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Article

Comprehensive ecological and biological assessment of soils of a medium-sized city in the Central Federal District, Russia

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Abstract. The ecological and biological state of the soil cover has been assessed comprehensively in the typical medium-sized industrial city of Gus-Khrustalny (population of up to 100000) in the Vladimir Oblast, Central Federal District, Russia. The results obtained demonstrate the heterogeneity of the soils in terms of organic matter content (0–10.22%), the activity of catalase (0.26–2.71 mL O_2/(min × g)) and urease (0–0.69 mg NH_3/(10 g of soil × 24 h)), and the integral indicator of the ecological and biological state of the soil (39.13–100%). The studied samples are characterized as 'poor' and 'very poor' in terms of catalase activity and as 'very poor' in terms of urease activity. The indices of enzymatic activity were more sensitive to changes in soil properties in comparison with plant testing methods. A strong uneven anthropogenic impact on urban soils is detected, changing soil biological indices and resulting in the soil cover heterogeneity in urbanized areas.

Keywords: enzymatic activity, plant testing methods, integral indicator of ecological and biological state of soil

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Научная статья

Комплексная эколого-биологическая оценка почв среднего по численности города Центрального федерального округа

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Аннотация. Проведена комплексная оценка эколого-биологического состояния почвенного покрова типичного среднего города Центрального федерального округа с численностью населения до 100 тысяч человек и развитым промышленным производством на примере г. Гусь-Хрустальный Владимирской области. Полученные результаты демонстрируют неоднородность почв по содержанию органического вещества (0–10.22%), активности ферментов каталазы (0.26–2.71 мл O_2/мин × 1 г) и уреазы (0–0.69 мг NH_3/10 г почвы × 24 ч), интегральному показателю эколого-биологического состояния почвы (39.13–100%). Исследуемые образцы характеризуются как бедные и очень бедные по степени обогащенности каталазой, очень бедные по степени обогащенности уреазой. Показатели ферментативной активности являлись более чувствительными к изменению свойств почв в сравнении с фитотестированием. Полученные результаты свидетельствуют о сильном неравномерном антропогенном воздействии на городские почвы, что приводит к изменению их биологических показателей и неоднородности почвенного покрова урбанизированных территорий.

Ключевые слова: ферментативная активность, фитотестирование, интегральный показатель эколого-биологического состояния почвы

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Introduction

Soils of urbanized areas are exposed to high technogenic load, primarily near industrial enterprises and highways (Korikova et al., 2016; Nikolaeva et al., 2019; Skugoreva et al., 2019; Troyanovskaya et al., 2011; Zykova et al., 2017). The high content of multicomponent pollutants and the limited number of standards establishing maximum allowable concentration (MAC) for chemicals cause certain difficulties in the hygienic and ecological-biological assessment of anthropogenically modified urban areas. Therefore, assessing the ecological and biological state of soils is of great importance in monitoring studies, along with physicochemical methods of pollutants' determining. The biological test methods are widely applied, since they are quite informative in these studies (Bardina et al., 2020; Chesnokova et al., 2016; Doneryan and Vodianova, 2018; Girotti et al., 2008; Kalinkina et al., 2016; Khaziev, 2018; Korikova et al., 2016; Nikolaeva et al., 2019; Olkova and Makhanova, 2020; Parkhomenko, 2018; Salnikov et al., 2018; Skugoreva et al., 2019; Trifonova and Zabelina, 2017; Troyanovskaya et al., 2011; Zykova et al., 2017). In particular, enzyme activity characterizes the intensity of biochemical processes. Due to the key role of soil in the biogeochemical cycle and regulation of gas exchange, enzyme analysis serves as a significant indicator of its ecological state (Bardina et al., 2020; Kazeev et al., 2003; Khaziev, 2005, 2018). Plant test is one of the most frequently used biotests in ecotoxicological studies, since the condition of plants is an important indicator of soil quality (Bardina et al., 2020; Nikolaeva et al., 2019; Olkova and Makhanova, 2020; Skugoreva et al., 2019; Troyanovskaya et al., 2011; Zykova et al., 2017).

