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Review article

Economic Geology

Cadastral registration of technogenic mineral formations in Russia: genesis and development issues

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Abstract

The problem of placing vast quantities of accumulated waste on the Earth's surface – with the mining industry and its associated processing facilities accounting for the largest share – underscores the need to improve the information support systems for waste management. The aim of this study is to substantiate and analyze materials characterizing the cadastral registration of technogenic mineral formations (TMF) and to develop measures to improve cadastral development activities. The information base of the study consists of data from scientific databases, materials from scientific reports and analytical papers, as well as regulatory and legal sources. The theoretical and procedural basis of the study comprises the systems approach, as well as methods of structural analysis, analogy, generalization and systematization, comparison, grouping, and logical-economic analysis. The study focuses on the period from the 1920s to the present. The study demonstrates the link between the approaches to data collection for cadastral registration and the classification criteria used for TMF and technogenic deposits (TD). Based on an analysis of classifications of TMF, TD and classification of facilities having a negative impact on the environment, the fundamental classification criteria regarding waste have been substantiated. The article outlines the evolutionary changes in the content of cadaster and identifies the stages in development of cadastral registration in Russia. The article also demonstrates the need to expand the information base by taking into account the following factors: the environmental situation of the area where the TMF is located; mineral associations with sulfate-bearing ores and their oxidation; and economic indicators – specifically, the economic damage associated with the TMF. Furthermore, the paper justifies the need to establish eight information blocks within the cadasters and proposes an algorithm for their construction. The study also offers proposals for improving the cadastral registration of TMF, thereby enhancing the information support for activities related to their formation and use.

Keywords

cadaster; classification; technogenic mineral formations; technogenic deposits; waste; industrial waste; content; algorithm; information support

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Introduction

A serious problem for industry today is the presence of a significant mass of production and consumption waste, which experts estimate at 80-100 billion tons [1-3]. Moreover, the vast majority of them (97-98 %) consist of waste from mining and related processing operations [4-6]. A negative factor is the continuous accumulation of technogenic mineral formations (TMF), driven on the one hand by the growing annual volume of TMF generation and on the other by their insufficient utilization rate

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(no more than 47-49 %) [7-9]. The increase in the volume of TMF generated is determined by a number of factors, including the growing share of open-pit mining, insufficient geological knowledge, and others [10-12]. The most significant among them is the extensification of mineral resource extraction [13-15]. A number of factors also account for the low level of TMF utilization. It is considered that this is primarily driven by inadequacies in the legal framework governing the geological study [16-18], licensing, and exploitation of anthropogenic deposits [8, 19, 20], as well as the lack of a full range of technologies for processing anthropogenic raw materials [21-23]. At the same time, one should not overlook the shortcomings in information support and the lack of sufficient information regarding the state of technogenic formations, the potential environmental and economic efficiency of their utilization [8, 24, 25], the availability of environmentally safe technologies [26-28], etc.

The lack of comprehensive information regarding TMF is largely attributable to insufficient attention paid to them by industry professionals and the scientific community [29-31], despite the fact that both fundamental [32-34] and specific, practice-oriented studies [35-37] have demonstrated the adverse impact of technogenic massifs associated with the mineral resource sector. As indicated by study [38], attention to TMF remained superficial for a long time, during which the requirement for the comprehensive utilization of raw materials-including the incorporation of technogenic deposits into economic circulation was not implemented [39, 40]. The gradual consolidation of the position of TMF dates only to the beginning of the 21st century [9, 41] (the concepts of cleaner production and the circular economy [42-44]). During this period, TMF began to be viewed as a source for expanding the mineral resource base. They are shifting from the category of secondary objects of subsoil use regulation to that of primary ones. They are gaining increasing importance as a source for expanding the mineral resource base, with the mineral-resource aspect becoming their defining characteristic.

The rational use of TMF requires new research, as well as the synthesis and systematization of information to support decision-making regarding their use. Establishing an accounting system is made possible by the development of cadasters – specifically, in the context of mining operations, by creating cadasters of TMF and technogenic deposits (TD). Thus, the aim of this study is to substantiate and analyze materials characterizing the cadastral registration of TMF and to develop measures to improve cadastral registration in Russia. Achieving this goal required setting the following research objectives:

• to identify basic classification criteria for waste based on an analysis of the classifications of TMF, TD, and facilities with a negative environmental impact;

• to review publications and the regulatory framework regarding the evolution of cadastral registration in Russia and identify the key stages;

• to identify fundamental trends and issues in the improvement of TMF and TD cadasters in Russia;

• to develop an algorithm for compiling a TMF cadaster and a general information structure for TMF and TD cadasters. This algorithm and structure are designed to eliminate the identified problems and shortcomings of current cadastral registration.

Materials and methods

Information sources were compiled taking into account the interdisciplinary nature of the issues surrounding the handling of TMF and TD. The information base was compiled from publications in the RSCI scientometric databases (which include research from Scopus and WoS) and ResearchGate; materials from scientific and analytical reports hosted on the portal of the Unified State information system for accounting research, development, and technological activities for civil purposes (USIS ARDTACP) and held in the collections of the V.G.Belinsky Sverdlovsk regional scientific library (Yekaterinburg) and the Empress Catherine II Saint Petersburg Mining University; as well as

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regulatory and legal sources from the Consultant Plus database. At the data collection stage, a systematic review methodology [45] was employed to minimize the risk of overlooking important sources of information.

Inclusion criteria for the database:

• the subject matter under study – based on keywords (cadaster, classification, technogenic/man-made mineral formations, technogenic/man-made deposits, waste/tailings, industrial waste, content, algorithm, information support, mining, remanufacturing, reuse, recycling, environmental management, mineral resource base, circularity, disturbed, impact) and their Russian equivalents in various interpretations and variations;

• time period – 1900-2026;

• publication type – article, report, dissertation, monograph (book/preprint);

• the languages of publication are Russian and English.

