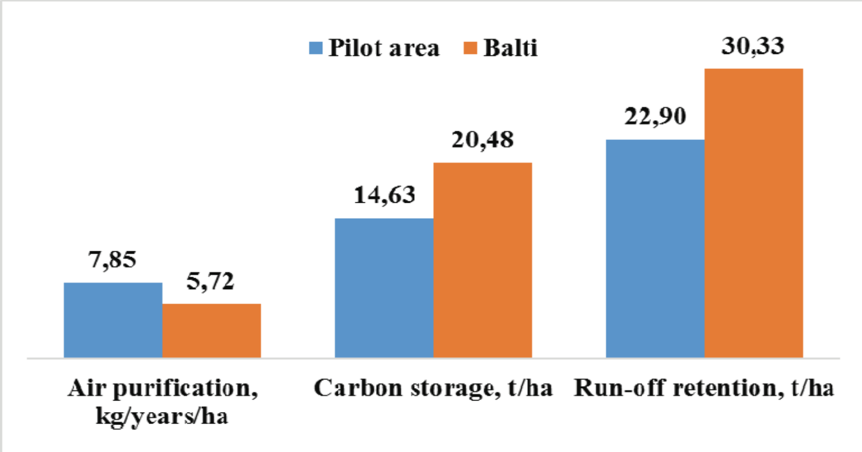

Figure 9. The intensity of air purification, carbon storage and rainwater retention in the pilot area and the average in the city of Bălți.

CONCLUSIONS

The composition of green urban infrastructure largely determines the value of ecosystem services in the urban ecosystem. ES air purification and carbon storage are largely determined by the density of forest parks as well as solitary trees in street alignments. Runoff retention is carried out more intensively in grassy areas.

Under the conditions of Bălți, USG can remove about 51.6 t/year of particles from the air, store 116.5 thousand tons of carbon and retain rainwater in an event of 10 mm precipitation 289.8 thousand t/year.

In peri-urban areas (Sadovoe and Elizaveta villages), the volume of ES is determined by the specifics of the agricultural use of the land.

The change of habitat (from natural to urban) substantially modifies the amount of exosystemic services, which in turn is determined by the composition of USG.

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