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ASSESSMENT OF GREEN AND BLUE INFRASTRUCTURE IN URBAN ECOSYSTEMS IN THE REPUBLIC OF MOLDOVA AND THE IMPACT ON ECOSYSTEM SERVICES

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Abstract. Green infrastructure is a key element of a sustainable urban ecosystem. It is recognized as an effective approach based on the way nature works, being an important source of ecosystem services provided to the population. Green and blue solutions are one of the new tools that can help cities increase their resilience and sustainability. The green infrastructure (forest plantations, forest-parks, agricultural land, hedges, lineaments, etc.), the blue infrastructure (lands under marshy waters, rivers, ponds) was evaluated and compared with the grey infrastructure (roads, streets and squares, constructions) in cities and rural areas in the development regions of the Republic of Moldova. The results show that the spatial share of green infrastructure in cities with a population greater than 30 thousand inhabitants (Chișinău city, Bălți city, Cahul city) represents about 25-35% of the total area, the share of grey infrastructure is 50-60 %, and the blue one only 2-4%. In smaller cities, the share of green infrastructure can reach values of up to 50-70 percent, and in rural areas, the share of green infrastructure reaches around 70-90%, blue infrastructure 2-3%, and the built one 10-12%. Cultural ecosystem services related to different types of ecosystems were identified in terms of supply, regulation and support. The dependence of the amount of ecosystem services (air purification, carbon storage, leakage retention) on the weight of the ecological infrastructure in the investigated ecosystems was investigated.

Keywords: ecological infrastructure, urban ecosystems, ecosystem services.

Rezumat. Evaluarea infrastructurii verzi și albastre a ecosistemelor urbane din Republica Moldova și impactul asupra serviciilor ecosistemice. Infrastructura ecologică este un element cheie a unui ecosistem urban durabil. Ea este recunoscută ca o abordare eficace bazată pe modul în care funcționează natura, fiind o sursă impotantă de servicii ecosistemice furnizate populației. Soluțiile verzi și albastre reprezintă unul dintre instrumentele noi, ce pot ajuta orașele să-și crească reziliența și durabilitatea. A fost evaluată infrastrutura verde (plantații forestiere, păduri-parcuri, teren agricol, garduri vii, liniamente e.t.c.), infrastuctura albastră (terenuri sub ape mlaștini, râuri, iazuri) și comparată cu infrastructura gri (drumuri, străzi și piețe, construcții) în orașele și spațiile rurale în regiunile de dezvoltare a Republicii Moldova. Rezultatele arată că ponderea spațială a infrastructurii verzi în orașele cu o populație mai mare de 30 mii locuitori (or. Chișinău, or. Bălți, or. Cahul) reprezintă circa 25-35% din suprafața totală, ponderea infrastructurii gri este de 50-60 %, iar a celei albastre doar 2-4 %. În orașe mai mici ponderea infrastructurii verzi poate atinge valori de până la 50-70 la sută, iar în localitățile rurale ponderea infrastructurii verzi atinge circa 70-90%, albasrtre 2-3%, iar cea construită 10-12%. Au fost identificate serviciile ecosistemice de aprovizionare, reglare și suport, culturale legate de diferite tipuri de ecosisteme. A fost investigată dependența cuantumului serviciilor ecosistemice (purificarea aerului, depozitarea carbonului, retenția scurgerilor) de ponderea infrastructurii ecologice în ecosistemele cercetate.

Cuvinte cheie: infrastructură ecologică, ecosisteme urbane, servicii ecosistemice.

INTRODUCTION

International practice shows that, without highly developed cities, a country cannot have developed regions or a robust national economy. At the same time, the trend towards urbanization in the recent decades leads to the significant expansion of urban areas. It is estimated that approximately 1,000 km^2 per year are transformed into artificial surfaces in the European Union (***. THE EUROPEAN ENVIRONMENT, 2015), mostly occupied by arable land.

According to the definition (***. MAPPING AND ASSESSMENT OF ECOSYSTEMS AND THEIR SERVICES, 2016), urban ecosystems (UE) are socio-ecological systems that are composed of ecological infrastructure (infrastructure green + blue infrastructure) and built infrastructure (grey infrastructure). Like any other ecosystem, the urban ecosystem is composed of physical and biological components that interact with each other.