To ensure a rigorous and reproducible approach to article collection, the Preferred reporting items for systematic reviews and meta-analyses (PRISMA) methodology has been employed [24, 46]. The process of compiling the research information base is illustrated in Fig.1.

This article uses the results of theoretical and practical scientific work, implemented using a combination of various analysis methods. Thus, methods of structural analysis, analogy, and grouping are employed as the primary approaches when defining the fundamental classification criteria for waste. Applying methods for generalizing and systematizing information sources within a systems approach made it possible to analyze and trace the evolution of the stages of cadastral registration in Russia, as well as to propose an algorithm for creating a TMF cadaster and an information structure for TMF and TD cadasters that addresses the identified shortcomings. Logical-economic analysis and the comparative method were employed to identify fundamental trends in current cadastral registration, as well as issues requiring resolution in the improvement of TMF and TD cadasters. The combination of the specified information sources and methods ensures a comprehensive analysis of the research problem.

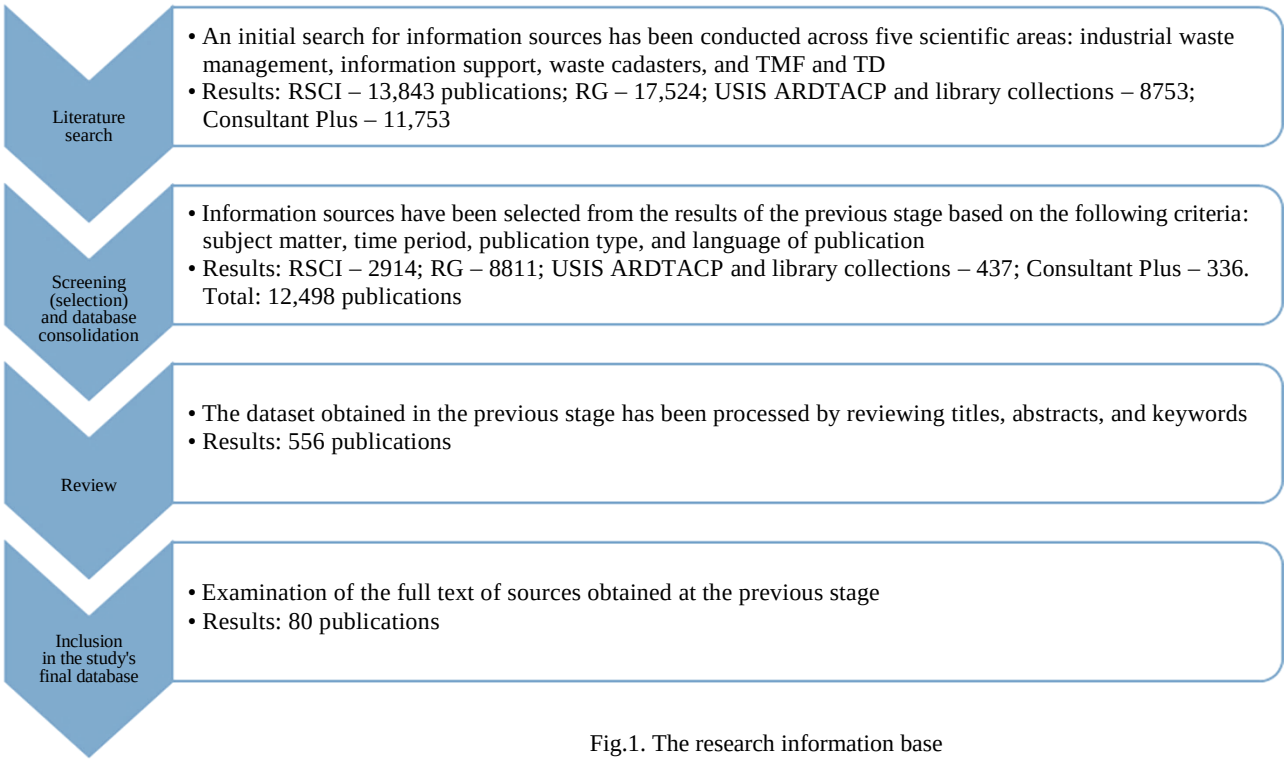


Fig.1. The research information base

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Results and discussion

Identification of the basic classification criteria for waste from an analysis of the classifications of TMF, TD, and facilities with a negative environmental impact

The TMF cadaster is an information resource that facilitates management decision-making. It constitutes a systematized compilation of economic, environmental, social, organizational, legal, and technical data characterizing the quantity, quality, and location of TMF, as well as the category of subsoil users (based on business legal structure). The completeness and reliability of data on TMF in cadasters enable investors to make informed decisions regarding the development of such deposits. Classifications of TMF and TD serve as the foundation for developing the cadasters. If a cadaster is a compilation of information, then classification is the division of objects, phenomena, and concepts into classes, divisions, and sections based on their common characteristics. The classification defines the main directions for collecting information distributed according to classification criteria [47]. Waste passportization (certification) is closely linked to the creation of waste cadasters, as the compilation of these relies on information contained in waste passports. The first classifications of TMF and TD emerged in the 1980s and 1990s – a period of growing interest in technogenic raw materials as a source for expanding the mineral resource base – and covered mining and processing, metallurgical production, and construction raw materials (Fig.2).

Thus, an analysis of existing TMF cadasters revealed, firstly, a number of shortcomings in their content and, secondly, the absence of fundamental criteria governing their compilation. The set of principles for compiling TMF and/or TD cadasters is presented in Fig.3. The core set of principles concerns the creation of the cadaster as a final product, highlighting specifics related to the mineral-resource and environmental aspects of TMF and TD. A number of principles determine the conditions for establishing the cadaster (selection of indicators, justification of physical units, valuation period, etc.).

