Waste management peculiarities in far north from the perspective of environmental hazard and emergency prevention

Yuri Shishkov, Irina Oltyan, Eduard Tshovrebov, Alexey Gordienko, Tatyana Sereda

Abstract. The paper considers the peculiarities of waste management in the system of housing and communal services of the northern regions of Russia in the conditions of permafrost and harsh climatic conditions. The authors have studied the topical issues from the point of view of preventing environmental hazards and emergencies of manmade character. Thus, the aim of the present study was to develop scientifically substantiated proposals for the prevention of environmental hazards and emergencies in the regions of the Arctic zone, as well as adjacent territories of the subjects of the Russian Federation, caused by man-made impact of waste. The conducted research with conclusions and recommendations according to its results are carried out on the basis of the developed forecast and within the framework of the chosen scenarios of development of the situation with waste management on ecologically vulnerable territories. In order to achieve the goal of the research, the following scientific and applied tasks have been solved: a systematic analysis of the hazardous waste management situation in the Far North; identification of dangerous environmental factors and threats, which may contribute to emergencies with irreversible consequences for the environment, population and economic development of the Arctic; scientific justification of proposals for the prevention of technospheric impact of waste through the transition of regions to resource-saving. The results of the study can be used in the development and updating of concepts, federal target, regional programs in the field of environmental security, prevention of man-made emergencies in the process of life support regions of the Far North, the northern part of Siberia, the Urals, the Far East.

1 Introduction

A special role in the sustainable socio-economic development of the Arctic zone is played by the issues of environmental protection, protection of population and territories from emergency situations [1-5].

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The development of a comprehensive system of waste management, the construction of modern environmentally friendly waste processing complexes is defined as "the main task in the sphere of environmental protection and environmental safety" in the Foundations of State Policy of the Russian Federation in the Arctic for the period up to 2035.

The assignment of this task to the category of strategic ones is connected with the fact that the management of hazardous wastes in the environmentally vulnerable Arctic zone becomes an actual social and environmental problem, directly determining the state of protection of nature, population and territories from man-made threats and risks, emergencies and their possible consequences.

According to the approved territorial schemes of waste management and regional reports on the state of the environment, about 2.4 million people live on the territory of the Arctic zone of Russia on the area of 3.7 million sq. km. In a number of regions, within the boundaries of the marked territory, there are urban districts and settlements with the lack of stable transport and information communication with the "big land". For example, in more than 30 settlements of the Yamalo-Nenets Okrug there are about 500 people who generate the products of their life activity in the form of waste of different degree of environmental hazard: municipal solid waste (MSW), construction, fuel, metallurgical slags, mining and ore processing, electronic and electrical equipment (EEE) [6-9].

The main method of waste disposal is disposal in landfills and dumps. Thus, as of 2018, there were 44 landfills in Chukotka, 18 landfills and 700 unauthorized dumps in the Murmansk region, and one official landfill and more than 40 small dumps in the Nenets Okrug. Part of the rubbish was removed within the framework of national projects and regional environmental programmes. At the same time, the coastline and a number of islands in the Arctic are significantly littered with construction and industrial waste, scrap metal, containers, tanks with oil products, chemicals [7-9]. This state of affairs creates a real threat of large-scale technogenic emergencies with extremely dangerous socio-economic and ecological consequences for the natural environment and the population.

Despite the adopted national and regional strategies, projects, programmes to improve the ecological situation, which led to the liquidation of a number of dumps, the problem of environmentally safe waste management has not been solved in its essence. Toxic wastes continue to be generated and buried in the permafrost, posing a threat to permafrost soils, flowing water bodies, hydraulically connected with the world ocean.

Taking into account the current complicated ecological situation, scientists and specialists of the Federal Centre of High Technologies of the All-Russian Research Institute of Civil Defense, Emercom of Russia, based on many years of research and accumulated experience in monitoring, forecasting and prevention of emergencies caused by negative impact of toxic waste on the environment in the north-west of the suburbs of Moscow.

The present paper proposes a number of organisational, managerial, technical and economic approaches and solutions, which can radically improve the environmental situation in the vulnerable territories of the Far North.

2 Materials and methods

The materials for the study were: published works of the authors, own research results in the field of sustainable development, resource conservation, rational nature management, environmental safety of population and territories, forecasting and prevention of man-made emergencies.