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. The “blue” infrastructure includes all the bodies of water (swamps, rivers, lakes, canals) within an urban ecosystem, which together with the green infrastructure constitute the Ecological Infrastructure (EI).

Urban ecosystems are considered in “good condition” if living conditions for people and urban biodiversity are good (***. MAPPING AND ASSESSMENT OF ECOSYSTEMS AND THEIR SERVICES, 2016). Another criterion concerns the balance within the ecosystem between built and green infrastructure. Green infrastructure provides a wide range of benefits for the population – including reducing air, water and noise pollution, providing protection against floods, droughts and heat waves, and maintaining a connection between people and nature.

The aim of the paper is to obtain new knowledge for the promotion of policies and management of urban ecosystems by identifying the contribution of ecological infrastructure to their state and ecosystem services.

MATERIALS AND METHODS

The green, blue and built infrastructure in the regional urban ecosystems of the Republic of Moldova was quantified and the relationships between these infrastructures were established depending on the size and specifics of the cities (number of population, extra-urban/intra-urban ratio, cities - development poles, etc.). In the municipality of Chișinău, the research was carried out at the level of the central city and the Functional Urban Area (FUA) 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).

The initial source of data was provided by the Land Registry (***. AGENȚIA RELAȚII FUNCIARE ȘI CADASTRU, 2004–2019). Green infrastructure includes agricultural land (arable land, perennial plantations, hayfields, pastures), forest plantations - green spaces (forest lands, shrub and shrub plantations, protective forest strips), and blue infrastructure includes lands under water (swamps, ponds, lakes, segments of rivers, streams, streams). The built infrastructure ("grey") included the lands under roads, streets and squares, buildings and yards. The total surfaces of the respective infrastructures were identified and calculated and the correlation between them analyzed.

The identification and assessment of different ecological infrastructure elements and their generation of various ecosystem services was carried out using the concept of the "waterfall model" (POTSCHIN et al., 2016). This model links ecological infrastructure to human well-being through the flow of ecosystem services. Ecological components are organized into ecosystem structures and interact through ecosystem processes that in turn determine the functions and range of ecosystem services, producing benefits and value.

The calculation of the amount of regulating ecosystem services - air purification, carbon storage and water retention was carried out according to DERKZEN et al. (2015) for different elements of the green and blue infrastructure using the coefficients (Table 1).

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
Forest	2,69	15,62	8,7
Forest vegetation	2,05	10,64	8,4
Cultivated land	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). ** Water retention is calculated for a 10 mm rain event.

RESULTS AND DISCUSSION

In the urban network of the Republic of Moldova, small and medium-sized cities predominate numerically, with a population of less than 20 thousand inhabitants each, a fact that is determined by the fairly large role of the agro-industrial sector in the national economy. More than 56% of the entire urban population of the country is concentrated in the 4 large municipalities: Chișinău, Bălți, Tighina and Tiraspol. Urban localities are ranked by rank: rank 0-municipality, capital - (Chișinău); first rank - 2 municipalities (Bălți, Tiraspol); rank II - 8 municipalities (Cahul, Ceadîr-Lunga, Comrat, Edineț, Hîncești, Orhei, Soroca, Strășeni, Ungheni, Bender); rank III-cities- 55. The number of population in the municipalities - district residences are from almost 20 thousand to -35 thousand inhabitants. Six municipalities were recommended for their development as growth poles: Edineț, Soroca, Ungheni, Orhei, Cahul and Comrat. According to the analyses, with the exception of the municipality of Bălți (122 thousand inhabitants) and the municipality of Chișinău (639 thousand inhabitants), only these 6 municipalities possess the necessary potential to become engines of economic growth at the national and regional level (SIRODOEV, 2015).

Specific for most cities in the Republic of Moldova is the high proportion of the extra-village, which is why the ratio between the total area and the inner-village, in some cases, approaches 20:1, which shows that many of these cities have characteristics of "large villages" with a significant share of agricultural land. The countryside includes cultivated land, pastures, hayfields, forests, waters, unproductive land, etc., where the population carries out a significant part of their production activities (ERDELI et al., 1999), the inner city, however, fulfills various functions: residential, agricultural, industrial, socio-cultural, transport, storage, leisure, etc. (SURD, 2003; MÎTCU et al., 2007).

