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Research article

ASSESSING AND RANKING OF BROWNFIELDS PER HEALTH RISK CRITERIA: EXPERIENCE GAINED IN THE PERM REGION

V.G. Kostarev[1,3,4], D.M. Shlyapnikov[2,4], A.V. Brazhkin[2,3], T.G. Pazderina[2], I.V. May[3], E.V. Maksimova[3]

[1]Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing: Perm Regional Office, 50 Kuibysheva St., Perm, 614016, Russian Federation
[2]Center for Hygiene and Epidemiology in Perm Region, 50 Kuibysheva St., Perm, 614016, Russian Federation
[3]Federal Scientific Center for Medical and Preventive Health Risk Management Technologies, 82 Monastyrskaya St., Perm, 614000, Russian Federation
[4]Perm State Medical University named after Academician E.A. Wagner, 26 Petropavlovskaya St., Perm, 614000, Russian Federation

Everywhere objects of accumulated environmental damage (brownfields) pollute surrounding areas and create elevated incidence rates among population. The necessity to establish an order for elimination of such objects is a primary task set within the General Cleaning Federal Project.

The aim of this study was to assess and rank regional brownfields per their hazards for people's lives and health in order to establish the order for their elimination.

Human health risk assessment under exposure in brownfield-influenced areas was conducted by experts of the Center for Hygiene and Epidemiology in the Perm region in accordance with the Rospotrebnadzor's certified methodology based on the fuzzy set theory. Forty to fifty indicators were estimated for each object considering specific features and types of brownfields. The analysis covered 29 objects located in the Perm region. Background materials were examined on each object; overall, 1100 additional laboratory tests were performed to assess quality of environmental objects (ambient air, soils, natural and drinking water.

According to the results obtained by the complex assessment, 4 brownfields were ranked as 'high risk objects' (R = 0.75÷0.62); 16 were ranked as 'medium risk objects' (R = 0.51÷0.41); 9 were ranked as 'moderate risk objects' (R = 0.39÷0.25). Among the identified high risk objects, three were represented by industrial waste landfills of mining and chemical enterprises; one was an unregulated dump. High risk objects were characterized with substantial volumes of accumulated wastes of formed economic activities, long existence period and unregulated effects on the environment; they were located within settlements where safe standards for the quality of the environment were violated in residential areas per indicators, which were typical brownfield markers.

Medium and moderate risk objects were located in small settlements or beyond their boundaries and safe standards for the quality of the environment were not violated in residential areas.

Data on health risks and priorities for funding and implementing activities aimed at eliminating objects of accumulated environmental damage were submitted to Rospotrebnadzor and executive authorities of the Perm region.

Keywords: *brownfield, General Cleaning Federal Project, health risk criteria, categorizing, ranking.*

Vitalii G. Kostarev – Candidate of Medical Sciences, Chief State Sanitary Inspector in Perm region, Head of Rospotrebnadzor office in Perm region (e-mail: urpn@59.rospotrebnadzor.ru; tel.: + 7 (342) 239-35-63, 239-34-35; ORCID: https://orcid.org/0000-0001-5135-8385).

Dmitry M. Shlyapnikov – Candidate of Medical Sciences, Chief Physician (e-mail: cgepo@mail.ru; tel.: + 7 (342) 239-34-09).

Anatolii V. Brazhkin – specialist of the Laboratory of Social and Hygienic Monitoring (e-mail: brazhkin.anatol@yandex.ru; tel.: +7 (342) 237-18-04).

Tatyana G. Pazderina – Head of the Department of Municipal Hygiene (e-mail: cgepo@mail.ru; tel.: +7 (342) 239-34-09).

Irina V. May – Doctor of Biological Sciences, Professor, Chief Researcher – Director Advisor (e-mail: may@fcrisk.ru; tel.: +7 (342) 237-25-47; ORCID: https://orcid.org/0000-0003-0976-7016).

