Ecological and Economic Assessment of the Impact of Industrial and Consumer Waste on the Quality of Gray Forest Soil

I A Verkhovets¹, L E Tuchkova¹, I M Tikhoykina²

¹Oryol State University named after I.S. Turgenev, Oryol region, Komsomolskaya street, 95, 302026, city Oryol, Russia
²Oryol State University of Economics and Trade, Oryol Oblast, Oktyabrskaya St., 12, 302028, Oryol, Russia

E-mail: lutuchka@ya.ru

Abstract. This article deals with the assessment of the degree of soil contamination with solid municipal waste (SMW), solid household waste (SHW), and the waste of sugar production (sugar lime) in the area of grey forest soils of Orlovskaya oblast. The data obtained demonstrate that SMW has a high impact on soil contamination. The analysis of the pollution load factor value for soils shows moderately dangerous contamination category. Across the territory under analysis, the soil pollution exceeds the maximum permissible concentration (MPC). The evaluation of the sugar lime pollution degree and its overall values exceed the background values by 7.3-246 times. The research conducted explicates the impact of various types of waste on the surrounding areas and their contamination with a set of heavy metals.

1. Introduction

Industrial waste disposal is a pressing problem leading to soil contamination [19]. As technology progresses, new types of industrial waste are generated and deposited in the soil. They consist mainly of organic compounds, inorganic complexes and non-biodegradable materials [9]. These contaminants affect and change the chemical and biological properties of the soil [13]. As a result, dangerous chemical substances can infiltrate the human food chain, soil or water and interfere with the chemical and biological processes leading to serious consequences for living organisms in the end [3].

A huge number of man-made heavy metals enter the atmosphere, and some of them are extremely toxic, capable of accumulating in trophic chains, and resilient against the environment. A large proportion of heavy metals containing in various compounds [7], including active forms, enter the soil as waste, which leads to the migration of heavy metals and their accumulation in the natural environment to the amounts hazardous for living organisms [2].

The storage and disposal of unwanted toxic chemicals is a pressing problem for the agricultural industry, alongside with SHW landfills containing heavy metals, dioxins, organochlorines that enter the soil [11, 12]. Heavy metals are among the most dangerous contaminants because even their small-scale presence in living organisms leads to their malfunctioning. It is the soil that accumulates are stored the contaminants that enter as a result of industrial activities of humanity [6, 17]. Soil contamination with heavy metals is a big national economic and environmental problem because
heavy metals do not decompose and they can actively enter the biological cycle and accumulate in vegetation and living organisms [5, 14].

Due to this, the goal of our work was to assess the degree of industrial and consumer waste on the quality of grey forest soil.

The objectives of the research were as follows:

1. Assessing the degree and the intensity of soil contamination with industrial and consumer waste.
2. Conducting an environmental and geochemical appraisal of the soils contaminated with industrial and consumer waste.

In order to assess the degree of waste impact on the soil, samples of agricultural soils contaminated with sugar lime (sugar production waste), SMW (solid municipal waste), and SHW (solid household waste) were taken as well as the control soil samples from uncontaminated areas (background).

The area of sugar lime contamination is located at the following address: Orlovskaya oblast, Zalegoshchenskiy district, Oktyabrskoye rural settlement, Blagodatnoye OJSC. The area of contamination is 1.54 ha. In order to determine the degree of sugar production waste impact on the soil, 20 soil samples, including 2 control samples, were analyzed (Tables 1 and 2).

Table 1. Environmental and geochemical appraisal of sugar lime impact on soils (samples 1-10).

| No | Indicator          | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 | Sample 6 | Sample 7 | Sample 8 | Sample 9 | Sample 10 |
|----|--------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|-----------|
| 1  | Nitric nitrogen    | 28.0     | 69.4     | 94.4     | 60.4     | 71.6     | 61.3     | 35.8     | 55.8     | 24.0     | 0.6       | ≤130.0    |
| 2  | Cobalt             | 0.96     | 0.59     | 0.16     | 0.2      | 0.78     | 0.11     | 0.8      | 0.43     | 0.3      | 0.19      | ≤5.00     |
| 3  | Manganese          | 71.9     | 65.0     | 49.0     | 62.4     | 115.0    | 60.6     | 51.6     | 82.5     | 57.6     | 9.26      | ≤140.00   |
| 4  | Copper             | 2.13     | 2.15     | 2.44     | 2.6      | 2.03     | 2.75     | 2.3      | 1.68     | 0.4      | 0.04      | ≤3.00     |
| 5  | Nickel             | 1.35     | 1.68     | 1.16     | 1.4      | 2.34     | 2.10     | 0.8      | 1.09     | 1.4      | 0.30      | ≤4.00     |
| 6  | Lead               | 4.34     | 3.94     | 2.61     | 4.9      | 9.35     | 3.31     | 10.0     | 1.40     | 0.6      | 1.13      | ≤6.00     |
| 7  | Zinc               | 7.27     | 7.12     | 6.13     | 7.1      | 6.64     | 9.17     | 5.4      | 5.58     | 1.5      | 1.83      | ≤23.00    |