The green infrastructure (GI) in the urban ecosystems of the republic (extra-urban + intra-urban) is presented in figure 1.

In component GI, both outside the village and inside the village, agricultural land predominates. Their share is 64%, varying from only 24% in the Chisinau municipality to around 77% in the Dondușeni district. With the exception of municipalities, in all districts of the republic, the share of agricultural land exceeds 50%, a fact that is explained by the presence within the boundaries of households of vast adjacent lands with agricultural use (MÎTCU et al., 2007). This peculiarity is mostly specific to the urban localities in the southern region of the republic – the cities of Cimișlia, Taraclia, Vulcănești, Ceadîr-Lunga, Comrat, which can be explained both by the less advantageous natural and economic conditions, and by the specific ethno-cultural the local population (Gagauz, Bulgarians). Within the outskirts, large areas are occupied by pastures.

The next element with a high weight in GI is represented by forest plantations (forests and other types of vegetation), more strongly spread in the cities of the central region of the republic – Nisporeni, Hîncești, Strășeni. In these cities, forest plantations occupy about 32-41% of the total area of urban land.

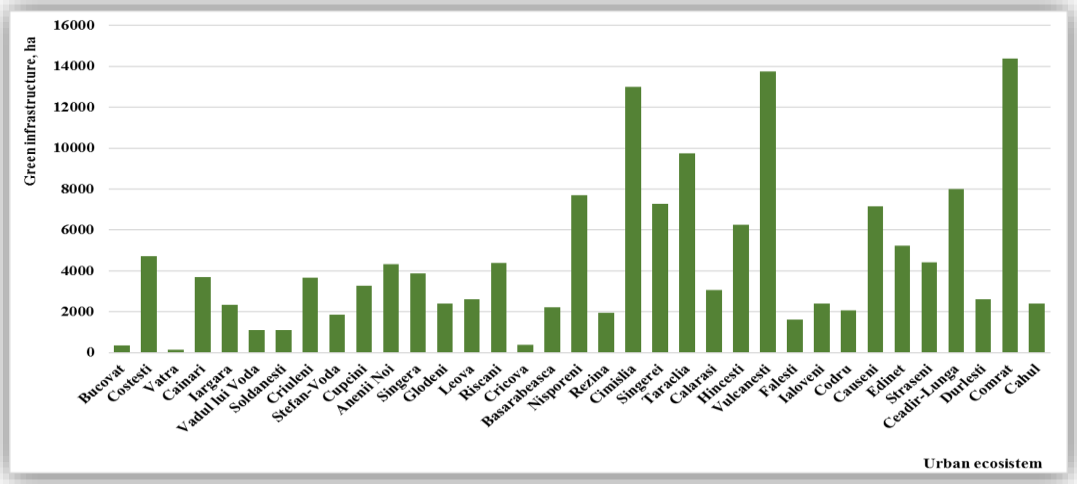


Figure 1. Land surface with green infrastructure in urban ecosystems in the Republic of Moldova.

Blue infrastructure (BI) is present in cities through natural water bodies (Răut r. - Bălți municipality, Orhei town, Bîc r. - Călărași town, Strășeni town, Chișinău mun., Anenii Noi town), r. Dniester - h. Soroca s.a., r, Prut - town. Ungheni, town Leova, town Cahul) and artificial (reservoirs, ponds, lakes), wetlands. The total area of BI in the cities of the Republic of Moldova is reflected in figure 2.