Ekaterina V. Maksimova – Junior Researcher at the Department for Systemic Procedures of Sanitary-Hygienic Analysis and Monitoring (e-mail: maksimova@fcrisk.ru; tel.: +7 (342) 237-18-04; ORCID: https://orcid.org/0000-0001-5714-9955).

Wastes, which were created by former economic activities and have existed for a long time, are an uncontrolled source of pollution. They pose hazards for environmental objects and the human environment as a whole. Long-term unregulated pollution of soils, ambient air, and natural water objects, drinking water sources included, is bound to affect human health [1–5].

Issues related to identifying, assessing and eliminating objects of accumulated environmental damage (brownfields) are common for many developed countries; efforts to resolve them have been made over decades. Since 90ties last century, Germany, Denmark, the Netherlands and other countries have started to actively implement relevant activities aimed at identifying brownfields and eliminating them [6–11]. Countries that have accumulated useful experience in eliminating brownfields usually follow several basic principles: first, an area should be examined to detect any hazardous chemicals; next, actual harm or a threat of harm should be estimated; last, cause-effect relations should be established between revealed harm and economic activities performed by an economic entity[1]. If an owner or a former owner or a brownfield is known, they are made to take necessary measures to eliminate environmental damage at their expense. In case an owner is not known, the responsibility for eliminating environmental pollution belongs to regional or federal authorities.

Everywhere, priority in redevelopment of polluted areas is given to the most hazardous objects with most detrimental effects on the environment and human health [10–12]. To emphasize how relevant the issue is and to demonstrate what great efforts are taken by state authorities to provide safety for citizens, legislation in some countries stipulates creating and maintaining web-sites and registers of brownfields [11, 12].

Some experts from the World Bank believe that the issues related to brownfields are as acute and large-scale in Russia as they are in the USA[2], where Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Law on Superfund) has been valid since 1980[3]. The Law is supplemented with the Superfund Amendments and Reauthorization Act (SARA)[4]. The document establishes the rules and procedure for assessing brownfields, makes it possible to estimate caused harm and establish the most polluted areas in the country.

In the Russian Federation, such legal concepts as “accumulated environmental damage” and “an object of accumulated environmental damage” were first introduced by the Federal Law issued on July 3, 2016 No. 254-FZ[5]. According to it, objects of accumulated environmental damage include *“territories and water areas where environmental damage has been detected, which occurred as a result of past economic and other activities; obligations to eliminate this damage haven’t been fulfilled, partially or completely”*.

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[1] Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage. *An official website of the European Union*. Available at: https://eur-lex.europa.eu/eli/dir/2004/35/oj/eng (February 04, 2025); Environmental Liability Directive Guidelines. Denmark, The Environmental Protection Agency and the Agency for Spatial and Environmental Planning, 2012; Guidelines for Part 17.2 of the Dutch Environmental Management Act: measures in the event of environmental damage or its imminent threat. The Netherlands, 2008.

[2] Proshlyi ekologicheskii ushcherb v Rossiiskoi Federatsii [Past Environmental damage in the Russian Federation]. *World Bank, Department for Sustainable Development, European and Central Asia region*, May 2007, pp. 39. Available at: http://expert.gost.ru/EC/DOC/PECU.pdf (February 04, 2025) (in Russian).

[3] Superfund: CERCLA Overview. *US EPA*. Available at: https://www.epa.gov/superfund/superfund-cercla-overview (February 04, 2025).

[4] The Superfund Amendments and Reauthorization Act (SARA). *US EPA*. Available at: https://www.epa.gov/superfund/superfund-amendments-and-reauthorization-act-sara (February 04, 2025).

[5] O vnesenii izmenenii v otdel'nye zakonodatel'nye akty Rossiiskoi Federatsii: Federal'nyi zakon ot 3 iyulya 2016 g. № 254-FZ [On making alterations into certain legal acts of the Russian Federation: The Federal Law issued on July 3, 2016 No. 254-FZ]. *KonsultantPlus*. Available at: http://www.consultant.ru/document/cons_doc_LAW_200513/ (February 06, 2025) (in Russian).