Integrated approach is used widely for a comparative assessment of the number of various indicators, which allows taking into account the adverse impacts on various components of ecosystems (Doneryan and Vodianova, 2018; Kalinkina et al., 2016; Korikova et al., 2016; Parkhomenko, 2018; Salnikov et al., 2018; Skugoreva et al., 2019). Calculating the integral indicator of the ecological and biological state of the soil (IIEBSS) is one of such methods (Kazeev et al., 2003), which is applied widely to assess the degree of pollution of urban soils (Kalinkina et al., 2016; Korikova et al., 2016; Parkhomenko, 2018; Salnikov et al., 2018; Skugoreva et al., 2019). The choice of the particular indicators to be determined is not standardized, but it is recommended to use the most informative ones; several indicators are used widely: enzymatic activity (Kalinkina et al., 2016; Korikova et al., 2016; Parkhomenko, 2018; Salnikov et al., 2018; Skugoreva et al., 2019), organic carbon content (Korikova et al., 2016; Skugoreva et al., 2019), and plant test data (Skugoreva et al., 2019).

Urban settlements are divided into several groups[1] by the population: metropolitan (over 1000000 people), large city (250000–1000000), big city (100000–250000), medium-size city (50000–100000), and small city (up to 50000). Most often, soil studies are carried out in the metropolitan (Eremchenko et al., 2014), large cities (Kalinkina et al., 2016; Olkova and Makhanova, 2020; Parkhomenko, 2018; Salnikov et al., 2018; Skugoreva et al., 2019; Trifonova and Zabelina, 2017; Troyanovskaya et al., 2011), and big cities (Korikova et al., 2016). However, the ecological and biological assessment of the soil state in medium-sized and small towns is also relevant due to their predominant distribution on the territory of the Russian Federation in combination with high anthropogenic load observed there (Chesnokova et al., 2016; Olkova and Makhanova, 2020; Smirnov, 2019; Zykova et al., 2017).

In the Vladimir Oblast of Russia, the studies of the soils of urbanized territories were previously carried out for the cities of Vladimir (population 346771 people) and Sudogda (10150), when biological indicators of enzymatic activity, soil acidity, and heavy metal content were determined (Chesnokova et al., 2016; Trifonova and Zabelina, 2017).

[1] SP 42.13330.2016. Urban development. Planning and development of urban and rural settlements.

Gus-Khrustalny is the fifth largest city in the Vladimir Oblast, both in terms of population and area; it has a developed production sector, represented mainly by glass industry enterprises (Trifonova et al., 2023). Gus-Khrustalny is one of the typical medium-sized cities; in 2010, there were 155 such cities in the Russian Federation (of which 40 were in the Central Federal District); it is characterized by a high technogenic load, so assessing the state of the soil cover here is important (Smirnov, 2019). To date, heavy metals and arsenic pollution have been studied during the ecological and hygienic assessment of the soil cover in Gus-Khrustalny. The multi-element pollution here is associated with the functioning of glass production. It is also reported that most of the population lives in areas with moderately hazardous and hazardous soil categories, and main pollutants are Zn, Pb, and As (Trifonova et al., 2023). Therefore, strong pollution with heavy metals calls for the study of the ecological and biological state of the soils of Gus-Khrustalny.

The study aims to assess comprehensively the ecological and biological state of the soil cover in Gus-Khrustalny of Vladimir Oblast as an example of a typical medium-sized city in the Central Federal District of the Russian Federation.

Materials and methods

Gus-Khrustalny (N 55°37' E 40°39') is the administrative center of the Gus-Khrustalny District of the Vladimir Oblast; its total area is 43 km², population, 51552 people (as of 2021). Sampling site map of the study area is presented at Fig. 1. Samples were collected mainly near industrial enterprises (sampling sites nos. 4–10) and highways (nos. 11–14), which are the sources of pollution. Most sampling sites in the industrial zone are located near glass industry enterprises, which are predominant in this city: no. 4 – JSC OS Steklovolokno, nos. 5 and 6 – JSC Gusevsky Glass Factory named after F.E. Dzerzhinsky, no. 7 – LLC Gusevsky Crystal Factory named after Maltsov, no. 8 – LLC Experimental Glass Factory. Soil sampling was also carried out in the areas located near pipeline fittings manufacturing enterprises: sampling site no. 9 – LLC Gusevsky Fittings Factory Gusar, no. 10 – OJSC Armagus. The natural landscape and recreational zones were set as a background: city park of culture and recreation "Barinova Roshcha" (no. 2) and suburban summerhouse territory (nos. 1, 3).

Soil sampling was carried out in August 2022 in accordance with GOST 17.4.4.02-2017[2], the surface soil layer of 0–10 cm was cut and analyzed.

