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Research article

ON ASSESSING IMPACTS EXERTED BY OBJECTS OF ACCUMULATED ENVIRONMENTAL DAMAGE ON HUMAN HEALTH AND LIFE EXPECTANCY

N.V. Zaitseva[1], I.V. May[1], S.V. Kleyn[1], D.A. Kiryanov[1], A.M. Andrishunas[1], N.N. Sliusar[2], E.V. Maksimova[1], M.R. Kamaltdinov[1]

[1]Federal Scientific Center for Medical and Preventive Health Risk Management Technologies, 82 Monastyrskaya Str., Perm, 6140045, Russian Federation
[2]Perm National Research Polytechnic University, 29 Komsomolsky Ave., Perm, 614990, Russian Federation

This research work is topical since there are a lot of objects of accumulated environmental damage (AED) in the Russian Federation and the task to eliminate them is fixed in the country legislation. These objects are typically brownfields, abandoned industrial building or constructions, abandoned waste disposal landfills etc. In accordance with the "General cleaning" Federal project we have developed methodical approaches to assessing impacts exerted by AED objects on human health and life expectancy. The aim of the methodology is to spot out priority objects which are to be eliminated as soon as possible.

Fuzzy set theory is chosen as a basic method. A unified set of indicators (40 and more) has been developed for each type of AED objects; this set allows assessing how hazardous an object is for population health. The indicators are combined into several conditional groups: overall profile; climatic and spatial characteristics; geological and hydrological properties of a territory; indicators related to quality of the environment in a zone influenced by a specific object. We have used scales to grade a health hazard taking into account weight contributions made by specific indicators and a group of them to the total risk of health disorders. Impacts are assessed allowing for types and severity of potential functional disorders of critical organs and systems in the human body under exposure to contamination.

We suggest an algorithm and techniques for calculating risks of negative impacts. A scale with risk ranges (from 0 to 1) allows determining several risk rates including "low", "moderate", "average", "high" and "extremely high" risk. An AED object is assigned into a risk category which corresponds to the maximum value of the membership function.

Impacts exerted by objects assigned into "high" and "extremely high" risk categories are to be assessed more profoundly and assessment should involve specific medical and biological examinations.

The methodology was tested successfully. The results proved that the selected approaches were relevant and that it was extremely important to collect complete and actual initial data of environment quality in zones influenced by AED objects.

Nina V. Zaitseva – Academician of the Russian Academy of Sciences, Doctor of Medical Sciences, Professor, Scientific Director (e-mail: znv@fcrisk.ru; tel.: +7 (342) 237-25-34; ORCID: https://orcid.org/0000-0003-2356-1145).

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

Svetlana V. Kleyn – Doctor of Medical Sciences, Head of the Department for Systemic Procedures of Sanitary-Hygienic Analysis and Monitoring (e-mail: kleyn@fcrisk.ru; tel.: +7 (342) 237-18-04; ORCID: https://orcid.org/0000-0002-2534-5713).

Dmitrii A. Kiryanov – Candidate of Technical Sciences, Head of the Department for Mathematical Modeling of Systems and Processes (e-mail: kda@fcrisk.ru; tel.: +7 (342) 237-18-04; ORCID: https://orcid.org/0000-0002-5406-4961).

Alena M. Andrishunas – Junior researcher at the Department for Systemic Procedures of Sanitary-Hygienic Analysis and Monitoring (e-mail: ama@fcrisk.ru; tel.: +7 (342) 237-18-04; ORCID: https://orcid.org/0000-0002-0072-5787).

Natalia N. Sliusar – Doctor of Technical Sciences, Associate Professor, Professor at the Department of Environmental Protection (e-mail: nnslyusar@gmail.com; tel.: +7 (342) 239-14-82; ORCID: https://orcid.org/0000-0003-0123-6907).

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).

Marat R. Kamaltdinov – Candidate of Physical and Mathematical Sciences, Senior researcher acting as the Head of the Department for Situation Modeling and Expert and Analytical Management Techniques Laboratory (e-mail: kmr@fcrisk.ru; tel.: +7 (342) 237-18-04; ORCID: http://orcid.org/0000-0003-0969-9252).

In 2022 approximately 192 objects are to be assessed; the express-evaluation is to be accomplished by experts of the Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing. As per the evaluation results, all AED objects are to be ranked and those creating the highest health risks are to be detected. The latter are to be eliminated immediately and complete profound assessment is to be performed at them.