The Federal Law "On Environmental Protection" regulates issues related to discovering, evaluating, accounting and eliminating brownfields[6]. The Federal Project titled Elimination of Hazardous Objects is being implemented in the country to resolve this long-term issue; it envisages profound analysis of each such object and assessment of its influence on environmental objects, people's lives and health[7]. Inclusion of effects produced by brownfields not only on the environment but also on people's lives and health is substantiated in the Project by multiple research works and convincing evidence [1, 5, 13, 14]. Following the results obtained by examining and assessing brownfields, their step-by-step elimination is expected considering ranks assigned to them according to their hazards and established priorities.

Results of health risk assessment are considered together with ecological criteria and this allows covering all aspects of negative outcomes appearing due to brownfields and making a well-grounded decision as regards priorities in allocating funds and implementing measures for elimination of such objects.

At present, the State Register of Brownfields contains data on more than 3.5 thousand of such objects; they are of various types and origins and have existed for different periods of time. Several objects are located in the Perm region. They are former industrial sites, deserted mines, ownerless disposal sites for solid and liquid wastes, buildings and constructions not in use and partially demolished and household waste landfills, which are no longer exploited[8].

The aim of this study was to assess and rank regional brownfields per their hazards for people's lives and health in order to establish the order for their elimination.

Materials and methods. The research objects were 29 brownfields located in the Perm region: 18 exhausted sections of a coalfield, 2 land spots polluted with oil products, 4 solid household and / or industrial waste landfills, 3 wood waste heaps, 1 ash heap, and 1 industrial sludge pit.

All brownfields located in the region were divided into the following types fixed in the Russian legislation: a) solid waste disposal sites; b) liquid chemical waste disposal sites; c) polluted areas.

Effects produced by the analyzed brownfields on people's lives and health were assessed in conformity with the Methodology for Assessing Effects of Brownfields on Citizens' Lives and Health approved by the Rospotrebnadzor's Order issued on November 27, 2023 No. 851[9].

Instruments described in the methodology are based on the fuzzy set theory and allow considering any sets of numeric and logical variables [15]. Each brownfield type was estimated using a set of indicators typical for such objects (not less than 40 indicators for each brownfield type). We considered those indicators that could both directly and indirectly shape the quality of the environment and, accordingly, affect human health (hazardous chemicals in wastes, protective barriers around a brownfield, proximity to drinking water sources, hazardous chemicals typical for a brownfield detected in ambient air, water, soils in residential areas, etc.)

Scales grading a hazard level for each indicator (from low to very high) were used to estimate influence exerted by each analyzed

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[6] Ob okhrane okruzhayushchei sredy: Federal'nyi zakon ot 10.01.2002 № 7-FZ (poslednyaya redaktsiya) [On Environmental Protection: the Federal Law issued on January 10, 2002 No. 7-FZ (the latest edition)]. *KonsultantPlus*. Available at: http://www.consultant.ru/document/cons_doc_LAW_34823/ (February 06, 2025) (in Russian).

[7] General Provisions: the Statute on the Ministry of Natural Resources and Environment of the Russian Federation. *Ministry of Natural Resources and Environment of the Russian Federation*. Available at: https://www.mnr.gov.ru/en/ (February 06, 2025).

[8] O sostoyanii i ob okhrane okruzhayushchei sredy Permskogo kraya v 2023 godu [On the state and protection of the environment in the Perm region in 2023]: the State Report. Perm, Ministry of Natural Resources, Forestry and Ecology of the Perm region, 2023, 112 p. (in Russian).