The research strategy correlates with the principles accepted in the international community: "Zerowaste" (zero waste), reuse, recycling into secondary resources), "Circular economy" (closed-loop economy) [10-14], acts as a development of domestic paradigms and...
3 Results and discussion

Systemic analysis of the negative impact of technosphere objects on the permafrost condition has shown that waste management in the Arctic territories under the conditions of constantly changing climate and hazardous natural processes has its own specific features. Environmentally vulnerable territories of the Far North are dangerously affected by landfills and unauthorized dumps of solid waste and similar wastes in the form of negative mechanical, chemical, biological, physical impact on the permafrost ecosystem, contributing to its steady melting, pollution, destruction as an established habitat of fauna and aquatic bioresources.

The principles of ecologically safe waste management in the Arctic zone differ considerably from those adopted in regions with less severe climate due to the presence of natural phenomena specific for these territories, climatic, geographical peculiarities, – low air temperatures; – high wind and snow loads and the potential for snowstorms, blizzards; – presence of permafrost soils in lithosphere and lack of fertile soils in most of them; – scattered sources of waste generation, due to low population density living in small urban and rural settlements and shift work methods; – organisational and technical problems of selective collection and primary treatment of solid waste caused by climatic conditions; – underdeveloped road transport and logistics infrastructure, information communications; – remoteness from the places of possible utilization and reuse of solid waste recycling products and similar wastes.

Thus, factors of unsafe waste disposal in the permafrost zone are caused by the absence of fertile soils and extremely low temperatures, which prevents the natural biological decomposition of waste in the absence of the necessary active microorganisms' activity. The situation is even worse for the major groups of hazardous wastes that have almost no decomposition processes under these conditions: plastics, scrap metals, minerals (especially silica), plastics and ceramics (primarily silicate and glass breakage).

Even inert waste piles with the area of 10 and more square meters, such as: metal, wooden, polymer chips and sawdust, coal dust, suspensions, crumbs, fuel ashes and slags having only mechanical impact on the lithosphere under the influence of sunlight, rotting processes, heating, temperature difference lead to reduction of ice particles adhesion forces, melting of the snow-ice cover.

Some technological developments in environmental protection, for example, cementation, concreting of the enclosing structures of waste disposal facilities, have not given positive results in terms of increasing the level of ecological safety of waste disposal facilities either. The destruction of such constructions under the influence of low temperatures or their difference, together with the falling into the pores and cracks of the liquid reactive substance of the leachate of the decaying waste, led only to the additional quantity of the contaminated mineral construction waste. Fencing of landfills by dikes with impervious compacted frozen ground under conditions of reactive environment, temperature differences and steady warming also leads to destruction of such facilities with the subsequent formation of polluted...
Surface runoff, naturally leaking into tundra ecosystems, including: frozen ground, natural landscapes, river basins and, eventually, into the world's oceans.

Some waste management operators and communal services did not contribute to sanitary and environmental safety by storing waste in sealed plastic bags and containers. The smell of food waste attracted the keen sense of smell, and the glare of broken glass, mirrors and metal reflected through the bags accentuated the keen eyesight of predatory animals and birds who easily tore open such containers and scavenged for prey. As practice showed, not all polymeric materials could withstand low temperatures, or the temperature difference between the dark bag heated by sunlight and the ambient frosty air (more than 20-30°C), which naturally led to the destruction of toxic waste storage bins.

The disposal of solid municipal, construction and other wastes in mines and rock dumps in the cryolithic zone, as shown by long-term geoecological studies of the lithosphere of the Arctic territories (areas of the cities of Neryungri, Vorkuta, Longyear, Apatity). Neryungri, Vorkuta, Longyear, Apatity), under the influence of temperature and reaction processes, can cause deterioration of hardness and strength characteristics of the ice-loam base of these natural-anthropogenic objects, threat of fractures, lithosphere fractures, ingress of toxic leachate into ground and surface waters.

In connection with the above, the storage or burial of non-degradable solid municipal, construction and other wastes in permafrost soils is extremely dangerous from the environmental, sanitary and epidemiological points of view. It is even more problematic to locate thermal waste disposal facilities taking into account the geological, climatic and other features of permafrost. Due to the presence of more than 20% of polymer, wood, paper, mineral-polymer waste in the waste, medium-temperature incineration (up to 800-1100°C) is unacceptable due to the threat of spreading extremely toxic dioxins, dibenzofurans, formaldehyde and other compounds destructive for people and biorganisms. For the same reason the use of RDF, made from shredded and compacted household waste containing polymer particles, is extremely dangerous for the public.