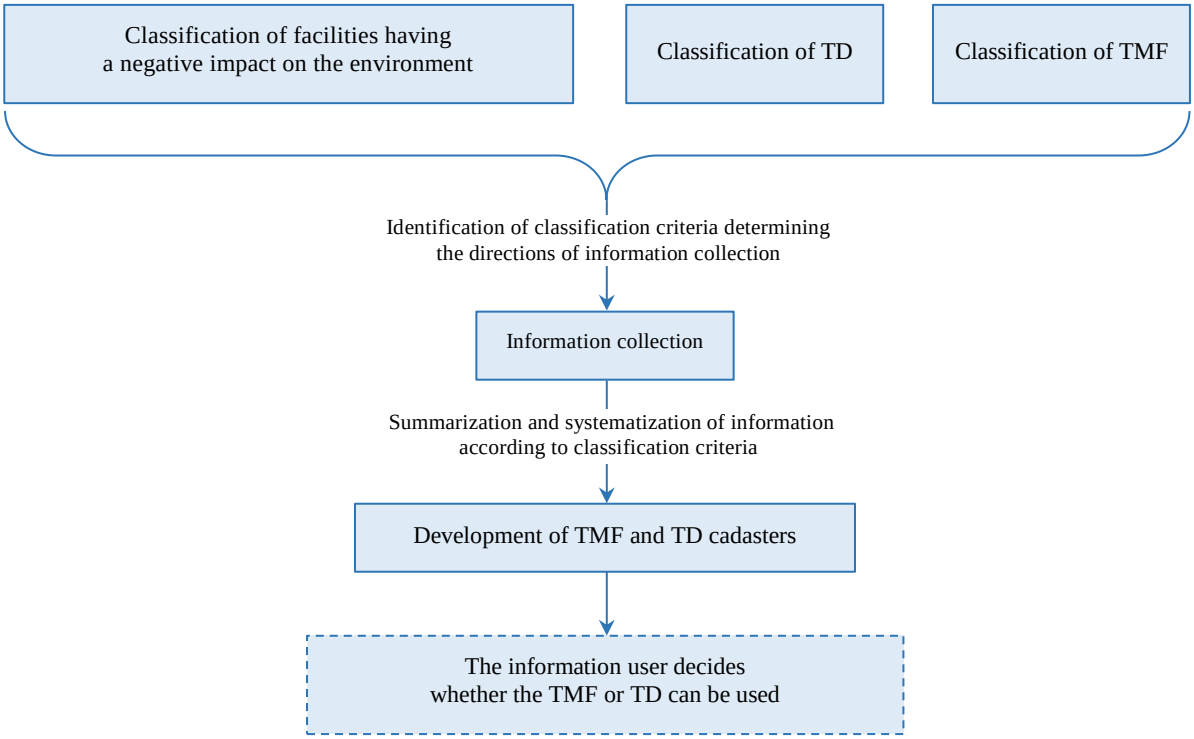


Fig.2. Interrelationship between classifications and cadasters of TMF and TD

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<table>
<tr><td colspan="5">Principles characterizing the development of the cadaster as a result</td></tr>
<tr><td rowspan="2">Mineral and raw material aspect</td><td rowspan="2">Completeness, comprehensiveness</td><td>General</td><td rowspan="2">Environmental friendliness, toxicity</td><td rowspan="2">Environmental aspect</td></tr>
<tr><td>Integrity
Cost-effectiveness
Resource availability
Preservation
Complementarity
Lawfulness</td></tr>
<tr><td colspan="5">Continuity, moderation, reliability, dynamism, transparency</td></tr>
<tr><td colspan="5">Principles characterizing the development of the cadaster as a process</td></tr>
</table>

Fig.3. Fundamental principles for developing the TMF cadaster

The developed fundamental principles characterize TMF simultaneously as potential technogenic deposits and as sources of negative environmental impact. Thus, a fundamental principle of cadaster formation is *integrity*, which requires completeness regarding mineral resources-specifically, both metallic and non-metallic minerals. The mineral-resource aspect entails the application of the principle of *comprehensiveness* – a thorough characterization of the TMF regarding the presence of valuable components suitable for extraction, as well as rock materials that can be utilized as associated mineral resources. The principle of *completeness* requires that the full list of valuable components be reflected in the cadaster, taking into account potential future uses. An assessment of the environmental hazard posed by TMF is a mandatory requirement; this necessitates the application of the *toxicity* principle, given that even small percentages of toxic components increase the hazard from TMF. The principle of *environmental friendliness* entails assessing not only the current state but also the potential for negative environmental impact during the storage of TMF. One of the parameters evaluated in cadasters is the technologies currently in use or projected for use. The principle of *manufacturability* involves characterizing TMF in terms of the availability of technologies for its processing. A detailed analysis of the material composition of the TMF – as well as its physicochemical and physicomechanical properties – makes it possible to formulate recommendations for the application of technologies, drawing upon existing practical experience. The principle of *cost-effectiveness* is demonstrated by calculating various effects – economic, environmental, social, and indirect – associated with the development of mineral resources, encompassing the utilization of both primary and associated mineral resources. At the early stages of assessment, prior to reserve estimation, the principle of cost-effectiveness entails determining the economic loss. The principle of *resource availability* is implemented through the disclosure of information regarding the resources required for the development of the TD – such as labor, local raw materials, infrastructure, and so on. The principle of *preservation* requires the inclusion of information in the cadaster regarding monitoring systems, operational control, and environmental protection systems. The principle of *complementarity* reflects information regarding the location and siting of TMF, its transport accessibility, land categories, forest cover, and the presence of water bodies, as well as natural conditions concerning topography, climate, humidity, and heat. The principle of *lawfulness* requires the availability of information regarding land use rights, the siting of TMF and land reclamation, as well as approved limits for maximum permissible emissions and discharges, waste disposal standards, an environmental impact assessment conclusion, the establishment of a sanitary protection zone (SPZ), and other relevant data.