[9] Metodika osushchestvleniya otsenki vozdeistviya ob"ektov nakoplennogo vreda okruzhayushchei srede na zhizn' i zdorov'e grazhdan [Methodology for Assessing Effects of Brownfields on Citizens' Lives and Health]. Moscow, Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing, 2023, 57 p. (in Russian).

indicator on human health. Indicators were combined in groups and the weighting coefficient was established for each group taking a brownfield type into account (v_j): the general profile of a brownfield (v_j = 0.10÷0.15); climatic parameters (v_j = 0.10); spatial characteristics (v_j = 0.30÷0.40); geological and hydrological properties of a given area (v_j = 0.15÷0.35); indicators describing the quality of the environment in a given area (v_j = 0.10÷0.40).

The total health risk per all indicator groups (R) was calculated per the following formula:

$$R = \sum_j R_j v_j \,, \qquad (1)$$

where R_j is the health risk caused by the j-th indicator group; v_j is the weighted contribution of the j-th indicator group to the total health risk.

The calculated risk level was matched with a relevant scale range, the score estimate of which is used in the overall brownfield assessment and its subsequent ranking (Table 1).

The first stage in assessing effect of brownfields on people's lives and health in the Perm region involved examining background materials (project documents, results of brownfield assessment performed by Rosprirodnadzor, etc.). Based on the initial data, programs of additional laboratory measurements were developed and implemented in order to estimate the quality of the environmental components in an area influenced by a brownfield and the closest residential area.

Points where instrumental measurements were taken were located at outer boundaries of brownfields and in the closest residential areas. All tests were conducted by the accredited test laboratory center of the Center for Hygiene and Epidemiology in the Perm region using only certified measuring techniques.

More than 100 laboratory tests were conducted at each point for instrumental research to measure chemical, microbiological, and radiological factors in order to cover all aspects of effects produced by brownfields on people's lives and health.

Upon completion of data analysis, the results were fed into program modules that implemented the mathematical apparatus of the approved methodology. Health risk levels and their criterion scores were calculated for each analyzed brownfield.

Results and discussion. The test results have revealed that practically all analyzed brownfields are unsafe for the environment and pose potential threats for people's lives and health. Thus, 19 brownfields out of analyzed 29 are located directly within settlements, starting from small urban ones (exhausted sections of coal-fields) to the regional center (solid household waste landfills). Some brownfields have been acting as pollution sources for a very long time, up to several decades. Thus, effusions of acidic mine waters have been polluting soils and water objects in

Table 1

Scale ranges for health risk categories and score estimate of health risk

Scale indicator	Health risk categories				
	Low	Moderate	Medium	High	Very high
Range	(0; 0.25]	(0.15; 0.45]	(0.35; 0.65]	(0.55; 0.85]	(0.75; 1.0]
Mean range value	0.125	0.300	0.500	0.700	0.875
Score estimate[10]	0	1	2	2.3	3

[10] O vedenii gosudarstvennogo reestra ob"ektov nakoplennogo vreda okruzhayushchei srede: Postanovlenie Pravitel'stva RF ot 23.12.2023 № 2268 (s izmeneniyami na 14 marta 2024 goda) [On keeping the State Register of Brownfields: the RF Government Order issued on December 23, 2023 No. 2268 (the latest edition as of March 14, 2024)]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1304418172 (February 04, 2025) (in Russian).

neighboring areas for 24–60 years. For more than 20 years, wood waste heaps of closed pulp and paper productions and food processing plants have been the reason for chemicals penetrating water objects by migration of pollutants into subterranean and storm waters, ambient air, and soils. It should be noted that only one object (a sludge pit of a former chemical plant) out of 29 analyzed brownfields has a protective barrier for partially preventing and / or slowing down penetration of chemicals into the environment.

Masses and volumes of wastes accumulated due to former economic activities differ considerably, from 2 to 812 thousand tons and from 4 to 68 thousand m^3. Practically all brownfields contain chemicals able to produce carcinogenic, mutagenic, embryotoxic or reprotoxic effects.

