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Assessment of Environmental-Landscape Condition of Territories Botanical Gardens of Forest-Steppe Zone

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Abstract. This research looks at the results of a study of the environmental-landscape state of the territories of Botanical Gardens of the forest-steppe zone using generally accepted methods of environmental diagnostics and the territorial balance. The data on anthropogenic tension of the territories of Botanical Gardens, the level of internal protection of their natural landscapes from anthropogenic impacts and disturbances, the ratio of the area ecosystems with environment forming and environment stabilizing functions; an environmental sustainability of their territories. According to the results of the study, the territories of Botanical Gardens have mainly unsatisfactory values of the main environmental-landscape indicators.

1. Introduction

The environmental-landscape crisis of some Botanical Gardens (BGs) in the XXI century is, first of all, a crisis of the structure of the territory, the organization of its space and the ratio of natural and anthropogenic geosystems. The structure of the territories of BGs depends on how the distribution and redistribution of anthropogenic pressures occurs and, as a result, the stability of landscapes [1, 2-4].

East European forest-steppe zone refers to highly developed and transformed areas, where the structure of vegetation was determined by long-term human exposure [5]. Location of BGs in the system of large urban settlements determines the environmental conditions of their development [6, 7]. Recreational degradation of land and vegetation, soil and air pollution, loss of biodiversity, biological invasions contribute to the transformation of geo-ecosystems of BGs [8, 9, 10].

Over the past 100 years, the external territories of forest-steppe BGs have been transformed from natural and agricultural natural-anthropogenic landscapes into residential and man-made landscapes.

The aim of this work is to study the assessment of environmental-landscape conditions of territories forest-steppe BGs. Objectives of the study: to calculate anthropogenic tension of the territories of BGs, the level of internal protection of their natural landscapes from anthropogenic impacts and disturbances, the ratio of the area ecosystems with environment-forming and environment-stabilizing functions; to conduct an environmental assessment of the sustainability of territories of BGs with using the mosaic structure of plant communities and the diversity index ecotones.

2. Equipment and devices used in studies

The objects of research are geo-ecosystems of 6 Botanical Gardens within the forest-steppe Black Soil Region: Botanical Garden of Belgorod State University (BG BSU, 70.8 ha), Botanical Garden of Voronezh State Agricultural University (BG VSAU, 2.5 ha), Botanical Garden of Voronezh State University (BG VSU, 72.3 ha), Botanical Garden of Samara State Aerospace University (BG SSAU, 33.7 ha), Botanical Garden of Penza State University (BG PSU, 3.8 ha), Botanical Garden of Mordovia State University (BG MSU, 31.7 ha). Their area is 214.8 hectares.



The study is based on the actual data collected during the field studies of forest-steppe BGs in the period 2010-2018. To determine the areas and configurations of lands for various purposes, the Sentinel-2 sample satellite images for 2015-2017, downloaded from the official website of the United States Geological Survey (USGS), were used. To calculate the environmental-landscape state of the BGs, generally accepted methods of environmental diagnostics and territorial balance are used [11- 13].

In the BGs is represented by the following categories of lands: L1 – lands of natural ecosystems with low anthropogenic disturbance; L2 – lands of natural-anthropogenic ecosystems with low anthropogenic disturbance; L3 – lands of plantations forest, woodland and parkland areas, with medium values of anthropogenic impact; L4 – agrogeocenoses: arable land, plant nurseries, fallow lands, areas of botanical collections with high level anthropogenic impact; L5 – technogenic-transformed lands (residential and commercial buildings, roads with surface and communications) with maximum anthropogenic pressure.

The coefficient of absolute intensity anthropogenic impact of territory within the BGs is calculated by the formula:

$$C_{ab} = L_5/L_1 \quad (1)$$

It shows the ratio of highly transformed spaces and lands practically untouched by economic activity. The C_{ab} is lower, the environmental and landscape condition of the territory is more safe.

The coefficient of relative intensity anthropogenic impact was calculated by the formula.

$$C_r = (L_4 + L_5) / (L_1 + L_2) \quad (2)$$

It reflects the ratio of the intensity anthropogenic impact to the restoration potential of the natural landscapes of the BG. Its optimal value is 1.

To calculate the total area of ecosystems with environment-forming and environment-stabilizing functions (L_{ef}), which form the ecological fund of the lands of the BG, used the formula:

$$L_{ef} = L_1 + 0.8 L_2 + 0.6 L_3 \quad (3)$$

The level of internal natural protection of landscapes (C_{np}) of the Botanical Garden from anthropogenic impact and disturbance were calculated as:

$$C_{np} = L_{ef} / L_t \quad (4)$$

L_t – total area of the territory. C_{np} is an integral indicator, the higher it is, the better the protection level.