According to the analysis conducted, samples 5 and 7 show the lead level exceeding the MPC 1.6 and 1.8 times (MPC = 6.0 mg/kg) - 9.35 mg/kg and 10.73 mg/kg respectively. None of the samples has MPC overruns for zinc, nickel, manganese, copper, cobalt, or nitric nitrogen.

Sample 14 shows the lead level exceeding the MPC by 7.3 times (MPC = 6.0 mg/kg). Its concentration comprises 43.7 mg/kg. None of the samples has MPC overruns for zinc, nickel, manganese, copper, cobalt, or nitric nitrogen and lead.

In order to assess the degree of SMW impact on the soils, 10 samples were taken, including 2 control ones. The area of contamination comprised 2.95 ha. The samples were taken from the area located at the following address: Orlovskaya oblast, Maloarkhangelskiy district, Oktyabrskoye village settlement, near Repyovka (Table 3).
### Table 2. Environmental and geochemical appraisal of sugar lime impact on soils (samples 11-20).

| No | Indicator       | Sample | MPC (back ground) |
|----|-----------------|--------|------------------|
|    |                 | 11     | 12               | 13               | 14               | 15               | 16               | 17               | 18               | 19               | 20               |
| 1  | Nitric nitrogen | 3.1    | 5.7              | 0.8              | 33.2             | 1.1              | 29.9             | 3.7              | 2.6              | 13.0             | 0.4              |
| 2  | Cobalt         | 0.2    | 0.2              | 0.1              | 0.1              | 0.3              | 0.7              | 0.2              | 0.1              | 0.2              | 0.1              |
| 3  | Manganese      | 16.2   | 17.6             | 18.8             | 34.8             | 25.4             | 68.2             | 23.9             | 33.6             | 28.4             | 23.1             |
| 4  | Copper         | 0.1    | 2.3              | 0.1              | 0.4              | 0.2              | 1.4              | 0.1              | 0.3              | 0.3              | 0.1              |
| 5  | Nickel         | 0.4    | 0.5              | 0.1              | 0.4              | 0.1              | 0.7              | 0.1              | 0.6              | 0.1              | 0.1              |
| 6  | Lead           | 0.1    | 0.9              | 0.6              | 43.7             | 0.4              | 3.9              | 1.8              | 1.3              | 0.6              | 0.5              |
| 7  | Zinc           | 1.6    | 1.9              | 1.3              | 2.4              | 1.4              | 6.2              | 1.6              | 2.1              | 1.9              | 1.4              |

The analysis shows that samples 6, 7, and 9, as well as the control sample 10, do not have MPC-exceeding levels of active heavy metal forms, including cobalt, copper, lead, manganese, arsenium, nickel, and zinc. None of the samples analyzed show MPC-overruns in such heavy metals as cobalt, manganese, copper, and nickel. In sample 8, the level of active forms of lead makes up 21.82 mg/kg (MPC = 6.0 mg/kg) which exceeds the MPC by 3.6 times. Other indicators do not exceed their permissible values. Samples 1-5 show insignificant MPC overrun for the active form of arsenium (2.96-3.21 mg/kg), and samples 1-3 also have excessive levels of lead (6.99-7.19 mg/kg). The highest MPC overrun for zinc was in samples 2, 4, and 5, and its value was between 50.36-52.34 (MPC = 23.0 mg/kg).
In order to assess the degree of SHW impact on the soils, 30 samples were taken including 2 control ones from the area of 61070.1 square meters located at the following address: Orlovskaya oblast, Zalegoschenskiy district, Nizhnezalegoschenskoye village settlement. The analysis of agricultural soils condition contaminated by the SHW deposited on their surface shows a significant accumulation of active heavy metal forms in the upper humus/root layer. Their levels exceed both the background heavy metal level values and their MPC for soil (Tables 4 and 5).