The organic matter content was determined according to GOST 26213–2021[3].

Catalase activity was determined by gasometric method proposed by A.Sh. Galstyan based on the rate of decomposition of hydrogen peroxide during interaction with soil based on the volume of oxygen released during the reaction (Khaziev, 2005).

Urease activity was determined by photocolorimetric method based on measuring the amount of ammonia formed during the hydrolysis of the introduced urea after 24 hours of incubation (Kazeev et al., 2003).

For plant test, the standard method M-P-2006 FR.1.39.2006.02264 was used (Kapelkina et al., 2009). The test object was spring soft wheat (*Triticum aestivum* L.), "Madam" variety. Petri dishes were incubated for 5 days at a temperature of 25 °C and lighting of 4000 Lux. The indicators of root length, shoot height, and seed germination were determined.

All studies were carried out in triplicate.

To compare the obtained data comprehensively, the integrated indicator of the ecological-biological state of the soil (IIEBSS) was calculated as:

$$\text{IIEBSS} = \frac{\text{S avg.}}{\text{S avg. max.}} \times 100\ \%,$$

where $S_{avg.}$ is the average assessment score of all indicators; $S_{avg.\ max.}$ is the maximum assessment score of all indicators (Kazeev et al., 2003).

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[2] GOST 17.4.4.02-2017. Methods of sampling and preparing samples for chemical, bacteriological, and helminthological analysis.

[3] GOST 26213–2021. Soils. Methods for determination of organic matter.

Fig. 1. Map of the city of Gus-Khrustalny. The numbers indicate sampling sites.

The maximum value of each of the indicators was taken as 100%, and the relative value of the same indicator in the remaining samples was expressed as percentage:

$$S = \frac{S\,x}{S\,max} \times 100\%,$$

where S is the relative indicator score, S_x is the indicator score for the sample, S_{max} is the maximum indicator score in the general sample (Kazeev et al., 2003). The relative indicator scores of the organic matter content (Som), catalase activity (Scat), urease activity (Sur), wheat root length (Srl), wheat shoot height (Ssh), and wheat seed germination (Ssg) were calculated.

The mean of the studied indicators' scores was calculated by the equation:

$$S\,mean = \frac{(Som + Scat + Sur + Srl + Ssh + Ssg)}{6},$$

where Smean is the arithmetical mean score of the studied indicators, 6 is the number of indicators (Kazeev et al., 2003).

Statistical data processing was performed using the Statistica 7.0 program. The arithmetical mean and error of the mean were calculated. Pearson correlation analysis was applied.

Results and discussion

Table 1 represents the data on the content of the soil organic matter, enzyme activity of soil, and wheat growth parameters (gemination, shoot and root length).

The organic matter content ranges from 0 to 10.22% (Table 1). The maximum value was found in the soil collected at sampling site no. 10, located in the industrial zone in the central part of the city. The minimum organic matter content was found in the north-eastern part of the city (natural landscape and recreational zone sites nos. 1 and 2, the industrial zone site no. 8), as well at the site no. 13 near the highway. Similar variations in the properties of urban soils in terms of organic matter content were noted during the studies in the cities of Perm (0.3–16.49%) and Kirov (2.4–13.0%) (Eremchenko et al., 2014; Skugoreva et al., 2019). This phenomenon was explained by a strong change in the city soils due to anthropogenic impact: mixing, replacement of primary soils with soils of different chemical composition, and technogenic pollution.

Catalase activity of soils in Gus-Khrustalny varies within the range of 0.26–2.71 mL O_2/(min × g) (Table 1). The maximum value of the indicator was found at the sampling site no. 11 located in the transport zone of the southwestern part of the city. Minimum catalase activity was revealed in soil samples from different functional zones of the northeastern part of the city: natural landscape and recreational zone (no. 2), industrial zone (no. 8), transport zone (no. 13). According to the enzyme activity scale proposed by D.G. Zvyagintsev (Kazeev et al., 2003), the soils collected at the sampling sites nos. 1, 3 (natural landscape and recreation zone), nos. 7, 10 (industrial zone), nos. 11, 12 (transport zone) were characterized as poor in catalase activity; at the sampling sites no. 2 (landscape and recreational zone), nos. 4, 5, 6, 8, 9 (industrial zone), nos. 13, 14 (transport zone), as very poor. This is consistent with the data reported for Kirov city (Skugoreva et al., 2019) and Astrakhan city (Kalinkina et al., 2016; Salnikov et al., 2018). Similar studies of soils in Vladimir city (Trifonova and Zabelina, 2017), Perm city (Eremchenko et al., 2014), Taganrog city (Korikova et al., 2016), and Astrakhan city (Kalinkina et al., 2016; Parkhomenko, 2018; Salnikov et al., 2018) also show that catalase activity varies widely depending on the level of technogenic load, actual soil acidity, content of organic matter, heavy metals and petroleum products.