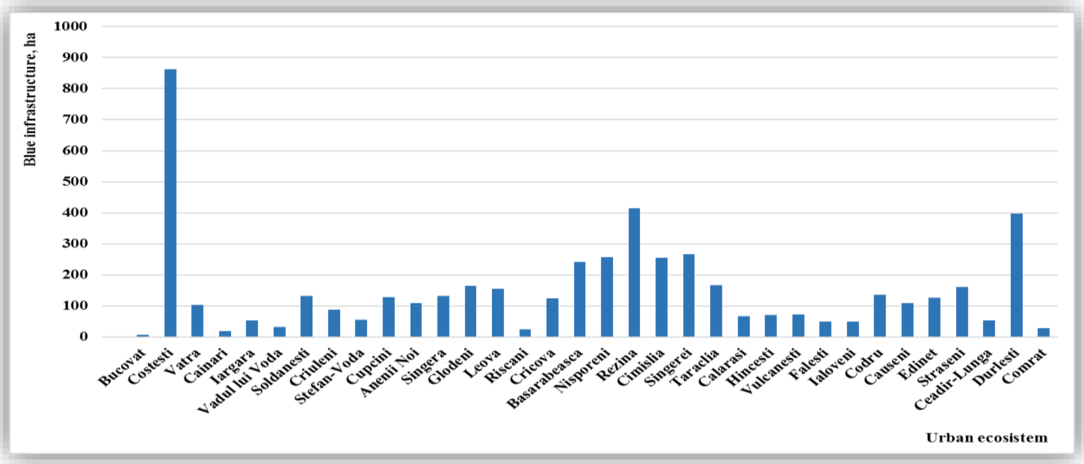


Figure 2. Land surface with blue infrastructure in urban ecosystems in the Republic of Moldova.

The functions of BI within urban ecosystems are multiple: habitats for a wide range of aquatic and semi-aquatic plants and animals; elimination of nutrients from urban activities; fishing, rest and recreation. Spatially, BI is unevenly distributed. Relatively large areas of land under water are in towns: Costești (reservoir – 2370 ha), Vatra (reservoir – 862 ha), the towns of Cimișlia, Comrat, Taraclia.

The share of built-up areas in the cities of the Republic of Moldova is approximately 30%. In terms of spatial profile, the share of built-up areas exceeds 50% only in the municipalities of Chișinău, Bălţi and Tighina. Among the district centers, these values are approached by Ungheni (42%). Otherwise, they vary from 21.8% in Donduşeni to 38.2% in Edinet (Fig. 3).

The connection between the ecological infrastructure, the built infrastructure and the number of the population was researched in a series of cities (Fig. 4) consisting only of the urban area (buildable perimeter) which represents the area delimited within the territorial development process.

In small and medium-sized cities, the surface of the ecological infrastructure (GI + BI) belonging to one person prevails over the built one, the ratio between them reaching the value of 2:1 (Fig. 4). Exceptions are made by some small (relatively young) cities where large agro-zootechnic complexes for animal breeding and processing of agricultural production were built in certain periods. Along with the growth of cities, there is an obvious decrease in the area of EI per person: in cities with a population of up to 10 thousand inhabitants, this is 700 - 1000 m^2/person; in cities with a population between 10-30 thousand inhabitants - 300-700 m^2/person, and in large cities (Tighina, Bălți, Chișinău municipalities) the area of the EI decreases to 40-135 m^2/person (Fig. 5). This difference is explained by the fact that small towns include areas with individual houses with garden plots.

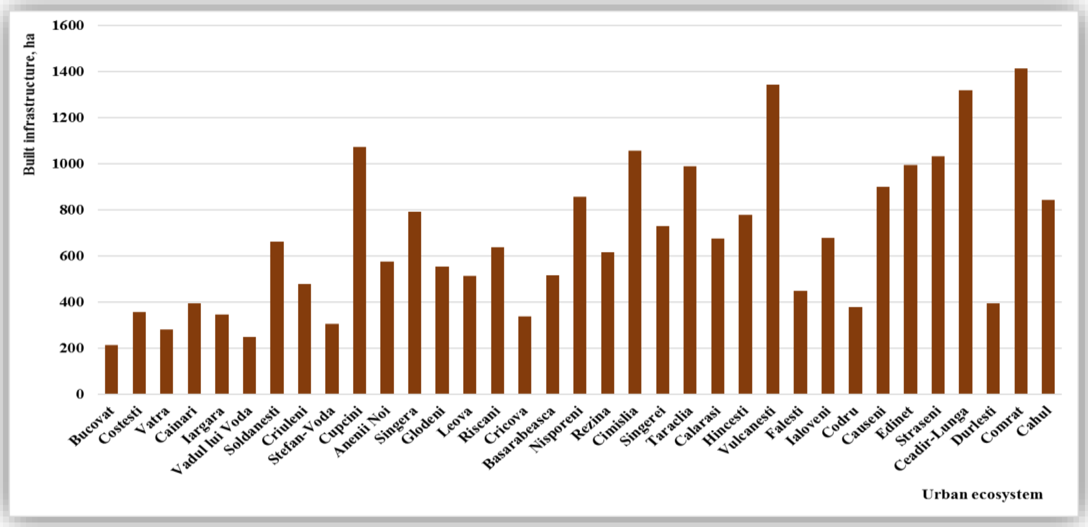


Figure 3. Land surface with built infrastructure in the urban ecosystems of the Republic of Moldova.