The coefficient of the mosaic structure of the territories of forest-steppe Botanical Gardens was obtained by the formula:

$$M = T/S \quad (5)$$

T – the number of bounded contours in units; S – area of BG (ha). Values M to 0.5 – weak mosaic structure, 0.5 - 1 – medium, > 1 – high.

For assessment of environmental sustainability of territories of BGs used the index of a variety of ecotones. Ecotone – a transitional strip between various biocenoses (the wood and a meadow, a pond and an oak grove, a meadow and steppe deposit and an orchard, etc.). In relation to the territory of a BGs used the index of a natural ecotonization. Ecotones between natural biocenoses were considered (the wood and a meadow, the wood and the meadow steppe, etc.). Ecoton zones are characterized by high biological diversity. The index was calculated by the formula:

$$Y_{ec} = \Sigma L_i / S \quad (6)$$

ΣL_i – the sum of lengths of all revealed ecotones,

S – area of Botanical Garden, hectare (ha).

The index $Y_{ec} < 5$ m/ha – very weak ecotonization, 5-10 m/ha – weak, 10-20 m/ha – medium, >20 m/ha – high.

To assessment the environmental sustainability of the territory of BG the coefficient is used, it was calculated by the formula:

$$C_{es} = \sum_{i=1}^n S_i C_i C_{gm} \quad (7)$$

C_i – coefficient of the environmental importance of this type of land use;

S_i – specific area of this type of land use;

C_{gm} – coefficient of geomorphological stability of a relief ($C_{gm} = 1.0$ – for the stable flat areas and slopes which are not exceeding 20° and $C_{gm} = 0.7$ – for unstable areas with biases more 20°).

$C_{es} \leq 0.33$ – environmentally unstable territory;

$C_{es} = 0.34-0.50$ – low stability of the territory;

$C_{es} = 0.51-0.66$ – medium environmental stability of the territory;

$C_{es} \geq 0.67$ – environmentally stable territory.

The coefficient of the environmental importance of this type of land use (C_i) has the established values taking into account features of a BG (table 1).

Table 1. Coefficient of the environmental importance of different types of land use within forest-steppe Botanical Gardens.

№	Land use type	C_i
1	Deciduous forests	0.63
2	Coniferous forests	0.38
3	Reservoirs	0.79
4	Natural herbal communities	0.70
5	Fallow meadow-steppe communities	0.68
6	Meadows	0.62
7	Perennial plantations: botanical collections	0.43
8	Forest belts	0.38
9	Arable lands	0.14
10	Land roads with coating and building	0.00

To establish the boundaries of the favorable influence of geo-ecosystems of BGs on the surrounding landscapes, the width of the environmentally zone (EZ, m) was determined for each forest-steppe BG by the formula:

$$EZ = L_n S 100 L_n (10/C_2) \quad (8)$$

S – area of Botanical Garden, hectare (ha);

C_2 – coefficient of environmental influence of landscapes of the BG on the surrounding areas.

The coefficient of environmental influence of the territory of BG was calculated by the average value of the coefficients of favorable influence of all lands (arable land, forest belts, shrub thickets, fallow lands, ponds, forests of natural origin, etc.) included in its composition.

3. Results and Discussion

Forest-steppe BGs are localized within the urbanized territories (table 2) with population density more than 1000 people/km² (1743.14-3220.0 people/km²).

Table 2. Population density in the cities with Botanical Gardens.

Botanical Garden	City	Population density* of the people/km ²
BG BSU	Belgorod	2402.0
BG VSAU, BG VSU	Voronezh	1743.14
BG SSAU	Samara	2162.48
BG PSU	Penza	1809.0
BG MSU	Saransk	3220.0

*www.statdata.ru Population density in the constituent entities of the Russian Federation

Settlement data on key indicators of an environmental-landscape condition of BGs of the forest-steppe Black Soil Region are presented in table 3.

Table 3. Key indicators of an environmental-landscape condition of territories of forest-steppe Botanical Gardens.

Botanical Garden	Indicators				
	C_{ab}/C_r	L_4+L_5 , ha	L_1+L_2 , ha	L_{ef} , ha	C_{np}
BG BSU	0.19/1.74	33.10	19.0	28.80	0.41
BG VSAU	-1.22*	2.20	0.15*	0.30	0.12
BG VSU	0.46/1.02	13.99	13.71	48.07	0.66
BG SSAU	0.22/1.03	8.16	7.86	17.47	0.52
BG PSU	-1.92*	2.50	0.20*	1.30	0.22
BG MSU	0.20/1.73	11.6	6.70	20.10	0.45

*For the Botanical Gardens of VSAU and PSU the calculation of C_r was carried out using data on L_2 and L_3 , since the lands of natural ecosystems (L_1) are not represented in their territories.