Brownfields located close to water objects and / or agricultural lands are extremely hazardous as regards their potential effects on human health. Thus, 10 brownfields (34 % of all analyzed ones) are located in close proximity to water objects, less than 50 meters away from shore lines of rivers or ponds, including those used as drinking or household water sources or as recreational areas. One of such objects is located 5 meters away from water and in the second belt of drinking water intake created to supply water to a town with its population of approximately 60 thousand people.

The situation is aggravated further by small occurrence depth of subterranean waters; background data on bedrocks are available for some objects and according to them subterranean waters occur at a depth not more than 2 meters below the foundation of an object. This poses a threat that pollutants could penetrate the upper water-bearing horizon and spread over the whole area.

More than a half of all analyzed brownfields have agricultural lands in areas influenced by them. This creates a threat that certain chemicals, including mobile phases of metals, could migrate into plants used as raw materials for food products or forages.

Hazards and threats identified by analyzing background materials on the examined brownfields have been confirmed by instrumental measurements of the environment quality.

Chemical pollution of the environment is established as a main health risk factor in areas influenced by brownfields. Such pollution is especially typical for industrial brownfields. To illustrate the point, Table 2 provides the results obtained by instrumental tests of the chemical structure of soils in an area influenced by an ash heap of a former metallurgic plant (28 test sites and 2 background sites). The object is located 5 meters away from the shore line of a water reservoir (a pond in the Lysva River). The closest residential area is located 215 meters away from the ash heap. A gardening association is located 125 meters away from the brownfield boundary.

Obviously, soils in an area influenced by this brownfield are heavily polluted with metal compounds, including their mobile phases, oil products, and anion-active surfactants. Identified chemicals are hazardous since they can affect human health. Lead, cadmium, nickel, and arsenic compounds are established carcinogens. Concentrations of these chemicals identified in some soil samples taken in the nearest settlement are by many times higher than the background levels: lead, up to 18.5; nickel, up to 9.7; arsenic, up to 5.8; cobalt, up to 4.8 times. Compounds of mercury, a hazardous toxicant, have been established in concentrations up to 33.6 times higher than the background level.

Soil pollution near the water object leads to water pollution as well. Thus, safe standards have been found to be violated in the water from this pond located in the settlement per levels of lead, mercury, oil products, and other chemicals typical for the brownfield (up to 2 MPL).

Any violations of safe standards for chemical contents in ambient air have not been established in the area influenced by this brownfield; however, significant concentrations have been detected for such chemicals as nickel, benzo(a)pyrene, chromium, cobalt, lead, and zinc compounds, which allows

Table 2

Chemicals detected in soil in an area influenced by an ash heap of a former metallurgic plant and potential negative health effects

Indicator	Level, mg/kg			Potential negative health effects
	Mean value	Maximum	Permissible level (background)	
Oil products	741 ± 223	1480	140 ± 42	Carcinogenic effects, affects respiratory organs and the nervous system
Anion-active SAS	3.69 ± 1.23	6.0	2.70 ± 0.90	Affects the nervous system
Aluminum	7731 ± 2275	18766	5093 ± 1732	Affects the nervous system and the liver
Mercury	0.92 ± 0.48	3.02	0.09 ± 0.05	Affects the nervous system, development and kidneys
Copper	577 ± 143	1838	51 ± 16	Affects the cardiovascular system, nervous system and respiratory organs
Zinc	1399 ± 350	4408	142 ± 36	Affects the immune system and blood
Manganese	2922 ± 584	5042	994 ± 199	Affects the nervous system
Lead	484 ± 121	1091	59 ± 18	Carcinogen. Affects the nervous system, blood, development, endocrine system, etc.
Nickel	162 ± 41	330	34 ± 9	Carcinogen. Systemic harm
Cadmium	7.68 ± 2.62	21	3.8 ± 1.3	Carcinogen. Affects the kidneys
Cobalt	3.32 ± 1.37	14	2.9 ± 0.9	Carcinogen. Affects the endocrine system
Arsenic	1.15 ± 0.58	1.74	0.30 ± 0.15	Carcinogen. Affects development cardiovascular system, nervous system, etc.

assuming that people living in adjoining areas are exposed to heavy metals in various environmental objects.