Table 4. Environmental and geochemical appraisal of SHW impact on soils (samples 1-11).

| No | Indicator | Sample M | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 MPC (background) |
|----|-----------|---------|---|---|---|---|---|---|---|---|---|---|-------------------|
| 1  | Benz(a)pyrene | 0.005  | 77 | 0.7 | 0.00 | 0.00 | 0.00 | 0.2 | 0.1 | 0.05 | 0.0 | 0.37 | 0.0 < 0.02 |
| 2  | Cobalt | 0.31 | 0.0 | 0.04 | 0.44 | 0.31 | 0.8 | 0.8 | 0.31 | 0.4 | 0.67 | 0.5 < 5.0 |
| 3  | Manganese | 196.2 | 11 | 135. | 196. | 175. | 114 | 125 | 196. | 146 | 122. | 17. < 100 |
| 4  | Copper | 3.96 | 4.0 | 3.96 | 4.72 | 5.95 | 6.1 | 4.7 | 42.7 | 7.6 | 8.40 | 0.5 < 3.00 |
| 5  | Nickel | 4.04 | 4.0 | 3.44 | 0.62 | 3.95 | 6.7 | 4.6 | 4.44 | 5.2 | 6.47 | 0.2 < 4.0 |
| 6  | Lead | 6.01 | 6.1 | 6.70 | 163. | 6.01 | 6.8 | 48. | 6.19 | 20. | 12.3 | 0.2 < 6.0 |
| 7  | Zinc | 26.15 | 24. | 25.8 | 23.1 | 25.2 | 73. | 37. | 53.8 | 79. | 115. | 2.3 < 23. |

All of the soil samples analyzed show a dramatic increase of active forms of such metals as cobalt, manganese, copper, arsenium, lead, nickel, zinc, as compared with the control samples that did not undergo adverse impacts.

According to the analysis of samples 1-10 and 12-21 and 2, there is an overrun of benz(a)pyrene MPC by 7 and 12 times respectively (MPC = 0.02 mg/kg). The levels of manganese exceed the MPC (100.0 mg/kg) by 1.4 and 1.1 time, lead levels (MPC = 6.0 mg/kg) - 2.1 and 2 times, zinc levels (MPC = 23.0 mg/kg) - 6.6 and 37.6 times respectively, while MPC-overruns for cobalt, copper, and nickel were not found.

Thus, the identified adverse changes in grey forest soils and its fertility decrease in areas experiencing anthropogenic impacts in the form of solid household waste (SHW) due to the accumulation of heavy metals and the deterioration of the fertile soil layer [1] due to the presence multi-element anomalies in soil environment and the hazardous properties of the heavy metals in question [15] call for the environmental and sanitary audit of the identified industrial contamination and geochemical anomaly areas, as well as the development of recommendations and actions aimed at preventing and mitigating the adverse impact on ecosystems [4].

One of the key provisions for agricultural activities on the contaminated territories is getting detailed and scientific information on contamination levels of agricultural soils. The degree of soil contamination with heavy metals is determined by the proportion of the actual level of the contaminant in the soil and the permissible or background concentration values (Table 6).
**Table 5.** Environmental and geochemical appraisal of SHW impact on soils (samples 12-22).

| No | Indicator | Sample | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | MPC |
|----|-----------|--------|----|----|----|----|----|----|----|----|----|----|----|------|
| 1  | Benzpyrene | 0.03   | 0.0 | 0.02 | 0.02 | 0.0 | 0.00 | 0.00 | 0.02 | 0.0 | 0.0 | 0.0 | 0.0 | ≤0.02 |
|    |           | 2      | 30  | 34  | 2   | 6   | 07  | 8   | 2   | 28  | 32  | M   | 0.00 |