The construction of high-temperature waste incineration facilities, with the thermal treatment temperature between 1250 and 1300°C, is not financially and economically feasible due to the unbalanced and uneven flows of mixed waste and the long distances to transport them. In addition there is a need for disposal of moderately toxic incineration slag in the amount of about 25% of the incoming waste.

The study reveals that some of the unresolved problems are inaccurate source accounting system, lack of consistent approaches to the qualification of the morphological composition of waste produced, unpreparedness of the monitoring and forecasting system of technosphere hazard to possible scenarios of adverse situations that could escalate into emergencies.

Comparative average indicators of the morphological composition of waste generated in some regions of the Far North (according to the materials of territorial waste management schemes) are given in table 1.

<table>
<thead>
<tr>
<th>Table 1. Comparative average indicators of the morphological composition of MSW in a number of regions of the Far North</th>
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<tbody>
<tr>
<td>Waste components</td>
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<tr>
<td>Food waste</td>
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<tr>
<td>Paper, cardboard</td>
</tr>
<tr>
<td>Wood</td>
</tr>
<tr>
<td>Metal ferrous and non-ferrous</td>
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<tr>
<td>Textiles</td>
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<tr>
<td>Glass</td>
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As follows from the results of the comparative analysis of the morphological composition of MSW, with similar systems of management and life support, the scatter of indicators on various items is 200-600%. The reason for that is absence of a clear, scientifically and methodologically grounded system of classification and qualification of resource components of wastes by types, morphological composition, hazard factors, directions, and restrictions of their reuse. Thus, containing moderately and highly toxic complex compounds of paper, mineral, wood-polymer waste (chipboard, fibreboard, fibreboard, linoleum, plywood, organolite, fiberglass, wallpaper, polymer-coated packaging, etc.) in different regions and municipalities refer to different categories of morphology: waste paper, wood, polymers, mineral, glass, other. Such waste ends up in medium temperature incineration and burial, causing irreparable damage to the natural environment and public health.

Scientists and specialists of the All-Russian Research Institute for Emergency Situations of the Russian Ministry for Emergency Situations worked out a preliminary tentative mid-term and long-term forecast of dynamics of the technosphere situation in these ecologically vulnerable zones, which showed that the problem of existing rubbish dumps, which are already overfilled or will be filled in the coming years, will significantly worsen. The analysis of the situation showed that due to the lack of cost-effective, environmentally and hygienically safe organisational and technical systems for separate collection, isolated waste accumulation, technologies for reclamation of disposal sites, landfills will continue to attract polar bears, foxes, other animals and birds that are potential carriers of dangerous pathogens. This may provoke a worsening of the epidemic situation with extreme consequences for the population.

In developing the forecast, it was taken into account that the landfills and dumps operated for decades were designed for a stable permafrost condition. However, trends and processes of climate change and annual increases in average annual temperatures are leading to permafrost melting phenomena. While scientists have different approaches to estimating the rate and intensity of permafrost melting, the forecast takes into account their unanimous opinion in one thing—permafrost in the Arctic zone will not be eternal, i.e. in the nearest 10-30 years the area of permafrost will significantly decrease and, as a consequence, wastes that have not lost their toxic, reactive and biologically dangerous properties will start to decompose and poison the soil and tundra waters. Under these conditions, national and global emergencies are predicted. Such a scenario, which we must prevent already today, now, is qualified by scientists of the institute as catastrophic.

According to All-Russian Research Institute for Civil Defence and Emergencies of the Russian Ministry of Emergency Situations, scientists, the Russian Arctic needs a completely different scenario—an innovative technological breakthrough, optimal, effective, scientifically grounded solutions for environmentally safe waste management based on the principles of energy and resource saving, involvement of useful secondary resources of used life items into economic turnover.

The primary thing in this process is clearly organised ecologically safe system of selective collection of useful resource elements of solid wastes from enterprises and population, their isolated accumulation with elements of primary processing (cleaning, sorting, separation) in specially determined places on condition of prevention of negative impact on the environment.

As a pilot project for adaptation in the conditions of the Arctic zone the organizational and technical scheme of selective collection of waste from the population and economic
Table 2. Classification scheme of the material composition, origin of the resource component of the used products

<table>
<thead>
<tr>
<th>Categories of secondary resources</th>
<th>Resource components of used products in the life support system involved in economic turnover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime, chalk, gypsum, asbestos, glass</td>
<td></td>
</tr>
<tr>
<td>Paper and cardboard</td>
<td>Packaging paper, cardboard, corrugated cardboard unpolluted.</td>
</tr>
<tr>
<td>Textile</td>
<td>Rope and rope products made of natural fibers. Used clothing made of natural fibers, including those intended for use as rags. Scraps, scraps of linen, cotton, wool and other mixed natural fabrics. Used sailors, blankets, pillows made of natural fibers. Scraps of felting and felt products.</td>
</tr>
</tbody>
</table>
clothing, shoes, protective equipment, rags contaminated in the mixture, containers, packaging, accessories. Tools contaminated in the mixture.