The value of urease activity ranges as 0–0.69 mg NH_3/(10 g of soil × 24 h) (Table 1). The minimum value of the indicator was found in the landscape and recreational zone of the north-eastern part of the city (site no. 2), as well as at the sampling sites nos. 12 and 13, representing the transport zone. The maximum urease activity was detected in sample no. 14 near the highway. All the studied samples are very poor in terms of urease activity according to the scale of D.G. Zvyagintsev (Kazeev et al., 2003). Similar results were obtained for the city of Sudogda, Vladimir Oblast, 0.052–1.54 mg NH_3/(10 g of soil × 24 h) (Chesnokova et al., 2016), which demonstrates low enzyme activity in the studied cities of the Vladimir Oblast. High variability of this soil parameter was noted for Sudogda city (Chesnokova et al., 2016), Vladimir city (Trifonova and Zabelina, 2017), Taganrog city (Korikova et al., 2016), Perm city (Eremchenko et al., 2014), and Astrakhan city (Kalinkina et al., 2016; Salnikov et al., 2018); anthropogenic impact, the content of heavy metals and organic matter were named as main factors.

In plant tests, the wheat root length and shoot height also varied widely (Table 1). The minimum root length was found for the soil collected at sampling site no. 14 (transport zone), the maximum, at sampling site no. 7 (industrial zone). The minimum shoot height was found for soil samples no. 13 (transport zone) and no. 2 (landscape and recreational zone), the maximum, no. 11 (transport zone) and no. 7 (industrial zone). Germination was a less sensitive indicator, which is consistent with other studies (Nikolaeva et al., 2019). The soil sampled at the sites nos. 13 and 14 (near highway) was the most toxic to plants in terms of its effect on the root length, at the sites nos. 2, 13, and 14, on the shoot length. The soil from the sites nos. 2 and 13 was also characterized by the absence of organic matter, low activity of both catalase and urease. At the same time, the soil taken at the site no. 14 had an inhibitory effect on plant growth, but the maximum urease activity.

The obtained data on the organic matter content, enzymatic activity of soils, root length, shoot height, seed germination, and IIEBSS are characterized by normal distribution. Positive Pearson’s

Table 1. Ecological and biological indicators of the soil of the city of Gus-Khrustalny, Vladimir Oblast, Russia.

Sample number	Organic matter, %	Catalase activity, ml O_2/min × 1 g of soil	Urease activity, mg NH_3/10 g of soil × 24 h	Plant tests (*Triticum aestivum* L.)		
				Root length, mm	Shoot length, mm	Seed germination, %
Landscape and recreational zone						
1	0.74 ± 0.1	1.01 ± 0.12	0.13 ± 0.06	74.3 ± 6.0	51.9 ± 7.9	98.33 ± 1.67
2	0	0.26 ± 0.04	0	73.9 ± 0.6	43.3 ± 0.9	98.33 ± 1.67
3	8.68 ± 0.85	1.24 ± 0.21	0.64 ± 0.01	97.3 ± 2.6	84.6 ± 5.1	98.33 ± 1.67
Industrial zone						
4	2.20 ± 0.4	0.51 ± 0.09	0.47 ± 0.09	102.0 ± 1.7	80.0 ± 3.2	98.33 ± 1.67
5	2.40 ± 0.47	0.63 ± 0.09	0.18 ± 0.00	99.5 ± 6.2	67.0 ± 6.0	98.33 ± 1.67
6	3.78 ± 0.56	0.66 ± 0.13	0.05± 0.02	82.5 ± 3.4	83.3 ± 1.1	95.0 ± 2.89
7	4.09 ± 0.6	1.63 ± 0.23	0.6 ± 0.05	103.2 ± 3.9	85.0 ± 2.8	93.33 ± 4.41
8	0.1 ± 0.0	0.33 ± 0.06	0.25 ± 0.02	93.4 ± 9.5	76.7 ± 8.1	93.33 ± 4.41
9	2.28 ± 0.45	0.92 ± 0.17	0.27 ± 0.01	92.3 ± 2.7	79.6 ± 3.9	96.67 ± 1.67
10	10.22 ± 0.95	1.93 ± 0.26	0.6 ± 0.04	89.6 ± 5.6	71.0 ± 2.4	91.67 ± 3.33
Highway zone						
11	2.87 ± 0.56	2.71 ± 0.3	0.41 ± 0.07	96.2 ± 3.3	85.5 ± 3.8	88.33 ± 6.01
12	6.15 ± 0.6	1.44 ± 0.11	0.0	84.9 ± 5.8	64.2 ± 5.4	93.33 ± 1.67
13	0	0.27 ± 0.07	0.0	61.3 ± 4.2	41.5 ± 2.6	85.0 ± 5.0
14	3.74 ± 0.56	0.69 ± 0.12	0.69 ± 0.03	56.5 ± 2.3	48.9 ± 1.2	88.33 ± 1.67