Key words: *"General cleaning" Federal project, objects of accumulated environmental damage, population health, exposure assessment, algorithm and methodology.*

Long-term, variable and not always environmentally friendly anthropogenic activities have created a lot of objects which are located both on natural and highly urbanized areas. Some of them are no longer used but they still pollute the environment. In Russia these objects are called "objects of accumulated environmental damage" (AED objects) and are typically represented by brownfields; abandoned waste disposal landfills, industrial buildings or constructions; agricultural chemicals which haven't been utilized; semi-finished products or package which hasn't been salvaged etc. [1–3]. The problem exists practically in all developed countries and each of them creates its own system of legal and organizational solutions [4, 5]. There are some basic concepts accepted by states which have accumulated considerable experience in liquidating environmental damage created by past activities (Denmark[1], the Netherlands[2], Great Britain[3], etc.[4]):

– making those who are responsible for occurrence of AED objects provide finance for their elimination; making the state bear all the costs in case those at fault can't be found, are not solvent, or the limitation period has expired;

– making regional authorities bear the primary responsibility for discovering and eliminating such objects; in this case regional authorities have the right to issue their own legal documents in the sphere which take peculiarities of a given territory into account;

– making rehabilitation of certain territories the top priority; usually, the top priority is assigned to territories with their influence on the environment and human health causing the greatest concern. Other objects can remain sealed (but not eliminated) for a long period of time;

– mandatory examinations of a land spot aimed at detecting any hazardous chemicals when there are changes in its legal status or functional purpose;

– creating and keeping publicly available information resources (web-sites, registers, etc.) with comprehensive data on environmental conditions existing on a given territory.

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 included *"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"*. The Federal Law

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[1] Environmental Liability Directive Guidelines. *Environmental Protection Agency, Agency for Spatial and Environmental Planning*, 2012. Available at: https://ec.europa.eu/environment/legal/liability/pdf/eld_guidance/denmark.pdf (December 31, 2021).

[2] 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. Available at: https://ec.europa.eu/environment/legal/liability/pdf/eld_guidance/netherlands.pdf (December 31, 2021).

[3] The Environmental Damage (Prevention and Remediation) Regulations 2009. Guidance for England and Wales. *Department for Environment, Food and Rural Affairs (Defra)*, 2009. Available at: https://webarchive.nationalarchives.gov.uk/ukgwa/20130402151656/http://archive.defra.gov.uk/environment/policy/liability/pdf/indepth-guide-regs09.pdf (December 31, 2021).

[4] The Environmental Liability (Prevention and Remediation) Regulations (Northern Ireland) 2009. *Department of Environment for Northern Ireland (DOENI)*, 2009. Available at: https://www.legislation.gov.uk/nisr/2009/252/regulation/1/made (December 31, 2021).

[5] O vnesenii izmenenii v otdel'nye zakonodatel'nye akty Rossiiskoi Federatsii: Federal'nyi zakon ot 03.07.2016 № 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/ (January 24, 2022) (in Russian).

"On environmental protection"[6] was added a chapter (XIV.1) which regulated issues related to discovering, evaluating, accounting and eliminating accumulated environmental damage (AED).

The law stipulates that objects of accumulated environmental damage should be assigned into certain categories and priority ones are to be spotted out, *"the aim being to substantiate the order in which objects of accumulated environmental damage are to be eliminated and emergency measures are to be taken"* (item 6 in Clause 80.1 of the Federal Law No. 7-FZ). There are seven specific indicators which determine a category an object should be assigned into. Two of them should directly describe population exposure: *"a number of people living on a territory where the environment is under negative influence due to an object of accumulated environmental damage"* and *"a number of people living on a territory where there are environmental threats due to an object of accumulated environmental damage"*. Unfortunately, at present there are no unambiguous criteria to clearly identify "territories under negative influence by AED objects" or "territories where there are threats of such influence". We haven't been able to find them in any regulatory or methodical document, including the Order by the RF Ministry of the Natural Resources and the Environment issued on August 04, 2017 No. 435 "The criteria for determining a category of objects of accumulated environmental damage elimination of which is the top priority"[7]. Accordingly, it is extremely difficult to estimate how many people are directly exposed or threatened to be exposed by an AED object. It is also rather difficult to assess exposure essence and intensity.