Forest-steppe BGs on coefficient of absolute tension (C_{ab}) of an environmental-landscape state have low values from 0.19 (BG BSU) till 0.46 (BG VSU). On coefficient of relative tension (C_r) – optimum: 1.02 (BG VSU); 1.03 (BG SSAU); 1.22 (BG VSAU) and raised: 1.73 (BG MSU); 1.74 (BG BSU); 1.92 (BG PSU) of value.

In BGs, the areas of environment-forming and environment-stabilizing biogeocenoses are represented by different values in the range from 0.3 ha to 48.07 ha (Fig. 1).

According to the internal natural protection of landscapes from anthropogenic impact (C_{np}), BGs have the following levels: insufficient – BG VSU (0.66); satisfactory – BG BSU (0.41), BG MSU (0.45) and BG SSAU (0.52); unsatisfactory (weak security) – BG PSU (0.22), critical (dangerous) – BG VSAU (0.12). Optimal values (C_{np} – more than 0.8) were not revealed. Values (L_{ef} , ha) and C_{np} correlate at the level $r = 0.9006$.

Assessing the environmental sustainability of the territories of BGs was determined by the mosaic structure of plant communities (introduction and natural) and the index of diversity of ecotones. Mosaic structure reflects the diversity of landscape units in the system of plant collections, natural phytocenoses and land use regimes. BG to increase the mosaic structure of their territories were as follows: BG BSU – 0.34 (weak), BG VSAU – 0.34 (weak), BG VSU – 0.47 (weak), BG SSAU – 0.65 (medium), BG MSU – 0.85 (medium), BG PSU – 3.95 (high).

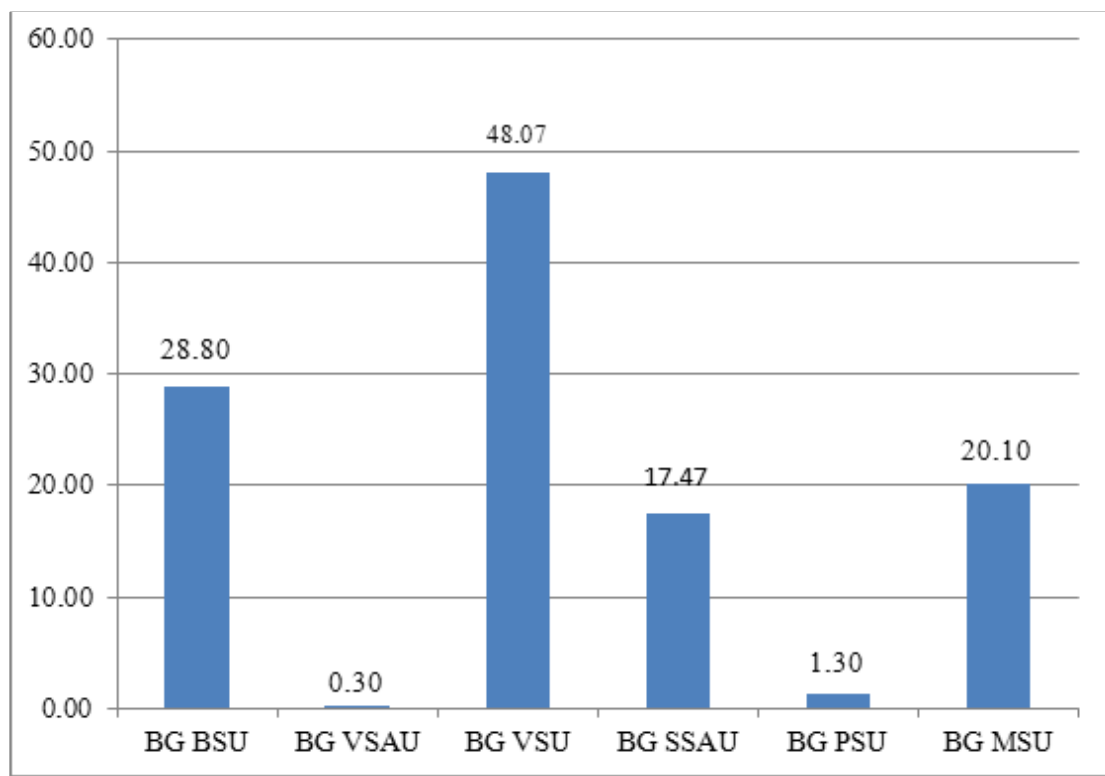


Figure 1. Ratio of areas of biogeocenoses with environment-forming and environment-stabilizing functions (L_{ef} , ha) in the forest-steppe Botanical Gardens.