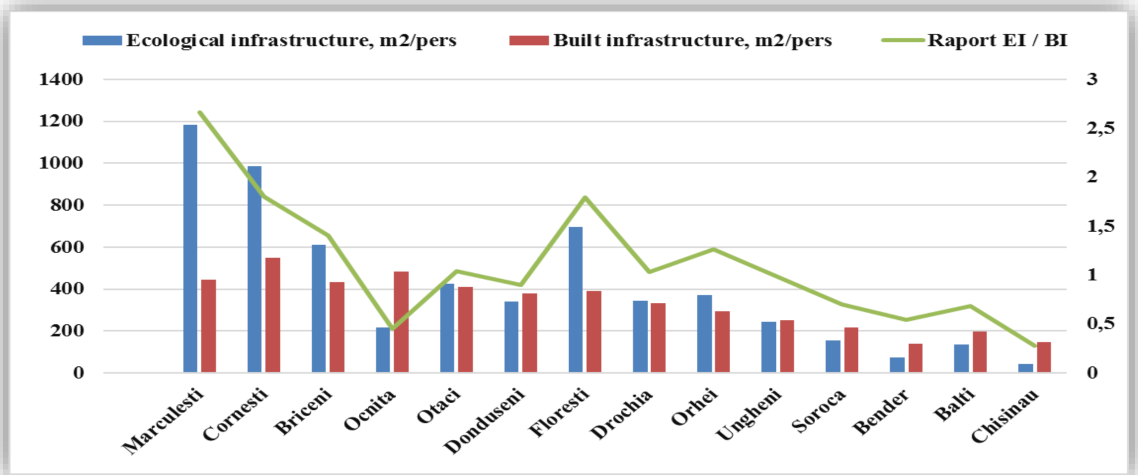


Figure 4. The surface of the ecological and built infrastructure in the inner city of some urban ecosystems.

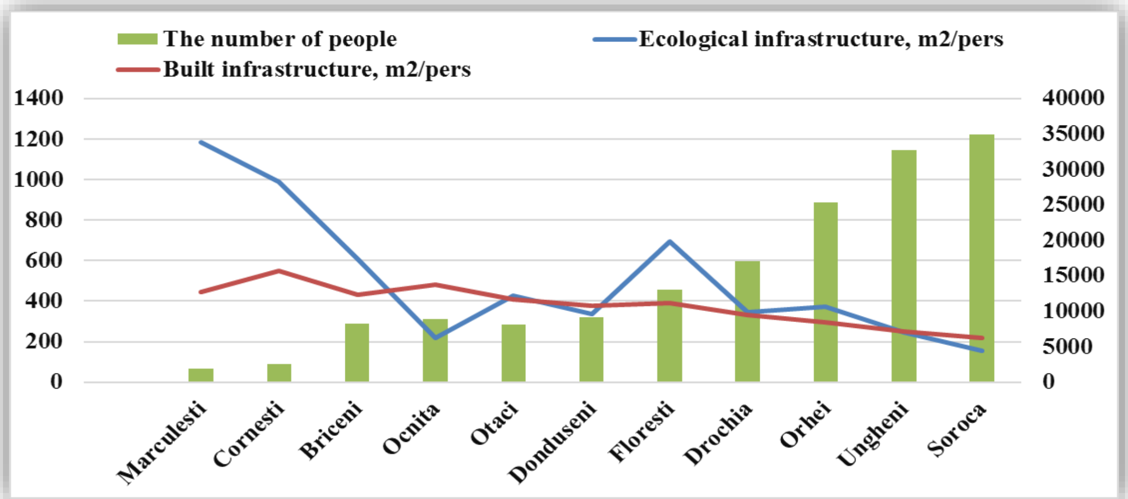
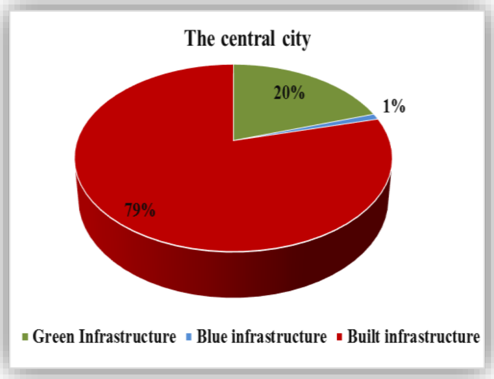