correlations are found between the content of organic matter and catalase activity (r = 0.5653; p = 0.035) and urease activity (r = 0.5531; p = 0.040) in the soil, which is supported by published data (Korikova et al., 2016). The wheat root length and the shoot height correlate positively (r = 0.8506, p = 0.000). No correlation is found between the root length and several soil parameters: the organic matter content (r = 0.2420, p = 0.405), catalase activity (r = 0.2622, p = 0.365), and urease activity (r = 0.2345, p = 0.420). No correlation is found as well between the shoot height and the organic matter content (r = 0.3780, p = 0.183), catalase activity (r = 0.3921, p = 0.166), and urease activity (r = 0.3847, p = 0.174).

The previously obtained data (Trifonova et al., 2023) on pH, specific conductivity of the soil extract, and total soil pollution index (Z_c) were used to analyze the dependence of the organic matter content, catalase and urease activity, wheat root length and shoot height on these parameters. According to Pearson's correlation analysis, pH did not affect organic matter content (r = −0.3820, p = 0.178), catalase activity (r = −0.1849, p = 0.527), urease activity (r = 0.0930, p = 0.752), wheat root length (r =

−0.1412, p = 0.630) and shoot height (r = −0.0106, p = 0.971). Specific electrical conductivity had no effect on the content organic matter (r = 0.2256, p = 0.438), catalase activity (r = 0.1878, p = 0.520), wheat root length (r = −0.2845, p = 0.324) and shoot height (r = 0.0223, p = 0.940). However, urease activity depended on specific electrical conductivity (r = 0.6115, p = 0.020). No correlation was found between the total soil pollution index Z_c and the organic matter content (r = 0.1258, p = 0.668), catalase activity (r = −0.0440, p = 0.881), urease activity (r = −0.1892, p = 0.517), wheat root length (r = −0.0198, p = 0.946) and shoot height (r = 0.3231, p = 0.260).

These results demonstrate that the soil organic matter content may be a limiting factor for enzyme activity, but it does not have such a strong effect on wheat seed germination. In addition, urease activity increase is accompanied by the ion concentration increase in the soil solution. Therefore, the content of organic matter and enzyme activity in the soil of Gus-Khrustalny do not depend on belonging to a certain city zone and by pollution with heavy metals, but are associated with a combination of several factors.

In Table 2, the average scores of the studied indicators and the integral indicator of the ecological and biological state of the soil are presented.

The relative scores of the indicators (Table 2) vary widely, which is associated with a large range of the results obtained (Table 1). The greatest variability is noted for the relative scores of organic matter (Som), urease activity (Sur), and catalase activity (Scat). The wheat seed germination (Ssg) is characterized by the lowest fluctuations in relative scores. The integral indicator of the ecological and biological state of the soil ranges as 39.13–100% (Table 2). This indicates the heterogeneity of the soils in Gus-Khrustalny, associated probably with anthropogenic impact, which varies in different parts of the city. Samples nos. 10 (industrial zone, city center) and no. 3 (natural landscape and recreational zone, the south-western suburban summerhouse area) are characterized by the highest IIEBSS values. The lowest IIEBSS values are found at the sampling sites nos. 13 (eastern transport zone) and 2 (the northeastern natural landscape and recreational zone).