But at the same time it is extremely vital to produce objective assessments regarding these issues. Most AED objects are located in close proximity to settlements (cities, urban settlements, or villages) since they were initially located either close to places where there were certain economic activities (industrial wastes disposal landfills, abandoned industrial sites, buildings and constructions, etc.) or places where people lived (tips and landfills for communal wastes disposal). Such objects often create chemical, biological, or radiation hazards for human health and can cause medical and demographic losses which are not taken into account in environmental criteria [6–8].

The "General cleaning" Federal project stipulates developing methodical guidelines on assessing risks of exposure to objects of accumulated environmental damage and their impacts on human health and life expectancy[8]. The purpose of the document is to create instruments for spotting out objects which can potentially exert the most considerable negative impacts on human health. The document doesn't cancel any environmental criteria; instead, it gives an opportunity to take into account certain aspects related to exposure to objects of accumulated environmental damage which have similar importance. These aspects are impacts on human health and life expectancy.

Our research goal was to develop and test methodical approaches stipulated by the federal legislation which made it possible to assess influence exerted by objects of accumu-

[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 last edition)]. *KonsultantPlus*. Available at: http://www.consultant.ru/document/cons_doc_LAW_34823/ (January 24, 2022) (in Russian).

[7] Ob utverzhdenii kriteriev i sroka kategorirovaniya ob"ektov, nakoplennyi vred okruzhayushchei srede na kotorykh podlezhit likvidatsii v pervoocherednom poryadke: Prikaz Ministerstva prirodnykh resursov i ekologii Rossiiskoi Federatsii ot 04.08.2017 № 435 [On Approval of the criteria and the term categorizing objects of accumulated environmental damage elimination of which is the top priority: The Order by the RF Ministry of Natural Resources and the Environment issued on August 4, 2017 No. 435]. *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/456089663 (January 24, 2022) (in Russian).

[8] Pasport federal'nogo proekta «General'naya uborka» [The profile of the "General cleaning" Federal project]. *The RF Government*. Available at: http://static.government.ru/media/files/DoFhF6zbaji5mAKgkefAjTssLoyUOyS.pdf (February 08, 2022) (in Russian).

lated environmental damage on human health and life expectancy.

Materials and methods. When developing these approaches, we took into account substantial experience accumulated in examining polluted, cluttered and other territories and objects which are considered to be "AED objects". We bore in mind that, when describing threats and hazards caused by objects of accumulated environmental damage, many experts stressed out the necessity to take into account the whole range of chemical ambient air pollution [9, 10], chemical and microbial contamination of soils [11–14] and surface water objects [15–17]. Some research works focused on significance of soil filtration parameters in soil profiles since they enabled correct predictive and analytical evaluation of pollution spread beyond landfills where liquid and semi-liquid wastes were accumulated and stored, including sludge accumulators [18, 19]. Recently, there have been a lot of discussions regarding threats and hazards imposed by objects of accumulated environmental damage in the Arctic zone [20–22]. It is also vital to give some attention to radiation safety of AED objects [23–25] etc.

As a result, we developed our methodology with an effort to create as a comprehensive list of indicators as possible trying to take into account all relevant ones which could describe influence exerted by an AED object on the environmental quality and human health.

We considered the fuzzy set theory (fuzzy logic theory) to be a relevant methodical basis for assessing impacts exerted by AED objects on human health and life expectancy [26]. Fuzzy logic methods are generally described in the standard[9] which was developed taking into account international approaches to risk management and risk assessment technologies. The reason we selected this method was that fuzzy sets modeling makes it possible to include both quantitative and qualitative variables into analysis, operates with fuzzy initial data with an opportunity to rapidly create models (including scenarios) of complicated dynamic situations and to perform comparative assessments with preset precision [27, 28].

To assess impacts exerted by each indicator on human health, we used scales to grade a health hazard taking into account weight contributions made by specific indicators and a group of indicators as a whole (component risks of a specific indicator and a group as a whole) and the aggregated risk of health disorders and shorter life expectancy for people who permanently live in a zone influenced by an AED object.

Impacts were assessed allowing for types and severity of potential functional disorders of critical organs and systems in the body under exposure to pollution created by a specific AED object. Critical organs and systems were defined in accordance with the methodical documents issued by the Federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing[10]. Severity of health disorders was determined based on data provided by the WHO and other relevant sources [29].

When developing the methodology, we took into account that AED objects were divided into several large groups (types) according to the Federal Law:

– territories where AED objects have been discovered;

– water areas where AED objects have been discovered;

– capital construction objects which are AED sources;

– wastes disposal landfills.