High levels of soil pollution with heavy metals have also been found in an area influenced by a solid household waste landfill located in Perm (Table 3).

Soil pollution in the area influenced by this brownfield occurs due to absence of any geological-technical constructions (no barriers or waterproofing screens). Therefore, chemical concentrations established directly in the area influenced by the brownfield are above permissible levels as regards such chemicals as mercury (32.5 times higher), copper (8.32 times), lead (4.75 times), oil products (3.33 times), nickel (up to 2.45 times), and zinc (up to 1.29 times).

Significant chemical hazard posed by industrial brownfields is also confirmed by the data describing quality of environmental objects in an area influenced by a sludge pit for solid industrial wastes (Table 4).

Water objects in the region, which are located in areas influenced by various brownfields, are polluted with a whole set of common and specific chemicals in concentrations substantially higher than safe levels: magnesium, up to 190 MPL; hydroxybenzene, up to 160 MPL; manganese, up to 20.0 MPL; benzo(a)pyrene, up to 19.8 MPL; mercury, up to 19.8 MPL; lead, up to 14.9 MPL; chlorides, up to 2.73 MPL; iron, up to 8.33 MPL; ammonia, up to 11.50 MPL; cadmium, up to 4.80 MPL; sodium, up to 2.93 MPL; sulfates, up to 2.70 MPL; chromium, up to 2.16 MPL; formaldehyde, up to 1.12 MPL.

Safe standards for environmental objects have been established to be violated per microbiological parameters in areas influenced by brownfields with accumulated household or industrial wastes and / or biodegradable organic wastes. Thus, soils in areas where solid household waste landfills are located within settlements or in close proximity to them contain elevated levels of total coliforms, up to

Table 3

Quality of environmental objects in an area influence by unregulated dump

Indicator	Measuring units	Value		
		Mean	Maximum	Permissible (MPL / norm / background)
Oil products	Mg/kg	143 ± 35.8	200	60.0 ± 24.0
Copper	Mg/kg	205 ± 51.3	308	37.0 ± 11.0
Mercury	Mg/kg	0.036 ± 0.009	0.13	0.004 ± 0.001
Zinc	Mg/kg	50.3 ± 12.6	62	48.0 ± 14.0
Lead	Mg/kg	31.8 ± 8.0	48	10.1 ± 3.0
Nickel	Mg/kg	24.5 ± 6.1	49	20.0 ± 5.0

Table 4

Quality of environmental objects an area influenced by a sludge pit of a former chemical plant

Indicator	Measuring units	Value		
		Mean	Maximum	Permissible (MPL / norm / background)
Soil in an area influenced by a brownfield and located within the city boundary				
Oil products	Mg/kg	1017 ± 308	8040	86.7 ± 30.7
Nitrites	Mg/kg	0.271 ± 0.11	0.52	0.193 ± 0.08
ASAS	Mg/kg	108.92 ± 29.99	547	4.95 ± 1.50
Copper	Mg/kg	353 ± 68.5	893	2.23 ± 0.433
Chromium	Mg/kg	3.132 ± 0.782	6.6	1.563 ± 0.393
Vanadium	Mg/kg	70.0 ± 21.1	118	34.3 ± 12.67
Sulfates	Mg/kg	620.9 ± 155.2	2193	14.6 ± 3.65
Water in a surface water object within the city boundary (500 meters downstream form the brownfield) and at the point with its assumed highest influence				
Oil products	mg/dm^3	0.16 ± 0.040	0.27	0.05 ± 0.01
Nitrite-ion	mg/dm^3	0.202 ± 0.04	0.230	0.08 ± 0.02
Copper	mg/dm^3	0.052 ± 0.013	0.080	0.010 ± 0.002
Chromium	mg/dm^3	0.037 ± 0.010	0.072	0.020 ± 0.005
Vanadium	mg/dm^3	0.003 ± 0.001	0.015	0.001 ± 0.0003
Sulfates	mg/dm^3	861 ± 172	1479	100 ± 25