The fundamental principles of cadastral valuation are continuity, moderation, reliability, transparency, and dynamism. Adherence to the principle of *continuity* entails analyzing and utilizing indicators recommended in existing classifications of TMF and TD. In turn, the principle of *moderation* requires optimizing the number of indicators. The number of indicators characterizing cadaster

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parameters should be neither excessive (excluding minor indicators that are also labor-intensive to assess) nor unjustifiably brief. The requirement for *reliability* is reflected in the use of data available in the public domain, which also ensures the transparency of cadaster information. The principle of *reliability* requires minimizing reliance on analogues and expert assessments, which are prone to the subjectivity of expert opinion. The principle of *dynamism* entails the continuous updating of cadaster information, the reflection of temporal dynamics, and the expansion of the indicators being tracked or the discontinuation of existing ones.

A synthesis and analysis of information sources regarding TMF [48-50], TD [51-53], and sites with adverse environmental impacts have shown that the sources suitable for gathering data to compile waste passports – and, consequently, waste cadasters – are those that provide a sufficiently comprehensive characterization of TD and TMF. To ensure the substantive content of the cadasters, it is proposed to collect information based on the following key classification criteria regarding waste: material substance (matter and energy); physical state; chemical composition; genesis (origin); stage of mining and metallurgical production (ore stockpiles and rock dumps – overburden and host rock); tailings and slimes generated during processing; slags formed during metallurgical processing; gases from open-pit mines, processing plants, and other sources generated during extraction and processing; potential for recovering valuable components (either currently viable or planned for the next 10-20 years, necessitating waste preservation); feasibility of use; intended applications (recovery of valuable components, production of construction materials, backfilling of mine workings, use in the chemical industry, agriculture, etc.); usability status (utilized vs. unutilized – including aggressive, poisonous, toxic, or spontaneously combustible materials, as well as those requiring disposal); suitability for land reclamation (suitable vs. unsuitable), etc.

Review of publications and the regulatory framework for the establishment of cadastral registration in Russia

Stage I (*1920-1990*). *The preliminary stage of cadastral registration for TMF*. The compilation of cadasters is considered to have begun in the 1920 with the creation of the first land resource cadaster. Later (in the 1930-1950), the need for such records was denied, and only subsequently the importance of developing these documents was recognized.

Government resolutions adopted in the 1980s provided the impetus for compiling TMF cadasters. However, the collection and aggregation of waste data had already been carried out as early as the 1960s by the Ukrainian branch of the Research Institute for Planning and Standards under the USSR State Planning Committee (State plan). Furthermore, efforts to compile cadasters of mining and industrial waste began to expand significantly starting in 1974. Pioneers in the development of cadasters included the Institute of Problems of Complex Mineral Resource Development of the USSR Academy of Sciences, the Donetsk Polytechnic Institute, the Zhdanov Metallurgical Institute, the Leningrad Mining Institute, the Voroshilovgrad Branch of the Institute of Industrial Economics of the USSR Academy of Sciences, and others[1].

For the first time, sources of co-products of extraction and production waste were included in the cadaster – a classification system for construction mineral raw materials in the Ukrainian SSR – alongside information on deposits of primary mineral raw materials [54]. The cadaster of construction mineral raw materials consolidated information from two distinct sources: natural deposits of clay-based mineral raw materials and sources comprising by-products of extraction and production waste. The characterization of associated minerals and waste products covered sources of secondary raw materials, locations, rock types, reserves, and the surface areas of waste dumps. Data were presented on the chemical-technological properties and techno-economic indicators of secondary raw materials, as well as recommended processing technologies; these materials were incorporated into a unified system of cadastral registration and assessment on par with primary natural raw materials. Subsequently, separate waste cadasters began to be created. For instance, in 1984, staff from the Council for the Study of

[1] On the Necessity of Establishing a National Database on the Utilization of Secondary Resources and Industrial Waste. Preprint of a report by the Institute of Industrial Economics, Academy of Sciences of the Ukrainian SSR. Donetsk: Institute of Industrial Economics, Academy of Sciences of the Ukrainian SSR, 1986, p. 36.

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Productive Forces of the Academy of Sciences of the Kazakh SSR and the "Djezkazgan" and "NIItsvetmet" institutes developed a cadaster of waste resources from non-ferrous metallurgy in Kazakhstan.

The late 20th century saw the emergence of guidelines for assessing the efficiency of developing technogenic deposits, as well as a number of industry-specific methodologies defining the procedure for the cadastral registration of waste-including the guidelines for the cadastral registration of waste from mining, processing, and metallurgical operations in the non-ferrous metals industry[2] – and industry-specific guidelines for establishing and maintaining a consolidated industry database on secondary material resources[3]. The methodology defined the fundamental principles for the accounting, valuation, and practical utilization of waste from mining, processing, and metallurgical operations at non-ferrous metallurgy enterprises, as well as the procedure for establishing a unified system for accounting for mineral and technogenic non-ferrous metal resources. Great attention was paid to the economic aspect of the cadaster, which made it possible to regard it as an economic waste cadaster. The procedure for developing the economic cadaster entailed the use of both raw and calculated indicators. The data indicate a focus on the final economic outcomes of waste utilization – an approach that did not see widespread practical application due to the low profitability of recovering secondary material resources. The proposed cadaster was not widely adopted.

During those years, the practical work of compiling TMF cadasters in the Murmansk Region was carried out by the Murmansk Geological Exploration Expedition and the Mining Institute of the Kola Branch of the USSR Academy of Sciences [55]. From 1986 to 1989, the Mining Institute of the Kola Branch of the USSR Academy of Sciences conducted research on the cadastral registration and potential utilization of technogenic raw materials in the Murmansk Region [56]. As the basis for the cadaster, they utilized data from waste passport records for mining and processing operations, which had been compiled by the "Sevzapgeologiya" Northwestern Geological Production Association in 1984. This summary information made it possible to assess the potential of the technogenic raw materials, as well as the extent of their utilization and their environmental impact [57, 58]. Similar studies assessing the potential use of mining waste in the Sverdlovsk Region (Urals) were conducted in 1987 under the supervision of E.P.Smirnov. However, this research did not progress further during the 1990s, as the issue of waste and its registration has receded into the background. This marked the end of the preliminary stage of cadastral registration for TMF.