To assess exposure as correct as possible, we divided wastes disposal landfills into those where solid wastes were stored and those with liquid wastes.

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[9] State Standard GOST R 58771-2019. Risk management. Risk assessment technologies (approved and introduced by the Order of the Federal Agency on Technical Regulation and Metrology issued on December 17, 2019 No. 1405-st). *KODEKS: electronic fund for legal and reference documentation*. Available at: https://docs.cntd.ru/document/1200170253 (February 08, 2022) (in Russian).

[10] Rukovodstvo po otsenke riska dlya zdorov'ya naseleniya pri vozdeistvii khimicheskikh veshchestv, zagryaznyayushchikh okruzhayushchuyu sredu [Human Health Risk Assessment from Environmental Chemicals]. Moscow, The Federal Center for State Sanitary and Epidemiologic Surveillance of the RF Public Healthcare Ministry, 2004, 143 p. (in Russian).

Our methodical approaches involve two-stage assessment of impacts exerted by objects of accumulated environmental damage on human health and life expectancy:

– express evaluation that involves assessing impacts exerted on population using documents, results produced by single and/or sample measurements of the environmental quality, or general medical statistics;

– complete profound assessment that involves targeted examinations of population health under exposure to an AED object, peculiarities of exerted impacts taken into account.

Express evaluation was considered to be a procedure aimed at calculating comparative profiles for objects of different types, capacity, duration of existence, and with different impacts exerted on the environment and human health. Another purpose was to rank AED objects as per their potential impacts on human health and life expectancy in order to spot out objects which should be eliminated immediately, their elimination being the top priority.

Complete profound assessment involved verifying negative exposure levels calculated by express evaluation; accumulating evidence-based data on the actual medical and demographic losses over the period of an AED existence; and assessing actual effects, including economic ones, achieved due to elimination of an AED object in a post-project period (after an AED objects has been eliminated).

We suggested an algorithm to determine priorities as per population exposures which included the following steps:

– collecting as many data on an AED object as it is only possible;

– express evaluation of impacts exerted by an AED object on human health and life expectancy and calculating a value to describe risks of negative health outcomes;

– ranking objects as per risks of negative outcomes;

– spotting out objects belonging to categories of "high" and "extremely high" health risks.

Basic results. We developed a unified set of indicators (40 and more) to make a profile of each AED object highlighting peculiar influence exerted by it on environmental objects and how hazardous it was for human health.

The indicators were combined into several conditional groups:

– general profile of an AED object (duration of existence, a square of an AED object, volume/mass of accumulated wastes or a number of abandoned buildings and/or constructions, availability of an owner, location of an object in a permafrost area, how cluttered an area is around an AED object, etc.);

– climatic profile of a territory where an AED object is located (climate, frequency of winds blowing towards residential areas, precipitations, etc.);

– spatial characteristics of an AED object with respect to residential areas and places used by population (a distance to the closest settlement; a number of people who permanently live in a zone influenced by an AED object; existing sanitary protection zones; a distance to the closest water source; location of an AED objects regarding sanitary protection zones drinking water sources etc.);

– geological and hydrological parameters of a territory (subsoil types; how deep underground waters are located; existing waterproofing screens, dikes, derivation canals, etc.);

– quality of environmental objects in a zone influenced by an AED object (chemical, microbiological, and radiation indicators of ambient air quality, natural and drinking water quality, quality of soils and agricultural products grown in a zone influence by an AED object). This group also includes people's complaints about quality of environmental objects in a zone influenced by an AED object.

Negative effects produced by AED objects on human health are assessed as per the unified algorithm taking into account the whole set of potential threats and hazards which are typical for a given object. As a result, we obtain unified risk indicators which describe this negative influence on human health and life expectancy. These indicators make it possible to compare different AED objects and assign them into a specific risk category:

– 1st category (negligibly low risk of exposure);

– 2nd category (low risk);
– 3rd category (average risk);
– 4th category (high risk);
– 5th category (extremely high risk).

It is standard practice that if an object is assigned into high or extremely high risk category as per results produced by express evaluation, then it is advisable to perform complete profound assessment together with analyzing exposed population's health and creating an evidence base proving that health risks have actually been realized.

Express evaluation of impacts exerted by an AED object on human health and life expectancy relies on general profiles of AED objects, data on quality of the environment in a zone influenced by an AED object, and medical statistics about health of people who permanently live in a zone influenced by an AED object. Each relevant indicator is evaluated with interval values (ranges) and then assigned into a specific range on the scale with preset risk rates (negligibly low, low, moderate, high, and extremely high).