**Table 6.** The assessment of the degree of contamination and the overall index of soil contamination with waste.

| Samples | Sugar lime | SMW | SHW |
|---------|------------|-----|-----|
|         | Control    | MPC | Control | MPC | Control | MPC |
| 1.      | 119.1      | -   | 28147.4 | 2.3 | 0.6     | 2.4 |
| 2.      | 186.5      | -   | 31218.6 | 9.4 | 2.26    | 39.4 |
| 3.      | 227.9      | -   | 30074.9 | 1.7 | 15.5    | 1.9 |
| 4.      | 182.7      | -   | 31175.2 | 2.8 | 2.8     | 28.9 |
| 5.      | 193.7      | 1.6 | 2544.1  | 2.7 | 18.4    | 2.8 |
| 6.      | 186.9      | -   | 11224.7 | -   | 1.6     | 18.8 |
| 7.      | 130.6      | 1.8 | 6000.9  | -   | 1.6     | 16.0 |
| 8.      | 145.4      | -   | 9035.7  | 3.6 | 0.6     | 18.6 |
| 9.      | 60.4       | -   | 12972.5 | -   | 0.8     | 8.3 |
| 10.     | background | -   | background | - | 1.2     | 26.6 |
| 11.     | 21.1       | -   | -       | -   | background | - |
| 12.     | 241.3      | -   | -       | -   | 1.3     | 8.2 |
| 13.     | 7.3        | -   | -       | -   | 0.8     | 7.8 |
| 14.     | 128.1      | 7.3 | -       | -   | 0.2     | 4.3 |
| 15.     | 20.0       | -   | -       | -   | 0.7     | 5.1 |
| 16.     | 246.0      | -   | -       | -   | 1.0     | 13.2 |
The assessment of lead levels in soils shows the overrun of the MPC in sample 5 (1.6), sample 7 (1.8), and sample 14 (7.3) due to the contamination of soil with sugar lime. In other samples, the concentration of metals in question exceeds only the background level. A significant accumulation of heavy metals in question was found, as compared with the levels of these metals in the control (background) soil samples that did not experience the adverse impact of waste. Extremely dangerous soil pollution, as compared with the control (background) samples, was detected in samples 1-9, 12, 14, 16, 18, and 19, the moderately dangerous soil pollution was found in samples 11, 15, and 17.

The detected heavy metal accumulation in the soil of the affected areas is the result of soil contamination due to sugar lime deposit and its uneven distribution in the plowing horizon, as well as the impact of root systems of weeds, trees, and bushes consuming and then redistributing heavy metals. They promote the appearance of concentration areas for various metals in the soil, which leads in the end to the damage to soils as environmental objects and means of agricultural production [16, 18].

The overall SMW soil contamination compared to the MPCs was within the range of 1.9-9.4 times. A significant accumulation of heavy metals in question was found, as compared with the levels of these metals in the control (background) soil samples that did not experience the adverse impact of waste. The total overall contamination as compared with the control (background) values in samples 1-9 corresponds to the extremely dangerous level of contamination, while as compared to the MPC, it is only a permissible level of contamination.

Only in sample 5, the concentration factor of SHW soil contamination shows a moderately dangerous contamination value of 18.4 units as compared with the background value. As compared with the MPC, samples 2, 4, 6, 7, 8, and 9 have moderately dangerous contamination of 39.4; 28.9; 18.8; 16.0; 18.6; and 26.6 respectively.

Thus, virtually all metals in question, including their active forms, show high concentration levels and significant abnormality factors and their overall soil accumulation factors [8], which ordains the appearance of toxic concentration of heavy metals and their harmful cancerogenic, mutagenic, and inhibitory effects on organisms and leads to soil fertility deterioration [10].

In order to assess the degree of industrial and consumer waste impact, the damage inflicted to the soil as an environmental object was calculated (Table 8).

| Contamination source | Area in ha | Damage in thousands of rubles |
|----------------------|------------|------------------------------|
| Sugar lime           | 5.00       | 240000                       |
| SMW                  | 2.95       | 141600                       |
| SHW                  | 6.1        | 292800                       |

The largest area of SHW contamination comprised 6.1 ha, and the damage of its contamination amounted to 292 800 thousand rubles. The area contaminated with SMW was 2.95 ha and its damage was assessed 2 times less than the SHW area and comprised 141 600 thousand rubles.
2. Practical relevance
The conducted research helps us identify the scales and the consequences of the agricultural area contamination with industrial waste and prepare necessary actions to recreate the contaminated soils. The features and patterns identified allow justifying the methods and tools for soil fertility preservation and preventing the contamination of soil with industrial and consumer waste. The data obtained can be used in the development of a project for the restoration of the contaminated lands.