The analogue model for the organisation of a resource-recovery system for the collection and accumulation of the resource component of waste from households and enterprises, based on the above classification, is shown schematically in Figure 1.

Fig. 1.

Resource component of anthropogenic objects of the life support system

- Biodegradable (food, sewage, biological)
- Scrap metal (MET)
- Mineral (M)
- Glass (cement, gypsum, clay-asbestos, lime, chalk, asphalt-containing)
- Combustible SER of categories W, T, PC from collection sites or residues after processing
- Secondary raw materials for the production of products, works
- Secondary resources of categories P, PC, T, W - for use as secondary raw materials
- Medium-temperature energy utilization
- High-temperature energy utilization
- Combustible SER categories OSP, P, C
- Combustible organic and synthetic resource component
- Solid non-metallic resource component
- Solid resource component

The principal difference of new developments consists in scientific and methodological substantiation of organizational and technical solutions for prevention of environmental hazard at the source of its origin - at the early stages of disposal, design of facilities by technological transformation into useful secondary resources.

The main priority of the implementation of the developed organizational and technical schemes is the focus on the final technical, economic and environmental-resource result - the prevention of hazardous waste at source through the optimal schemes of separate collection, isolated accumulation, pretreatment and maximum involvement in economic turnover of secondary raw materials and alternative energy sources obtained by reuse of the resource component of municipal solid waste without

The developed scheme will allow initially to separate and delimit the flows of:

a) non-combustible recyclable mineral SMR (scrap concrete, reinforced concrete, bricks, hardened cement, ceramics, crushed stone, gravel, glass, lime);

b) non-combustible, non-disposable VMR of mineral origin for recultivative, transferring (at the landfills), preparatory, road and other similar works (mineral suspensions, soil, clay, boiler water treatment sludge, ash and slag, small construction waste);

c) sorted combustible OMW intended as secondary raw material for reuse in economic turnover (polymers of different kinds, natural wood, paper, cardboard, textile)
The proposed organisational and technical scheme, as applied to the Arctic zone, will help to prevent significant costs of processing unsorted wastes of various hazard levels, irrational resource and raw material transport flows, thus ensuring a significant (up to 70-75%) reduction in the amount of unmixed wastes received for high-temperature disposal or burial.

The study reveals that, if the proposed organizational and technical scheme of separate collection, isolated accumulation and pretreatment of resource components in the sources of formation is organized, most of the waste buried in the frozen ground can become a resource source for obtaining various highly needed products for the population life support and equipment of the emergency response system (Table 3). Given the difficult transport accessibility, inconstant logistics chains, ultra-high transport costs of delivery to the far northern territories, such solutions are extremely necessary for the livelihood of the population during everyday life and in the event of any kind of emergency.

Table 3. The use of secondary raw materials for the production of products and works for the elimination of emergencies