Stage II (*1990-2006*). *Organization of cadastral registration for TMF and TD*. This stage was marked by the adoption of the first legislative acts regulating the organization of cadastral registration. The Federal Law "On Subsoil Resources" was adopted in 1992. Furthermore, the need to maintain state natural resource cadasters – which facilitate accounting and socio-economic assessment – was included in the following documents:

• Directive of the Deputy Chairman of the Council of Ministers – Government of the Russian Federation N 58-rz dated May 7, 1993 "On Improving the Quantitative and Qualitative Accounting of Natural Resources";

• Order of the Ministry of Environment Protection and Natural Resources dated May 27, 1993 N 103 "On ensuring the conduct of an experiment to improve accounting and socio-economic assessment of natural resource potential";

• Decree of the President of the Russian Federation N 236 dated February 4, 1994 "On the State Strategy of the Russian Federation for Environmental Protection and Ensuring Sustainable Development" (reflects the requirement to establish natural resource cadasters).

As a result, efforts to develop cadasters at the regional level intensified (in the Vologda, Vladimir, Kaluga, Yaroslavl, Sverdlovsk, and Kostroma regions, among others). Relevant programs were adopted in a number of regions (such as the Kursk Region and Krasnoyarsk Krai). In 1993, the new state program "Environmental Safety of Russia" included the objective of establishing a regional

[2] Industry-Specific Guidelines for the Cadastral Registration of Wastes from Mining and Metallurgical Operations at Non-Ferrous Metallurgy Enterprises. Moscow: Ministry of Non-Ferrous Metallurgy of the USSR. 1987, p. 99.

[3] Industry Guidelines for Establishing and Maintaining an Industry-Wide Compilation of Data on Secondary Material Resources. Moscow: Ministry of Non-Ferrous Metallurgy of the USSR, 1988, p. 74.

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database of technogenic deposits. In the Murmansk Region, the Mining Institute was engaged to compile the database. A database was created based on cadastral information, with all data organized into eleven tables: one table containing general indicators and ten tables containing specific indicators. The new database structure allowed for a detailed characterization of each TD. A subsequent version of the database comprised 22 tables. Later, under State assignment N 0226-2018-0001, the Mining Institute of the Kola Science Center (RAS) carried out work to update the cadaster of technogenic formations in the Kola mining and industrial region [55].

Growing interest on TMF in the Sverdlovsk Region was driven by Sverdlovsk Region Government Resolution N 84-PP of March 23, 1993 "On the Certification of Technogenic Deposits in the Sverdlovsk Region", and Sverdlovsk Region Governor's Decree N 1 of January 9, 1996 "On Measures to Organize the Processing of Technogenic Formations", as well as the development of a special program titled "Processing of Technogenic Deposits in the Sverdlovsk Region", which was approved by the Government of the Russian Federation in 1996 and designated a Presidential program. Work on the program was halted in 2000 due to funding problems.

In 2000, Decree of the Government of the Russian Federation N 818 dated October 26, 2000 "On the Procedure for Maintaining the State Waste Cadaster and Conducting Hazardous Waste Certification", was issued. Hazardous waste certification was carried out[4], with hazard levels determined in accordance with Order N 511 of the Ministry of Natural Resources of Russia dated June 15, 2001 "On Approval of Criteria for Classifying Hazardous Waste by Environmental Hazard Class". The practice of developing industry and regional cadasters has expanded, as evidenced by the research conducted between 1997 and 2000. In the Sverdlovsk Region, a team of scientists (S.I.Mormil, V.L.Salnikov, L.A.Amosov, and others) compiled a cadaster of technogenic deposits in the Middle Urals and assessed their environmental impact [52]. The information base was compiled by collecting and systematizing archival, repository, and published materials, reports (Forms 2-TP (Waste), 71-TP, and 5-gr), tailings storage facility passports, and other data. The main avenues for utilizing TMF were examined, an overview of existing and emerging TMF processing technologies was provided, and an assessment of the environmental impact of TMF was conducted [52]. By the year 2000, 66 waste-generating enterprises – spanning the mining, metallurgical, mineral processing, energy, and chemical sectors – and 188 independent technogenic mineral sites had been inventoried in the Sverdlovsk Region, and an information database regarding them had been established. Further research is documented in the works of G.G.Khasanova [50, 59].

During the same period, in accordance with the orders of regional authorities, a cadaster of TMF and TD was developed in the Murmansk Region[5], Moscow Region[6], Moscow[7] and other regions. Based on research conducted between 1994 and 1997 under the supervision of Yu.Kharitonov, a methodological guide was developed for the rapid analysis, assessment, and creation of a computerized registry of technogenic raw materials for Russia's oldest mining regions[8].

The Consolidated Cadaster of Industrial and Consumption Waste of Moscow, developed in accordance with the Decree of the Government of Moscow dated October 14, 2003 N 865-PP[9], includes a classification catalogue of industrial and consumption waste in Moscow, a database of industrial and consumption waste, a database of use and disposal technologies, and a register of waste disposal facilities.

[4] Decree of the Government of the Russian Federation N 818 dated October 26, 2000 "On the Procedure for Maintaining the State Waste Cadaster and Conducting Hazardous Waste Passportization".

[5] Waste Cadaster of Mining and Metallurgical Production in the Murmansk Region (as of January 1, 2000). Apatity; Murmansk: Mining Institute, KSC RAS, 2000, p. 104.