100 and higher CFU/g (the permissible level is 1–9 CFU/g); enterococci (fecal), up to 100 CFU/g (the permissible level is 1–9 CFU/g). Water in water objects for recreational use, which are located close to such brownfields, has been found to contain *Escherichia coli (E.coli)* in a concentration equal to 130 CFU/100 cm^3 (the permissible level is not higher than 100 CFU/100 cm^3); enterococci, up to 240 CFU/100 cm^3 (the permissible level is not higher than 10 CFU/100 cm^3).

Overall, analysis of background materials and results obtained by instrumental tests has made it possible to assess and rank 29 brownfields per potential health risks for the regional population (Table 5).

Four brownfields, which are located within urban settlements, have been ranked as 'high risk objects' (Table 6). They are characterized with considerable volumes of accumulated wastes, long existence as ‘ownerless objects’, and proximity to water objects used by people.

Three objects do not have banks, barriers or any other protective constructions, which could prevent hazardous chemicals from

Table 5

The results of assessing and ranking brownfields in the Perm region per health risks for the regional population

No.	Brownfield	Risk level (R)	Risk characteristic
1	Ash heap of a former metallurgic plant in water-protection area	0.75	High
2	Household and industrial waste landfill	0.65	High
3	Unregulated dump in Perm	0.64	High
4	Sludge pit of a former chemical plant	0.62	High
5	Wood waste heap of a liquidated pulp and paper production	0.57	Medium
6	Exhausted section of a coal field (mine pit)	0.57	Medium
7	Wood waste dump	0.53	Medium
8	Household waste landfill in Kungur, Perm region	0.52	Medium
9	Soils in a closed settlement polluted with oil products	0.52	Medium
10	Soli household waste landfill	0.52	Medium
11	Exhausted section of a coal field (mine passage)	0.51	Medium
12	Exhausted section of a coal field, mine	0.50	Medium
13	Exhausted section of a coal field, mine	0.49	Medium
14	Soils in a closed settlement polluted with oil products	0.49	Medium
15	Exhausted section of a coal field (mine passage)	0.49	Medium
16	Exhausted section of a coal field (mine passage)	0.49	Medium
17	Wood waste heap	0.48	Medium
18	Exhausted section of a coal field (mine pits)	0.46	Medium
19	Exhausted section of a coal field (pipe passage)	0.45	Medium
20	Exhausted section of a coal field (mine passage)	0.41	Medium
21	Exhausted section of a coal field (mine pit)	0.39	Moderate
22	Exhausted section of a coal field (mine passage)	0.37	Moderate
23	Exhausted section of a coal field (mine shaft)	0.37	Moderate
24	Exhausted section of a coal field (mine passage)	0.36	Moderate
25	Exhausted section of a coal field (well)	0.36	Moderate
26	Exhausted section of a coal field (mine passage)	0.34	Moderate
27	Exhausted section of a coal field (well)	0.33	Moderate
28	Exhausted section of a coal field (mine pit)	0.31	Moderate
29	Exhausted section of a coal field (well)	0.25	Moderate