<table>
<thead>
<tr>
<th>Names of some products for monitoring, emergency response, life support during emergencies</th>
<th>Potentially usable secondary raw materials from recycled production and consumption waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical fibres for various protective and household products</td>
<td>Polyethylene terephthalate (PET), polyamide, polyacrylonitrile, polypropylene</td>
</tr>
<tr>
<td>Standard barrier boom</td>
<td>Polyvinyl chloride</td>
</tr>
<tr>
<td>Sorbent chemical fabric for petroleum products, acids, alkalis</td>
<td>Polypropylene</td>
</tr>
<tr>
<td>Wiping cloths for removing petroleum products, acids, alkalis</td>
<td>Polypropylene</td>
</tr>
<tr>
<td>Sorbent barrier booms for chemicals, petroleum products</td>
<td>Polymer-mineral fibre from polyamide, polyethylene, polypropylene, polyester with the addition of silicates (fuel ash, crushed slag)</td>
</tr>
<tr>
<td>Drainage trap-sorbent mat</td>
<td>Polypropylene, polyethylene</td>
</tr>
<tr>
<td>Sorbent dipping booms</td>
<td>Polypropylene</td>
</tr>
<tr>
<td>Woven polypropylene bags</td>
<td>Polypropylene and its copolymers</td>
</tr>
<tr>
<td>Track maintenance mat for railroad tracks</td>
<td>Polypropylene, polyethylene</td>
</tr>
<tr>
<td>Pressed mineral-filled booms</td>
<td>Crushed fuel slag, plastic bags (polyethylene sleeve film-polyethylene-polymer composites)</td>
</tr>
<tr>
<td>Sorbents for the collection of petroleum products</td>
<td>Peat sphagnum moss, mineral granulated fibres, polypropylene fibres, active coal from waste fuel ashes, slags, coal mining, oil shale, tyres, tyres</td>
</tr>
<tr>
<td>Gas masks, filtering load</td>
<td>Active carbon, polymer products</td>
</tr>
<tr>
<td>Bags for gas masks, first aid kits, instruments, tools, oil and chemical collection tanks</td>
<td>PET, polystyrene, polyethylene, polypropylene</td>
</tr>
<tr>
<td>Fire hoses</td>
<td>Rubberised, synthetic fabrics, latex, rubber residues and trimmings</td>
</tr>
<tr>
<td>Sleeves for transferring petroleum products, oily water impact</td>
<td>Impact-resistant polyvinyl chloride, butadiene nitrile rubber, scrap metal reinforcing wire</td>
</tr>
<tr>
<td>Deactivatable protective polymer coatings</td>
<td>Polyethylene, polypropylene</td>
</tr>
</tbody>
</table>
4 Conclusion

In the creation of waste collection, treatment and disposal complexes, it seems particularly important to maximize the involvement of local communities, small and medium-sized businesses interested not only in improving their well-being and material well-being, but also in the favourable living conditions and safety of the environment. Another socio-environmental aspect could be an important way of ensuring that the natural environment and Arctic territories are protected from environmental hazards and emergencies. Continuous feedback from the population on pressing socio-ecological problems, sociological studies, public hearings and active involvement of indigenous representatives into environmental and resource-saving business processes will ensure an increase in the level of environmental safety of the territories and water areas of the Far North. It is the indigenous population, primarily those leading a nomadic or semi-nomadic way of life, carrying out traditional economic activities, who are the most qualified and motivated citizens in protecting the assets of their native environment and life activities, improving its safety, quality and attractiveness.

In the harsh conditions of Arctic life, only the indigenous population can most accurately, timely draw the attention of and inform the authorities about the negative landscape or technosphere changes occurring in their places of residence, activities and behaviour of non-native inhabitants.

According to the authors of the paper, the resource-efficient way of environmentally safe life support of permafrost territories serves as an organizational and technological basis for the support of permafrost territories. The use of renewable resources, energy efficiency, and the development of technologies that minimize environmental impact can play a crucial role in achieving these goals.

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The scientific and methodological basis for decision-making in the field of environmental safety and prevention of environmental emergencies can be a well-grounded comprehensive forecast of the environmentally safe state of the Arctic zone, taking into account the relationship between all kinds of phenomena, processes and factors, based on the developed criteria of potentially dangerous situations and emergencies, integrated and localized in relation to the conditions and limitations of economic activities in the areas of permafrost.

The Russian Ministry for Emergency Situations is ready to develop such a comprehensive forecast as part of a national project, federal state or interregional programme for the development of the Russian Arctic.

As part of updating the legal support in the Special Arctic Economic Zone, it is proposed to develop a package of documents in the area of:

- Creation and prospective development of organizational and technological infrastructure of the cluster-type environmentally safe selective collection, isolated accumulation, reuse of secondary resources, administration and subsidizing of these activities;
- Formation of a special program for this ecologically vulnerable area of a comprehensive system of monitoring and forecasting of environmental threats, emergencies and their possible consequences;
- Development of methodological recommendations and standardization documents in the field of forecasting environmental threats and hazards within the framework of the established system of integrated monitoring of the Arctic zone, the concept of environmentally safe development of the Far North.

It seems necessary to develop and approve a roadmap for the formation of a comprehensive programme for the prevention of man-made emergencies at the interregional level in the Arctic zone of the Russian Federation, the main methodological tool for the implementation of which will be substantiated criteria and marker indicators of adverse condition of territories due to the environmental hazard caused by waste exposure. The aim of the proposed programme is to consolidate strategically important areas for ensuring environmental safety and preventing environmental emergencies in the system with the economic development of the Arctic zone in terms of the possibility of obtaining additional demanded raw materials, alternative energy sources from secondary resources of used products in the population areas of the Far North, the northern part of the Siberian, Ural and Far Eastern Federal Districts.

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