We suggest considering a zone influenced by an object of accumulated environmental damage as a territory (water area) described with a conditional boundary. This boundary is located at a distance equal to at least a twofold size of a sanitary protection zone of an object or up to 1 km downstream away from the boundary of a land spot an AED object is located on. Capital buildings or constructions for which sanitary protection zones are not stipulated in the sanitary classification are assigned into the 5th hazard category. The boundary of an influenced zone is considered to be located 100 meters away from the boundaries of a land spot where such an object is located.

Table 1 provides an example (a fragment) of an initial matrix applied to assess risks created by an object of accumulated environmental damage from the "solid wastes" group.

As we can see in the Table 1, quantitative indicators are given with a range of values which is divided into ranges with fuzzy boundaries. A number of such ranges is equal to a number of hazard categories. Using fuzzy sets involves a 20 % intersection of two neighboring ranges.

Each range of values for each quantitative indicator is a trapezoid fuzzy number with the membership function within a certain risk category which is given with four numbers (a_1, a_2, a_3, a_4). Generally the membership function for a value of an indicator is given as per the following formula (1):

$$\mu(x)=\begin{cases}0, & \text{if } x<a_1,\\ \dfrac{x-a_1}{a_2-a_1}, & \text{if } a_1\le x<a_2,\\ 1, & \text{if } a_2\le x\le a_3,\\ \dfrac{x-a_4}{a_3-a_4}, & \text{if } a_3<x\le a_4,\\ 0, & \text{if } x>a_4.\end{cases} \qquad (1)$$

Table 1

The list of indicators describing hazards caused by waste disposal landfills (solid chemical wastes) which are a source of accumulated environmental damage, hazard ranges provided: a fragment

Indicator	Unit of measurement	An AED object hazard category				
		Negligibly low	Low	Average	High	Extremely high
General profile of an AED object						
Duration of existence	years	[0; 2); [40; +∞]	(40; 30]	(30; 20]	(20; 10]	(10; 2]
Wastes mass / Wastes volume	thousand tons	[0; 50)	(50; 250]	(250; 500]	(500; 1000]	(1000; +∞)
Square of an object	hectares	[0; 0,1]	(0,1; 1]	(1; 100]	(100; 500]	(500; +∞)
A share of wastes from the 1st–3rd hazard category	%	(0; 10]	(10; 25]	(25; 40]	(40; 50]	(50; +∞)
A share of biologically degradable mass	%	[0; 10]	(10; 30]	(30; 60]	(60; 80]	(80; 100]
Carcinogenic and/or embryotoxic chemicals	–	no	no	yes	yes	yes

Table 1 (continued)