[6] Resolution of the Government of the Moscow Region N 802/41 dated October 2, 2009 "On Approving the Procedure for Maintaining the Waste Cadaster of the Moscow Region".

[7] Resolution of the Government of Moscow N 865-PP dated October 14, 2003 "On the Consolidated Cadaster of Production and Consumption Waste of the City of Moscow".

[8] Kharitonov Yu.F. Methodological guide for the rapid analysis, assessment, and creation of a computerized cadaster of technogenic raw materials for Russia's oldest mining districts. Report on Project 241 (1994-1997), ZABNII Branch (Chita city).

[9] Resolution of the Government of Moscow N 865-PP dated October 14, 2003 "On the Consolidated Cadaster of Production and Consumption Waste of the City of Moscow".

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Researchers at the Institute of Industrial Ecology (Ural Branch of the RAS) substantiated approaches to compiling a cadaster of production and consumption waste for waste management purposes in the Yamalo-Nenets Autonomous Okrug (YaNAO) [60]. The proposed cadaster envisaged maintaining nine information blocks containing data on: the origin of solid industrial waste, location, generation parameters, storage methods, protective measures, monitoring arrangements, the enterprise's business activities, the existence of limits and permits, waste management activities, processing facilities, processing technologies, and the availability of hazardous waste passports. A distinctive feature of the cadaster data is the brevity of the descriptions of TMF, as the information pertains to municipal waste. Information on production and consumption waste was provided by the regional office of the Federal Service for Technological and Environmental Supervision for the YaNAO, specially authorized executive bodies of the YaNAO, and municipal administrations. The information obtained primarily concerned large industrial municipalities where systems for the documentary tracking and control of waste flows from major industrial enterprises are in place; consequently, its reliability is insufficient due to the lack of data from small and medium-sized enterprises.

Stage III (*2007 – present*). *Improvement of the waste cadaster system*. The 2007-2019 period is considered the most significant – defining the core phase – during which updated procedures were approved for waste registration[10], the certification of Class I-IV wastes[11], and waste hazard assessment conducted in accordance with the Federal Classification Catalog (approved by Order N 242[12] of Federal Service for Supervision of Natural Resource Usage dated May 22, 2007). This period is characterized by the improvement of cadastral registration and the substantiation of the content of cadasters. In the Sverdlovsk Region, the procedure for maintaining the cadaster was approved by Sverdlovsk Region Government Resolution N 1036-PP of October 23, 2007 "On Approving the Procedure for Maintaining the Sverdlovsk Regional Cadaster of Production and Consumption Waste". The Center for Environmental Monitoring and Control, operating under the Ministry of Natural Resources and Ecology of the Sverdlovsk Region, is responsible for consolidating and systematizing data, as well as compiling and maintaining the cadaster. The cadaster comprises four sections: a database on waste; a registry of waste disposal facilities located within the Sverdlovsk Region; a database on legal entities and individual entrepreneurs engaged in the neutralization and disposal of hazard class I-IV waste; and a database on technologies (installations) for waste utilization and neutralization [61]. The content of the Sverdlovsk Region Cadaster is generally consistent with the approved procedure for maintaining the cadaster[13] (see Table). Data in the regional cadaster are subject to continuous updating, and the list of entries expands over time. The information provided is recorded using standardized forms. As of 2013, 967 waste disposal sites were registered: 511 for industrial and agricultural waste and 456 for municipal waste. The total area occupied by waste amounted to 175,000 ha.

Similar in content to the Sverdlovsk Region waste cadaster is the Moscow Region[14] waste cadaster, which includes: a registry of waste processing, recovery, neutralization, and disposal operations; a waste database containing information on the origin, quantity, properties, and hazard class of the waste; information on technologies for the recovery and neutralization of various types of waste; and a list of individual entrepreneurs and legal entities that generate waste through their economic or other activities, including details regarding the buildings, structures, and premises where waste management activities take place.

[10] Order of the Ministry of Natural Resources of Russia N 792 dated September 30, 2011 "On Approval of the Procedure for Maintaining the State Waste Cadaster".

[11] Decree of the Government of the Russian Federation N 712 dated August 16, 2013 "On the Procedure for Passportization of Waste of Hazard Classes I-IV".

[12] Order of the Federal Service for Supervision of Natural Resources N 242 dated May 22, 2017 "On Approval of the Federal Waste Classification Catalogue".

[13] Order of the Ministry of Natural Resources of Russia N 792 dated September 30, 2011 "On Approval of the Procedure for Maintaining the State Waste Cadaster".

[14] Order of the Federal Service for Supervision of Natural Resources N 242 dated May 22, 2017 "On Approval of the Federal Waste Classification Catalogue".

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Comparison of the procedure for maintaining the waste cadaster

Content of the State Waste Cadaster	Contents of the Cadaster of Production and Consumption Waste of the Sverdlovsk Region
Federal Waste Classification Catalog for determining waste hazard classes [15]	Certificate of Waste Hazard Class for the Natural Environment
State Register of Waste Disposal Facilities (name, purpose, location, information on environmental impact, details of the legal entity or individual operating the facility, etc.)	Waste disposal facility block. Information from the approved form "Characteristics of waste disposal facilities", name of the territory where the facility is located, legal address, geographic coordinates, nearest water body, nearest populated area, registration in the state register. Data block on legal entities and individual entrepreneurs engaged in waste management activities
Database on waste and technologies for the utilization and neutralization of various types of waste: waste code (per the Federal Waste Classification Catalog/FWCC), physical state, composition and origin, chemical composition and geological occurrence of rock formations, processing waste, technologies employed, material consumption, products manufactured, and availability of a state environmental expert review conclusion regarding the technology	The production and consumption waste data block contains information from the "Characteristics of Waste Disposal Facilities" form. Waste hazard class details include: physical state, pH, moisture content, water solubility, volatility, component composition, generation source, hazard class, hazardous properties, facility status, land use documentation, project documentation, hydrogeologist findings, state environmental expert review findings, accounting of maximum permissible emissions and discharges, project approval, facility operational start and end dates, capacity, scale, sanitary protection zone dimensions, control measures, protection systems, equipment, monitoring systems, waste inventory, and waste movement. Data block on waste utilization and neutralization technologies (facilities): data on operational technologies, general information, products manufactured, secondary waste, and information on technologies that have been developed and have undergone state environmental review