Figure 5. The relationship between ecological infrastructure,
built infrastructure and the number of inhabitants in urban ecosystems.

Research has shown that the share of built infrastructure (BuI) is 79%, GI occupies 20% of the city area, and BI only 1% (Fig. 6) in the Chișinău urban ecosystem (the central city). In the functional urban area (the central city + the commuting area, in the given case, the villages and communes that are part of the municipality), the ratio between the types of infrastructure changes substantially, with a decrease in BuI and an increase in GI and BI (MOGÎLDEA et al., 2022).



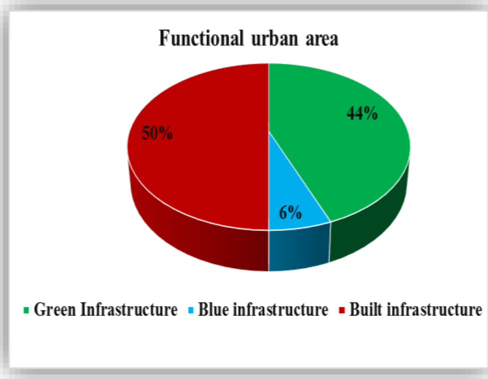


Figure 6. The distribution of infrastructure types in different urban areas of the municipality of Chișinău.

Unlike the solutions offered by IC, which normally only fulfills one function, green infrastructure has the possibility to solve several problems at the same time. Traditional built infrastructure is still needed, but can often be enhanced with nature-inspired solutions. Green infrastructure solutions are less expensive than gray infrastructure and offer a wide range of related benefits to local economies and the wider environment.

Ecosystem services are the benefits that people obtain from ecosystems (a definition according to the Millennium Ecosystem Assessment (***. ECOSYSTEMS AND HUMAN WELL-BEING, 2005) or according to the definition given by The Economics of Ecosystems and Biodiversity, TEEB – ecosystem services are the direct and indirect contributions of ecosystems to human well-being (***. THE ECONOMICS OF ECOSYSTEMS AND BIODIVERSITY, 2010).

Next, the Common International Classification of Ecosystem Services (CICES) was developed, according to which ecosystem services are defined as the contributions of ecosystems to human well-being. These contributions are framed in terms of "what ecosystems do" for people. Thus, the definition of each service identifies both the purposes or uses that people have for different types of ecosystem services and the specific ecosystem attributes or behaviours that support them (HAINES-YOUNG et al., 2018).

The benefits of EI for the sustainable development of both urban and regional ecosystems are diverse and multiple. On an urban scale, the key benefits are related to surface water runoff management and flood prevention, thermal comfort and population recreation, air quality regulation, etc. The most important cultural ecosystem services are nature-based recreation, education and cultural heritage (as it relates to the environment) (ANDERSSON et al., 2015). The demand (need) expression of ES includes three categories of indicators: risk or exposure (for regulatory ecosystem services); consumption (for supply ecosystem services); preference and potential or direct use (for cultural ecosystem services) (WOLFF et al., 2015).

Different models have been proposed for quantifying ecosystem services (BOLUND et al., 1999; BAUMGARDNER et al., 2012; NOWAK et al., 2013). Most publications aim to quantify ES at a regional or national scale, with a focus on natural and rural landscapes (JOHNSTON & RUSSELL, 2011). The limited attention of urban ecosystem services can be explained by the small size of urban ecosystems (DAVIES et al., 2011).