Indicator	Unit of measurement	An AED object hazard category				
		Negligibly low	Low	Average	High	Extremely high
Untreated medical wastes	–	no	no	no	no	yes
Wastes hazard category	–	[5]	[4; 5]	[3; 5]	[2; 5]	[1; 5]
Climatic profile of a territory where an AED object is located						
Permafrost	–	no	no	no	yes	yes
Climatic zone	zone	moderate	moderate	moderate	subtropical	arctic, subarctic
Precipitations	mm/year	[0; 800]	(800; 1000]	(1000; 1500]	(1500; 2000]	(2000; +∞)
Frequency of winds blowing towards at residential areas	%	[0; 5]	(5; 10]	(10; 20]	(20; 40]	(40; +∞)
Probability and scales of emergencies	–	no	no	no	yes	yes
Location in a zone where hazardous natural phenomena can occur	–	no	no	no	yes	yes
Spatial characteristics of an AED object with respect to residential areas and places used by population						
A distance to the closest settlement	m	(2000; +∞)	(1000; 2000]	(500; 1000]	[500; 0)	0
A number of people living in the closets settlement	thousand people	[0; 1]	(1; 5]	(5; 50]	(50; 100]	(100; +∞)
A distance to the closest water object	m	(1000; +∞)	[1000; 800]	(800; 500]	(500; 300]	[0; 300]
Location of an AED object regarding sanitary protection zones around water sources	–	Beyond SPZ	Beyond SPZ	In the 3rd subzone of SPZ	In the 2nd subzone of SPZ	In the 1st subzone of the SPZ
A distance from an AED object to a recreation zone/resort	m	(1500; +∞)	(1500; 1000]	(1000; 700]	(700; 300]	(300; –∞) / (300; within such a zone)
A distance to agricultural lands	m	(1000; +∞)	(500; 1000]	(300; 500]	[300; 0)	[0)
Incidence rates among population in the closest settlement against regional ones	times	[1]	(1; 1.2]	(1.2; 1.5]	(1.5; 2]	(2; +∞)
A number of people living in a zone which can potentially be polluted in case of emergency	Thousand people	[0; 1]	(1; 10]	(10; 40]	(40; 75]	(75; +∞)
Geological and hydrological parameters of a territory						
Subsoil filtration coefficient	m/sec	$1.0 \cdot 10^{-9}$	$1.0 \cdot 10^{-8}$	$1.0 \cdot 10^{-7}$	$1.0 \cdot 10^{-6}$	$1.0 \cdot 10^{-5}$
Depth of underground water occurrence	m	[5; +∞)	[4]	[3]	[1; 2]	[0; 1)
Quality of environmental objects						
Ambient air quality in a zone influenced by an AED object * (as per certain indicators)	shares of MPC or TSEL	[0; 0.5MPC]	(0.5MPC; 1MPC]	(1MPC; 2MPC]	(2MPC; 5MPC]	(5MPC; +∞)
People's complaints about ambient air quality	quantity/year	[0]	[0]	[1; 5)	(5; 10)	(10; +∞)
Drinking water quality in the closest settlements	measurement units	[0; BOR1]**	(BOR1; BOR2]	(BOR2; BOR3]	(BOR3; BOR4]	(BOR4; +∞)
People's complaints about drinking water quality	quantity/year	[0]	[0]	[1; 5)	(5; 10)	(10; +∞)
Soil quality	measurement units	[0; BOR1]**	(BOR1; BOR2]	(BOR2; BOR3]	(BOR3; BOR4]	(BOR4; +∞)
Quality of food products grown in a zone influenced by an AED object	measurement units	[0; BOR1]**	(BOR1; BOR2]	(BOR2; BOR3]	(BOR3; BOR4]	(BOR4; +∞)

N o t e : * The list of indicators is not ultimate and is determined only by specific features of an object and its influence on the environment; ** – BOR1, BOR2, BOR3, BOR4 are the upper limits of indicators describing quality of environmental objects in accordance with their belonging to 5 health risk categories accordingly.

For example, a value of an indicator is $x = 0.23$. If we consider the interval [0.2; 0.4], then a fuzzy number which corresponds to this section is equal to (0.16, 0.24, 0.32, 0.48), where $a_1 = 0.2{\cdot}0.80 = 0.16$, $a_2 = 0.2{\cdot}1.2 = 0.24$, $a_3 = 0.4{\cdot}0.8 = 0.32$, $a_4 = 0.4{\cdot}1.2 = 0.48$ (the interval boundaries were "blurred" by 20 %). Since $a_1 < 0.23 < a_2$, then the membership function value for the value of an indicator being $x = 0.23$, according to the formula (1), is equal to

$$\mu(x) = (0.23 - 0.16) / (0.24 - 0.16) = \\ = 0.07/0.08 = 0.875$$

This means that the examined indicator belongs to the given section by 87.5 %.

The value $\mu(x)$ describes belonging of a range for a value of an indicator within a corresponding hazard category.

The membership function is given as (2) for quantitative indicators:

$$\{x/\mu(x)\} = \\ = \{value1/\mu1, value2/\mu2, value3/\mu3, ...\} \quad (2)$$

Weights are fixed for each indicator or a group of indicators; they are taken into account when an aggregated risk of negative impacts is calculated. Weights fixed for groups of indicators are different for different types of AED objects and take into account their specific influence on the environment and human health.

If critical organs and systems are determined regarding a chemical and, accordingly, there are established average levels of severity for a given nosology (within a range from 0 to 1), then a weight is determined as per Fishburne's Rule [30] taking into account the most severe health disorder (3):

$$G\_l = (2\,(n-l+1)) / ((n+1)\,n), \quad (3)$$

where

G_l is a weight of an indicator for which critical organs or systems are determined (a negative response) holding the l-th rank as per their severity;

n is a total number of nosologies determined in the aggregated negative response;

l is a rank of a negative response (a nosology) as per its severity.

Initial tables which create a profile of a specific AED object are filled in based on available documents (project documentation, documents in the AED objects register, data taken from publicly available cadastre maps, research reports, test reports, expert examination reports, and other relevant ones).