Another source of information on TD is the State Cadaster of Mineral Deposits and Occurrences, managed by Federal Agency for Subsoil Use [62]. Deposits whose reserves have been approved by the State Commission on Mineral Reserves and entered into the State Balance of Mineral Reserves are subject to accounting. To track the exploration and development status of TD, an interactive map of technogenic sites associated with major types of metallic and non-metallic mineral resources in the Russian Federation was compiled between 2012-2022 under the auspices of the Federal Agency for Subsoil Use (A.P.Karpinsky Russian Geological Research Institute). This map contained data on a significant number of anthropogenic sites and their sources of formation. In total, information was gathered on 1607 sites, comprising 96 TD and occurrences, 252 specialized waste dumps associated with deposits, and 1259 other TMF.

Identification of fundamental trends and issues requiring resolution in the process of improving TMF and TD cadasters in the Russian Federation

The analysis of the content of waste cadasters reveals the following aspects:

• all the main classification features-reflected in the classifications of the TMF – are taken into account in the cadasters;

• the cadasters reflect the structure established by Order N 792 of the Ministry of Natural Resources and Environment of Russia dated September 30, 2011 "On Approval of the Procedure for Maintaining the State Waste Cadaster";

• the TMF parameters reflected in the cadasters are not always comparable, which complicates the analysis;

• the environmental aspect is insufficiently addressed. A qualitative assessment of the magnitude of the negative environmental impact is highly subjective. Moreover, the lack of information regarding the environmental conditions at the TMF disposal site makes it impossible to reliably estimate the economic damage that could be prevented through TMF processing;

[15] Order of the Ministry of Ecology and Nature Management of the Moscow Region N 41-RM dated January 25, 2016, "On Approving the Procedure for Maintaining the Waste Cadaster of the Moscow Region".

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• information characterizing TMF regarding their storage requires supplementation. In particular, it is necessary to identify mineral assemblages and determine the nature of sulfide oxidation. Priority targets for the assessment of physicochemical properties include pyrite, chalcopyrite, pentlandite, sphalerite, galena, pyrrhotite, and tetrahedrite-group minerals. Data on oxidation rates and storage life will enable well-founded decisions regarding investment in the utilization of TMF. Storage life is also a critical factor for overburden rocks, which gradually degrade and lose beneficial physicochemical and mechanical properties;

• there is a lack of information regarding economic indicators that reflect the efficiency of developing TD during exploration, or other economic indicators consistent with the nature of the assessment at the relevant stages of geological exploration. Taking into account the environmental aspect, the analysis of the efficiency of TD processing involves an ecological-economic approach, which provides for an assessment of the preventable economic damage caused by environmental consequences, and in some cases, the preventable damage caused by negative social consequences. The refusal to include economic justifications in cadasters is motivated by the absence and insufficient reliability of the information necessary for their implementation;

• a lack of information or the availability of fragmentary data that is often contradictory and requires verification. Particular difficulties in data collection arise with sites where the formation process has already been completed. As of early 2023, the registry listed 528 sites of accumulated environmental damage within Russia [63-65].

Creation of an algorithm for the layout of the TMF cadastral register and a general information structure for the TMF and TD cadasters, which will eliminate the identified problems and shortcomings of the existing cadastral registration

Despite its importance, Russian and international practice regarding information support for TMF has received very little coverage in publications.

It should be noted that the analysis of information support for TMF abroad [66, 67] is closely linked to the practical implementation of circular economy principles [68-70] at all management levels – national [71, 72], regional [73, 74], and local [75] – as well as to the coverage of scientific and technological advances in TMF processing and the utilization of TD [76-78]. Special attention is paid to the study of the socio-ecological aspects of TMF and the risks from the development of TD [74]. The issue of reflecting information about TMF and TD in government and corporate information systems is covered rather fragmentarily [73, 74].

Based on the analysis of the relevant literature and the previously described additional recommendations for data collection, the content structure of the TMF cadaster will comprise eight blocks. Increasing the number of blocks relative to the recommendations[16] will facilitate the consolidation of more comparable information.

The content of the TMF cadaster:

1. Information about the user (organizational profile; form of ownership; possession of a subsoil use license; waste storage; availability of a state environmental expert review conclusion; availability of a hydrogeologist's conclusion; availability of a land reclamation plan; availability of a project design for the geological study of TMF; project establishing waste generation standards and disposal limits; availability of a passport for TMF).

2. Information on the type of TMF and its location (industrial sector affiliation; affiliation with waste-generating enterprises; TMF formation stage within the production chain; TMF type; facility age (storage duration); waste volume; land allocation for the TMF (area); land type; land value; land owners; quantity of accumulated waste; map sheet designation, geographic coordinates; other data on the facility's area (distance from the center, transport accessibility, labor availability, etc.).

[16] Order of the Ministry of Natural Resources of Russia N 792 dated September 30, 2011 "On Approval of the Procedure for Maintaining the State Waste Cadaster".

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3. Formation of the TMF (controls on TMF storage and movement; facility infrastructure; approved monitoring program; operational monitoring; monitoring system; storage facility type; storage capacity; water saturation level).

4. Characterization of TMF (primary deposit type; main host rock type; mineral composition; chemical composition; main and associated components; deleterious impurities; physico-mechanical properties; particle-size distribution; mineral assemblages by the nature of sulfide oxidation, where sulfide-bearing ores are present).