Urban ecosystems include habitats that could be classified as other types of ecosystems, such as agroecosystems, grasslands, forests, shrublands, and freshwater bodies, and although these are typically small, unconnected, highly modified, and far from their state natural, can contribute to the provision of a wide range of ecosystem services, including food supply, green space for recreation, air quality regulation, flood protection and aesthetic value. In this context, the atmospheric air purification capacity, carbon storage and precipitation water retention by the ecological infrastructure elements agricultural land, forest plantations and water bodies in urban ecosystems at the level of development regions were quantified (Fig. 7).

Agricultural land with a total area of 135.9 thousand ha is able to retain about 1114.2 t of particles from the air, 28.8 thousand ha of forest about 641.5 t, and 5.5 thousand forest vegetation - 112.6 t, which corresponds to 60%, 34 and 6% respectively (Fig. 8).

Champions in carbon storage and water retention from precipitation in urban ecosystems are the forest plantations, which in the course of a year sequester about 4032.8 thousand tons of carbon and can retain almost 30 million m3 of water only for a 10 mm rain catch (Figs. 9; 10). Knowing the average amount of precipitation and the average number of rains for an urban ecosystem, we can calculate the total amount of precipitation retained annually by the ecological infrastructure as a whole or some of its elements.

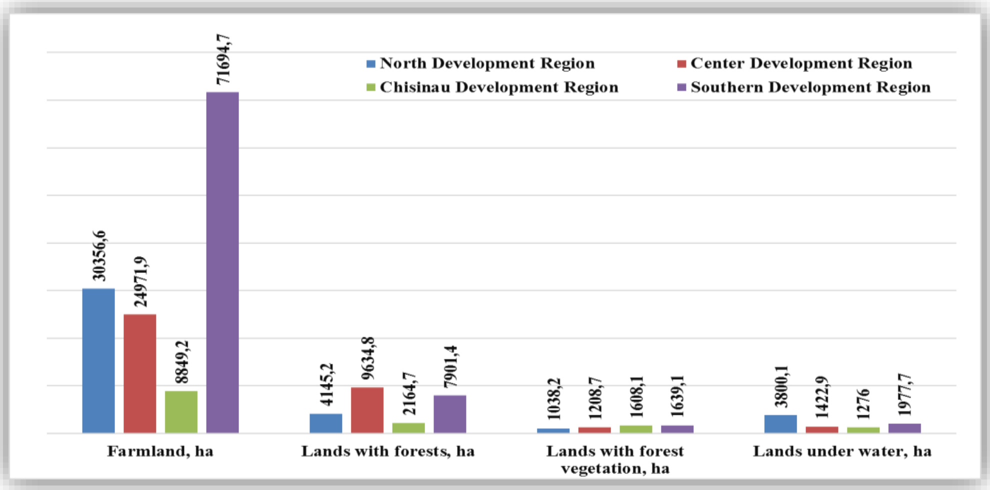


Figure 7. Share of lands providing ecosystem services in urban ecosystems in development regions.

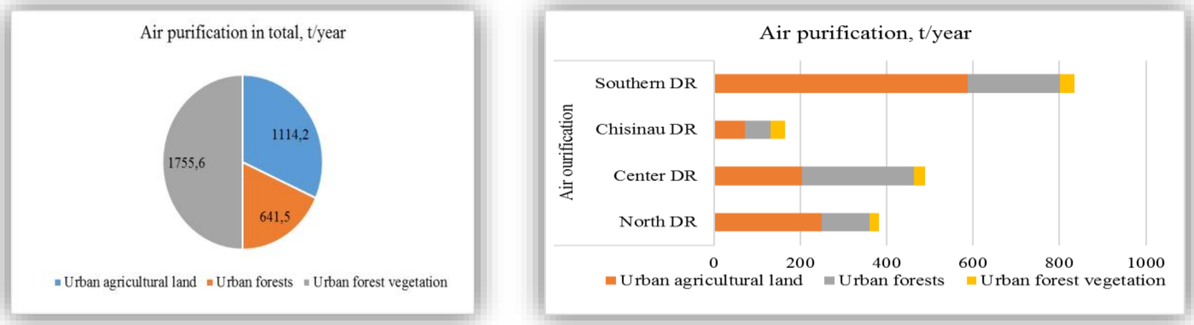


Figure 8. The air purification capacity of the urban ecological infrastructure.