References
[1] Vitkovskaya S E, Shilova Yu O, Malyukhin D M 2019 Assessment of the potential environmental hazard of filtration water from solid municipal waste landfills in the Leningrad Region Agrophysics 1 pp 1-7
[2] Dmitriev V V, Ogurtsoy A N, Rusakov A V, Mashkin Yu L, Petrov I M 2018 Features of the spatial structure of heavy metal pollution of soil cover in the design phase of the second stage of the landfill of Veliky Novgorod InterCarto. InterGIS vol 24 1 pp 382-393
[3] Dobrovolsky V V 1999 Geochemical criteria for assessing soil pollution by heavy metals Soil Science 5 pp 639–645
[4] Eremin V N, Pavlov P D, Reshetnikov M V, Sheshnev A S 2016 Ecological and geochemical assessment of the soil cover in the region of the Balakovo landfill for solid household waste (Saratov region) Engineering geology 2 pp 50-61
[5] Zamotaev I V, Ivanov I V, Mikheev P V, Belobrov V P 2018 Assessment of the condition of soils and vegetation in areas where landfills and solid waste landfills are located (review) Soil science 7 pp 907-924
[6] Ivanova Yu S, Konovalova L V, Lychagin E V 2011 Ecological and geochemical condition of the soil cover in the areas of natural landfills for household waste Ecological systems and devices 11 pp 3-7
[7] Kolesnikov S I, Kazeev K Sh, Valkov V F 2002 Ecological functions of soils and the effect of pollution by heavy metals Soil Science 12 pp 1509-1514
[8] Meshchaninov F V 2018 Ecological and geochemical condition of soils within the Zavetnensky municipal solid waste landfill (Rostov Region) 1 Natural and technical sciences 12(126) pp 241-245
[9] Mukasheva M A, Mukasheva G Zh, Nugumanova Sh M, Kazimova A E 2013 Heavy soil pollution of the industrial city territory Bulletin of Chelyabinsk State University 7(298) pp 152-154
[10] Pavlov P D, Reshetnikov M V, Eremin V N 2015 Assessment of soil pollution by mobile and gross forms of heavy metals in the zone of influence of the Gusel solid waste landfill (Saratov) Izvestiya Saratov University New series. Series: Earth Sciences vol 15 3 pp 53-56
[11] Polukhina M G 2019 Ecological block questionnaire study of rural residents Scientific journal NRU ITMO Series: Economics and Environmental Management 2 pp 163-170
[12] Polukhina M G 2018 Environmental management is the main factor in the socio-economic development of rural areas Scientific journal NRU ITMO. Series: Economics and Environmental Management 2 pp 91-102
[13] Sintsov A V, Barmin A N, Valov M V 2014 Dynamics of heavy metals in soils of urban ecosystems Geology, geography and global energy 4(55) pp 148-156
[14] Stepanova L P, Yakovleva E V and Pisareva A V 2019 Spatio-temporal dynamics of soil geochemical anomalies in the zone of impact of slag residuals Ecology and Industry of Russia 23(3) pp 44-48
[15] Stepanova L P, Yakovleva E V, Korenkova E A and Pisareva A V 2015 Agro-Economic assessment of fertility restoration of anthropogenically disturbed and recultivated gray forest soils Scientific notes of Orel state University 3 pp 256-261
[16] Tarasova T F, Baytelova A I, Guryanova N S, Baytelov V I 2015 The state of ecosystems in the conditions of environmental pollution by agricultural enterprises Bulletin of Orenburg State


*University* 10(185) pp 441-444

[17] Tuchkova L E, Verkhovets I A, Tikhoykina I M, Chuvashova E S 2018 Assessment of the degree of influence of the installation of the gas pipeline of Podvodspetsstroy LLC on the soil cover of the Zalegoschensky district of the Oryol region *Bulletin of the Kursk State Agricultural Academy* 9 pp 76-80

[18] Tuchkova L E, Verkhovets I A, Tikhoykina I M, Fedotova I E 2018 The influence of defecate on the state of soil cover and the assessment of economic damage to some farms in the Oryol region *Bulletin of OrelGIET* 4(46) pp 12-16

[19] Chernyshova A V 2018 Assessment of the ecological state of the Kemerovo region *Meteorological Bulletin* vol 10 5 pp 32-40