Natural ecotonic zones are not represented in the BGs of VSAU and PSU, which is determined by the absence of natural zonal phytocenoses in these small gardens. The highest index of an ecotonization of the territory has a BG VSU – 42.9 m/ha, further in decreasing order follow BG BSU – 30.7 m/ha; BG SSAU – 25.7 m/ha, to the BG MSU – 21.3 m/ha. These four botanical gardens have a high degree of ecotonization. There is a direct correlation between the degree of ecotonization and the garden area ($r = 0.844$).

As a result of the calculations, the following values of the environmental stability coefficient (C_{es}) of the territories BGs (table 4) were obtained.

Table 4. Values of the coefficient of environmental stability of Botanical Gardens

Botanical Garden	S , ha	C_{es}
BG BSU	71.0	0.41
BG VSAU	2.5	0.39
BG VSU	72.3	0.42
BG SSAU	33.7	0.45
BG PSU	3.8	0.40
BG MSU	31.7	0.45

In general, for all BGs, the coefficient of environmental stability of the territory has low values of $C_{es} = 0.39-0.45$. Its average value is $C_{es} = 0.42$.

For the forest-steppe BGs obtained the following values of the coefficient of environmental impacts (C_2) of the surrounding area: BG VSAU – 1.53; BG PSU – 1.53; BG VSU – 1.76; BG BSU – 1.82; BG SSAU – 1.82; BG MSU – 1.84. Using the values of the coefficient, we calculated the width of the environmentally friendly zone (EZ) of each BG in relation to urban development. Received the

following sequence in order of increasing values of the width of the *EZ*: BG VSAU – 38.23 m; BG PSU – 58.10 m; BG MSU – 583.79 m; BG SSAU – 613.84 m; BG VSU – 1272.89 m; BG BSU – 1289.62 m (table 5).

Table 5. The coefficient of environmental impact and the width of the environmentally friendly zone of forest-steppe Botanical Gardens

Botanical Garden	<i>S, ha</i>	<i>C₂</i>	<i>EZ, m</i>
BG BSU	71.0	1.82	1289.62
BG VSAU	2.5	1.53	38.23
BG VSU	72.3	1.76	1272.89
BG SSAU	33.7	1.82	613.84
BG PSU	3.8	1.53	58.10
BG MSU	31.7	1.84	583.79

A direct correlation between the area of BG (*S, ha*), the coefficient of environmental impact (*C₂*) and the width of the environmentally friendly zone (*EZ*) formed by the BG. The correlation coefficient of the area (*S*) and *C₂* is represented as $r = 0.7382$; *S* and *EZ* – $r = 0.9996$; *C₂* and *EZ* – $r = 0.7527$.

Increasing the area of plant introduction centers in urban areas is almost impossible, therefore botanical gardens face an urgent need for sustainable development of their internal environment.

4. Conclusions

Forest-steppe BGs are located within highly urbanized areas with a population density of 1743.14-3220.0 people/km².

Among the 6 forest-steppe BGs, only 4 have low values (0.19–0.46) of the absolute tension coefficient of the environmental-landscape state, which indicates the preservation of natural biosystems in them. According to the coefficient of relative intensity – the optimum (1.02; 1.03; 1.22) and elevated (1.73; 1.74; 1.92) values.

The territories of all BGs have a low natural protection of landscapes ($C_{np} = 0.12-0.66$), mosaic structure ($M = 0.34-0.85$) and ecological stability ($C_{es} = 0.39-0.45$). Nevertheless, BGs form around themselves environmentally favorable zones with widths from 38.23 to 1289.62 m, which is important for highly urbanized areas and the standard of living of the population.

The results of the study showed that the territories of forest-steppe BGs have mostly unsatisfactory values for the main environmental-landscape indicators, which confirms the instability and vulnerability of their ecosystems. This data can be the basis for the reconstruction of space and environmental management of the BGs, the development of their promising functional zoning.

For each botanical garden it is recommended to conduct a regular comprehensive survey and systematic analysis of the territory, which will allow to identify negative trends in the development of their geo-ecosystems and quickly take appropriate measures. To increase the internal natural stability of the landscapes of BGs, it is advisable to expand and create new environment-forming biosystems.

Comparison of the internal potential of the territories of the studied Botanical gardens shows that large gardens (BG VSU, BG BSU, BG SSAU) have more opportunities for the formation of sustainable geo-ecosystems.

To increase the sustainability of the geo-ecosystem of a forest-steppe botanical garden, it is necessary to create a green protective belt based on zonal phytocenoses and rationalize the landscape-planning structure of botanical collections and expositions.

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