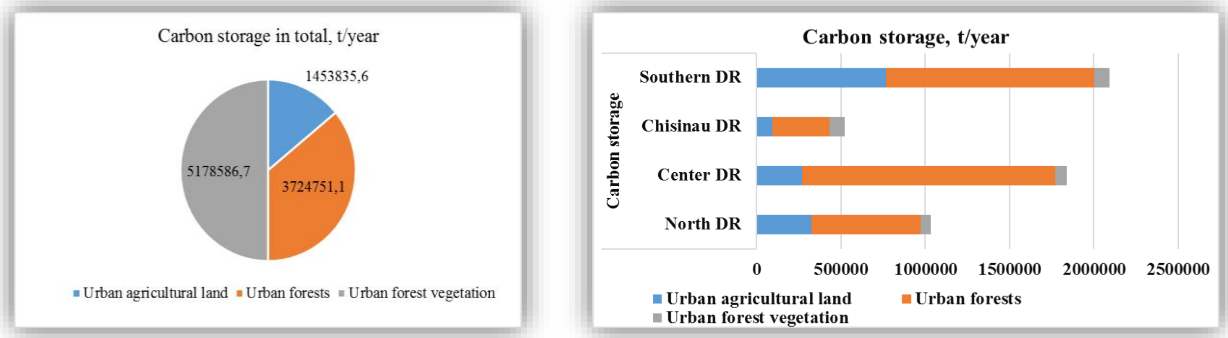


Figure 9. Carbon sequestration capacity of urban ecological infrastructure.

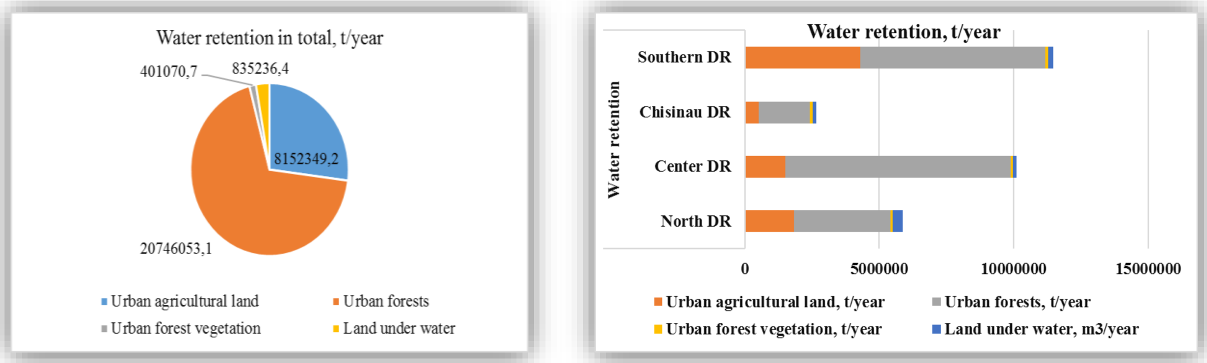


Figure 10. The water retention capacity of the urban ecological infrastructure.

The amplitude of the numerical expression of one or another ecosystem service in the urban ecosystem depends on the natural framework of the area but also the degree of preservation of natural ecosystems in the urban landscape. In the cities in the northern area, the dominant elements of ecological infrastructure are agricultural lands and lands under water, in the central area forests and in the southern one only agricultural lands. Accordingly, the regulation and maintenance ecosystem services - solid particle capture, carbon storage and water retention are more pronounced in urban ecosystems where the infrastructure element is more extensive and the service yield is higher.

CONCLUSION

The ecological infrastructure of urban ecosystems composed of arable land, perennial plantations, hayfields, pastures, forest lands, bush and shrub plantations, protective forest strips, swamps, ponds, lakes, river segments, in cities with a population of up to 10 thousand inhabitants constitutes 700 – 1000 m^2/person; in cities with a population between 10-30 thousand inhabitants - 300-700 m^2/person, and in large cities (Tighina, Balti, Chișinău municipalities) - 40-135 m^2/person. This has a positive impact on the environment, provides opportunities to adapt to climate change, thereby increasing urban resilience to risks such as droughts, floods and heat waves, increased carbon storage. Urban forests have a primary role in air purification, carbon storage and water retention from precipitation.

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