Values of the membership function ($\mu(x)$) of each indicator falling within a certain hazard category are determined in accordance with preset scaling conditions as per the formulas (1)–(2).

A risk rate is calculated for each group of indicators as per the formula (4):

$$R_j = \sum_k \bar{R}_k w_{kj}, \quad (4)$$

where

R_j is a health risk rate caused by the j-th group of indicators;

w_{kj} is average weighted membership of the j-th group of parameters to the k-th hazard category;

$\bar{R}_k$ is the middle of a scale range corresponding to the k-th hazard category.

Average weighted membership of a group of indicators to hazard categories w_{kj} is determined as per the formula (5)

$$w_{kj} = \sum_{i \in j} G_i \, \mu_k(x_i), \quad (5)$$

where $\mu_k(x_i)$ is the membership function of the i-th indicator within the k-th hazard category; G_i is a weight of the i-th indicator.

Risk scale ranges and their middles are given in Table 2.

The aggregated risk (R) as per all the groups of indicators is calculated as per the following formula (6):

$$R = \sum_j R_j v_j, \quad (6)$$

where v_j is a weight contribution by the j-th group of indicators into the aggregated risk.

A weight contribution made by a group of indicators into the aggregated health risk is determined according to the Table 3.

A risk rate of harmful impacts on human health is used as a basis for AED objects ranking. An object is assigned into a specific risk category as per its impacts on human health depending on the membership of the value R determined for this object within a range given in Table 1.

Since a risk rate can be on a boundary between values and belong to two different ranges simultaneously (for example, R = 0.22 belongs simultaneously to the "moderate" range and "low" range), an AED object is ultimately assigned into a specific risk category in accordance with the procedure outlined in Table 4.

An AED object is assigned into a risk category which corresponds to the highest value of the membership function.

Table 2

Ranges on the risk rates scale and their mean values

Indicator	Health risk categories				
	Low	Moderate	Average	High	Extremely high
Range ($\overline{R}_k$)	(0; 0.25]	(0.15; 0.45]	(0.35; 0.65]	(0.55; 0.85]	(0.75; 1.0]
Mean value in range ($\overline{R}_k$)	0.125	0.3	0.5	0.7	0.875

Table 3

Weights for groups of indicators describing different types of AED objects

Groups of indicators	Solid wastes	Liquid chemical industrial wastes	Liquid organic wastes	Capital buildings and constructions	Territories	Water areas
General profile	0.1	0.1	0.1	0.15	0.1	0.1
Climatic profile	0.1	0.1	0.1	0.1	0.1	0.1
Spatial characteristics	0.3	0.3	0.3	0.3	0.3	0.4
Geological and hydrological parameters	0.15	0.25	0.2	0.35	0.15	0
Quality of environmental objects	0.35	0.25	0.3	0.1	0.35	0.4

Table 4

A scale with ranges of rates and health risk categories

A range of health risk rates	The membership function for a risk rate falling within a specific range on the scale	Health risk category
[0; 0.25]	$\mu_1(R)=\begin{cases}1, & \text{if} \quad 0 \le R \le 0.15,\\ 10(0.25-R), & \text{if} \quad 0.15 \le R \le 0.25\end{cases}$	Low
(0.15; 0.45]	$\mu_2(R)=\begin{cases}1-10(0.25-R), & \text{if} \quad 0.15 \le R \le 0.25,\\ 1, & \text{if} \quad 0.25 \le R \le 0.35,\\ 10(0.45-R), & \text{if} \quad 0.35 \le R \le 0.45\end{cases}$	Moderate
(0.35; 0.65]	$\mu_3(R)=\begin{cases}1-10(0.45-R), & \text{if} \quad 0.35 \le R \le 0.45,\\ 1, & \text{if} \quad 0.45 \le R \le 0.55,\\ 10(0.65-R), & \text{if} \quad 0.55 \le R \le 0.65\end{cases}$	Average
(0.55; 0.85]	$\mu_4(R)=\begin{cases}1-10(0.65-R), & \text{if} \quad 0.55 \le R \le 0.65,\\ 1, & \text{if} \quad 0.65 \le R \le 0.75,\\ 10(0.85-R), & \text{if} \quad 0.75 \le R \le 0.85\end{cases}$	High
[0.75; 1]	$\mu_5(R)=\begin{cases}1-10(0.85-R), & \text{if} \quad 0.75 \le R \le 0.85,\\ 1, & \text{if} \quad 0.85 \le R \le 1\end{cases}$	Extremely high