When applying Pearson correlation analysis, positive relationships are found between IIEBSS and catalase activity (r = 0.7489, p = 0.002), urease activity (r = 0.7926, p = 0.001), wheat root length (r = 0.5645, p = 0.035) and shoot height (r = 0.7113, p = 0.004), and organic matter content (r = 0.7987; p = 0.001). No correlation is observed between IIEBSS and the total soil pollution index Z_c (r = 0.0162, p = 0.956), demonstrating that the integral indicator of the ecological and biological state of the soil does not depend on heavy metal pollution.

The soil from sampling site no. 2, located in the "Barinova Roshcha" culture and recreation city park (geochemical background) is characterized by one of the lowest values of IIEBSS, associated with the absence of organic matter content and, as a consequence, low enzymatic activity. Thus, the obtained data demonstrate the need for additional studies to identify the causes of the decrease in biological indicators of soils in the areas remote from industrial enterprises and highways. In addition, the causes of the high content of organic matter at sampling site no. 10, located in the central part of the city and subject to high technogenic load, are still unknown, so further studies are needed.

Conclusions

For the first time, the ecological and biological state of the soil cover was assessed comprehensively in Gus-Khrustalny, which is a typical medium-sized city of the Central Federal District of Russian Federation in terms of population and industrial potential. The soils of Gus-Khrustalny are very heterogenous by their main ecological and biological indicators, which may indicate uneven anthropogenic impact. The organic matter content varies as 0–10.22%, catalase activity, 0.26–2.71 mL O_2/(min × g), urease activity, 0–0.69 mg NH_3 /(10 g of soil × 24 h). All the studied samples are very poor in urease, poor and very poor in catalase. The average length of wheat roots (*Triticum aestivum* L.) ranges as 56.5–103.2 mm, shoot height, 41.5–85.5 mm, seed germination, 85–98.33%. The enzymatic activity indices showed greater sensitivity to the changes in soil properties compared to plant test. Significant fluctuations of the integral indicator of the ecological and biological state (39.13–100%) are not only due to the site belonging to a certain functional zone and pollution with heavy metals, but are associated with a combination of a number of factors, which are needed to be found during additional researches.

Table 2. Average assessment scores of the studied soil parameters in Gus-Khrustalny, Vladimir Oblast, Russia. Abbreviations: Som – organic matter content, Scat – catalase activity, Sur – urease activity, Srl – wheat root length, Ssh – wheat shoot height, Ssg – wheat seed germination; IIEBSS – integral indicator of the ecological and biological state of the soil.

Sample number	Som, %	Scat, %	Sur, %	Srl, %	Ssh, %	Ssg, %	Smean, %	IIEBSS, %
Landscape and recreational zone								
1	7.24	37.18	19.55	71.99	60.69	100	49.44	56.85
2	0	9.44	0	71.56	50.57	100	38.60	44.38
3	84.93	45.81	92.68	94.24	98.89	100	86.09	98.99
Industrial zone								
4	21.53	18.74	67.93	98.85	93.5	100	66.76	76.76
5	23.48	23.28	26.1	96.37	78.28	100	57.92	66.59
6	36.99	24.27	7.5	79.92	97.39	96.61	57.11	65.67
7	40.02	59.94	86.72	100	99.31	94.92	80.15	92.15
8	0.98	12.28	36.86	90.53	89.61	94.92	54.20	62.31
9	22.31	33.90	38.9	89.45	93.09	98.31	62.66	72.04
10	100	71.12	87.67	86.85	82.98	93.23	86.97	100
Highway zone								
11	28.08	100	59.69	93.16	100	89.83	78.46	90.21
12	60.18	53.26	0	82.29	75.0	94.92	60.94	70.07
13	0	9.85	0	59.42	48.51	86.44	34.04	39.13
14	36.59	25.41	100	54.73	57.15	89.83	60.62	69.7

Applying various methods of biological indication and the set of test objects with different degrees of sensitivity to toxicants allows to characterize the ecological and biological state of the studied soils most fully and thus to assess the level of technogenic load. The obtained data are of interest both to ecologists in developing measures aimed at enhancing environmental safety and improving the state of the environment of the Vladimir Oblast and to specialists in the field of soil science. Additional research is necessary to search for the reasons of significant changes in the biological indicators of soils in Gus-Khrustalny, including in the landscape and recreational zone. In order to prevent soil degradation and restore disturbed areas, it is recommended to conduct regular monitoring using physical, chemical and biological research methods, as well as to implement active measures to detoxify contaminated soils.

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