Table 6

Basic characteristics of brownfields that create high risks for human health

Brownfield	Ash heap of a former metallurgic plant in water-protection area	Household and industrial waste landfill of a former chemical plant	Unregulated dump in Perm	Sludge pit of a former chemical plant
Existence, years	4	12	27	12
Waste volume, thousand m^3	461.29	22.650	177.14	24.411
Square, hectares	34.18	5.78	11.6	1.33
Located within a settlement	yes	yes	yes	yes
Distance from the closest water object, m	5	5	680	18
Chemicals with carcinogenic, embryotoxic, teratogenic and reprotoxic effects in wastes	yes	yes	yes	yes
Depth of subterranean water occurrence, m	1.2	1.0	1.6	0.5
Banks, barrier, derivation canals, etc.	no	no	no	yes
Exposed population, thousand people	60.3	151.3	1049.2	151.3

penetrating environmental objects or keep people away from their territory. Accordingly, these brownfields are sources of chemical dusts and vapors coming from the surface of the accumulated waste mass; they pollute surface and subterranean waters through pollution filtration and wash-out with storm or melted waters, spread of chemical and biological agents by wild animals, etc.

Highly hazardous chemicals are present in wastes accumulated at all these brownfields; these chemicals are identified in the nearest residential areas, sometimes in concentrations higher than the valid safe standards. This creates hazardous levels of exposure for people who reside permanently near the analyzed brownfields (see Tables 2–4).

These brownfields are subject to immediate elimination with subsequent redevelopment of destroyed and polluted soils until the land spots are in a condition allowing their full-fledge use for municipal and regional needs.

Medium and / or moderate risk objects located in the region are mostly small landfills, areas polluted with oil products, and exhausted sections of a former coal-field; they all are located in small settlements or near them. It is noteworthy that safe standards have not been established to be violated in residential areas influenced by many brownfields ranked as medium or moderate risk objects. At the same time, it is still advisable to eliminate them, redevelop soils and recover quality of environmental objects. The matter is even more important due to the fact that most brownfields of the formed coal-field are located in areas, which have high potential for tourism and are actively visited by people living in the Perm region and its guests [16].

Our results are fully consistent with findings reported in similar research works, both domestic and foreign ones. Studies that focus on decision-making as regards elimination of brownfields and subsequent use of redeveloped land spots emphasize the importance and advisability of comprehensive multifactorial analysis of the environment and population health in areas influenced by brownfields (our study has followed the same principle) [17–19]. Some studies confirm that the highest health hazards are posed by long-existing waste deposit sites of former economic activities performed by chemical, petrochemical, metallurgic productions and oil extraction enterprises [20–22]. Microbial pollution identified by examining ownerless landfills of household wastes or mixed household and industrial wastes in the Perm region is confirmed by studies accomplished at similar objects in other areas [23, 24].

It is noteworthy that the hygienic research society in general emphasizes that it is vital to eliminate negative effects produced by brownfields as completely and promptly as only possible, first of all, bearing minimization of health risks in mind [25–27].

Conclusions. Health risk assessment is a powerful instrument for identifying priorities to rank brownfields per their hazards and establishing the order and urgency of their liquidation. It is a mandatory element in brownfield assessment, which allows obtaining more objective results necessary for providing environmental and hygienic safety of the country population.

Out of 29 analyzed and assessed brownfields located in the Perm region, four (14 %) were ranked as ‘high risk objects’. These objects are to be eliminated immediately since they all are located within urban settlements in close proximity to residential areas and water objects used by the regional population. Chemical pollution in soils and water objects, including carcinogens, mutagens, and reprotoxic chemicals, as well as microbial pollution of the environment are primary health risk factors.

Medium and moderate risk objects are mostly small landfills, soils polluted with oil products, and exhausted sections of former coal-fields located in small settlements or close to them; safe standards are not violated

in residential areas influenced by such brownfields. These objects are to be eliminated according to approved schedules after all health hazards created by high risk brownfields have been eliminated.

It seems advisable to organize specialized medical and preventive aid to people who permanently reside in areas influenced by high risk brownfields for the whole period until these hazardous objects are eliminated and the quality of the environment is brought to conformity with safe standards in all areas previously influenced by such brownfields.

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