Table 5

Results produced by express evaluation of several objects of accumulated environmental damage; the evaluation was accomplished when methodical approaches were being tested

An object of accumulated environmental damage	General profile	Climatic profile	Spatial characteristics	Geological and hydrological parameters	Quality of environmental objects	Risk rate	Risk category	Rank of an object
Sludge accumulator of a former chemical plant located within a settlement	0.21	0.11	0.15	0.06	0.33	0.86	Extremely high	1
Sludge landfill in a city	0.09	0.15	0.11	0.17	0.02	0.54	Average	2
Solid communal wastes dump close to an urban settlement	0.08	0.14	0.08	0.02	0.19	0.51	Average	3
Inert industrial wastes landfill at a boundary of a settlement	0.05	0.14	0.10	0.01	0.05	0.35	Average	4
Solid communal wastes dump beyond a boundary of a rural settlement	0.06	0.14	0.02	0.01	0.02	0.25	Moderate	5
Abandoned building beyond a boundary of a rural settlement	0.00	0.09	0.01	0.01	0.01	0.12	Low	6

We assessed probable effects such as changes in life expectancy of people who permanently lived in a zone influenced by a long existing AED object. The assessment was based on relationships determined by epidemiological studies [31, 32].

A probable change in life expectancy is assessed for a specific AED object with an established risk rate of harmful impacts on health as per the following formula (7):

$$\Delta LE = R \cdot K, \qquad (7)$$

where

ΔLE is a probable decrease in average life expectancy (LE) due to impacts exerted on health by an AED object;

R is the aggregated health risk calculated taking all the groups of indicators into account;

K is the coefficient showing actual risk realization as a change in life expectancy calculated on the basis of analyzing relevant scientific literature; $K = 1.6$.

Assessment of impacts exerted by AED objects on human health and life expectancy gives grounds for ranking them in order to determine priority ones which should be eliminated immediately.

Table 5 provides the results produced by tentative express evaluation of several AED objects with initial data on them being available to us at the moment we were developing our methodical approaches.

These results, according to expert estimates, provide relevant evaluation of the examined objects. But at the same time, when testing our methodical approaches, we revealed that initial data had certain drawbacks. One of them was that there were very few or even almost no indicators which described quality of the environmental objects. Given that, we can set a priority task which has to be tackled by Rospotrebnadzor's authorities and institutions which are responsible for performing express evaluation of AED objects. This task is to accomplish comprehensive analysis of historical data on abandoned objects or to perform instrumental research of ambient air quality, quality of natural and drinking water, and quality of soils, primarily, agricultural ones, in a zone influenced by an AED object.

If an AED object is assigned into high or extremely high risk category as per results produced by express evaluation, then complete profound assessment is to be performed at it with the focus on its impacts on human health and life expectancy.

By now substantial experience has been accumulated in Russia in performing specific studies with their focus on determining health risks caused by exposure to harmful environmental sources and factors [33–35].

An adverse impact which is a health disorder among people from risk groups living in a zone exposed to an AED object is proven by target studies focusing on human health. These studies can concentrate both on organs and systems determined as critical ones for certain exposure and on etiopathogenetic mechanisms of harmful effects developing under aggregated exposure.

Complete profound assessment gives a possibility to describe a degree and a scale of actual aggregated influence exerted by an AED object on human health and life expectancy. Health studies provide the maximum objectivity in assessing health damage, reduce social tension and help develop and implement recommendations on medical and preventive activities aimed at protecting people's health until an AED object is eliminated completely.

The suggested mathematical apparatus is implemented as a software set of instruments for automated risk calculation after all the initial data have been input.

These methodical approaches are to be tested in this year. As it is stated in the profile of the "General cleaning" Federal project (item 1.4.)[8], express evaluation is to be performed at approximately 192 AED objects by experts of the federal Service for Surveillance over Consumer Rights Protection and Human Wellbeing. The evaluation is to be based on data taken from external sources as well as results produced by studies, examinations, and instrumental measurements performed by the Service itself.

All the examined objects of the accumulated environmental damage are to be ranked according to the results produced by the accomplished express evaluation and those which create the highest risks for human health are to be spotted out. These objects should be eliminated immediately, their elimination being the top priority. Profound medical examinations will be recommended for people living in zones influenced by some AED objects which create high and extremely high health risks.

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