5. Information regarding TMF as sources of adverse environmental impact (hazard class; concentration of harmful impurities; degree of hazard associated with anthropogenic impact; state of the environmental situation in the area where the TMF is located; economic efficiency of the TMF processing technology).

6. Information on technologies (availability/absence of TMF processing technology; compliance of the technology with Best Available Techniques criteria; extent of knowledge regarding the physicochemical and physicomechanical properties of TMF).

7. Economic justification (assessment of economic damage).

8. Information on the possibility of use (possible direction of use; man-made indicators; possible commercial products; possible consumers of products; mining and technical conditions of development; hydrogeological conditions of development; basic information on the use of TMF or similar TD).

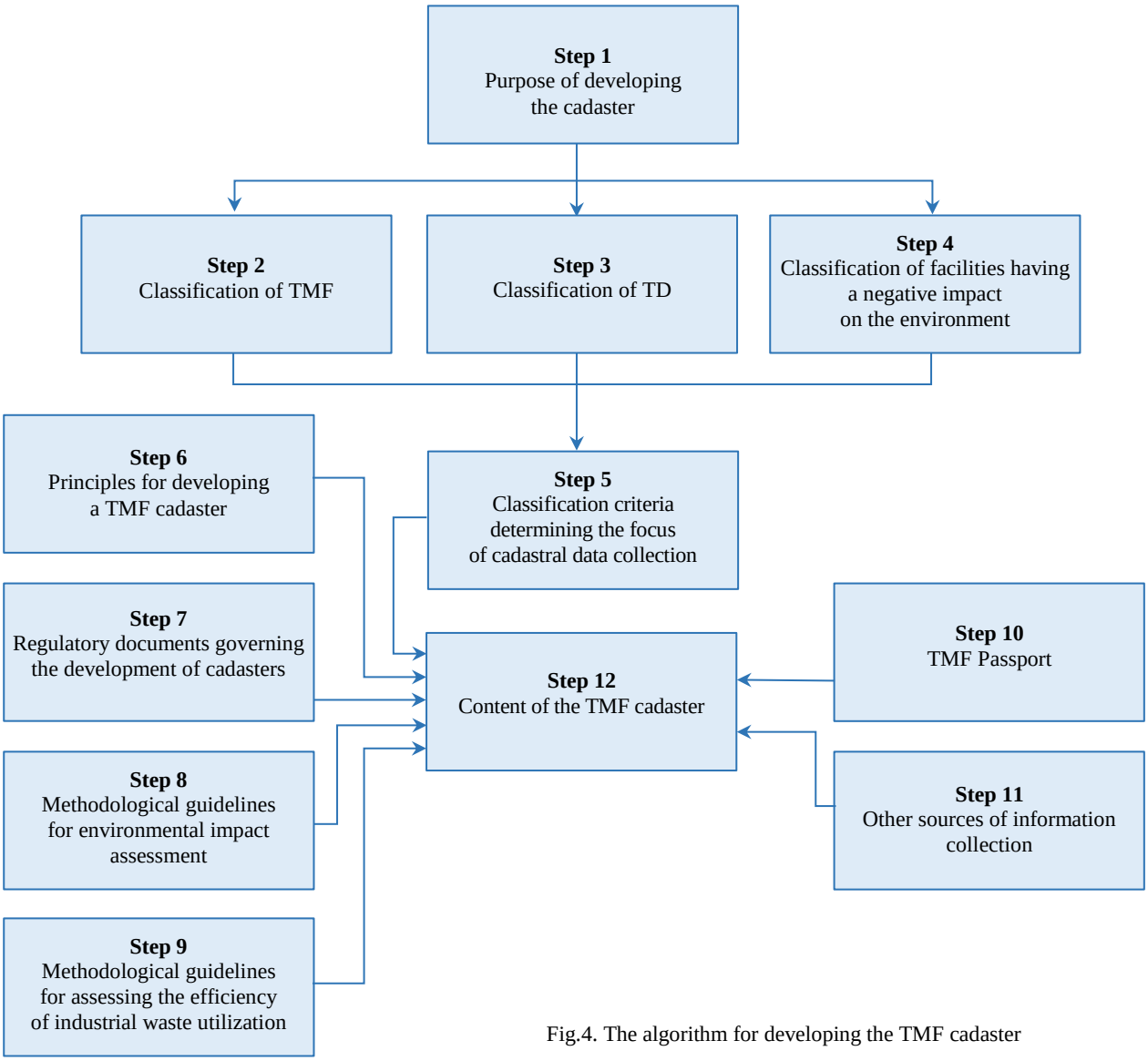


Fig.4. The algorithm for developing the TMF cadaster

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A section regarding the reserves of the anthropogenic deposit is added to the TD cadasters. Additionally, the economic characteristics are expanded to include the results of the environmental-economic assessment of the TD development-specifically the commercial effect, as well as the environmental, social, and indirect outcomes derived from processing the TMF. Figure 4 illustrates the procedure for developing the TMF cadaster, which – in addition to the substantive content of the cadaster-incorporates fundamental development principles, relevant regulatory and legal documents, and methodological guidelines for environmental impact assessment, as well as the assessment of economic damage and the efficiency of TD development (in the case of TD cadasters).

The sequence for developing the TMF cadaster is determined by the following steps:

• Step 1 – justification of the purpose of developing the cadaster.

• Steps 2-4 – analysis of the qualification features of classifications of TD and occurrences, TMFs and objects of negative impact on the environment.

• Step 5 – systematization of classification features that determine the focus of information collection for the cadastral register.

• Step 6 – understanding the essence of the fundamental principles of TMF development and taking them into account.

• Step 7 – systematization and recording of regulatory and legal documents during the development of the cadaster.

• Step 8 – consideration of the guidelines for assessing the adverse environmental impact of TMF.

• Step 9 – consideration of the guidelines for assessing economic damage.

• Step 10 – summarizing information from TMF passports.

• Step 11 – other sources of information.

• Step 12 – development of the TMF cadaster.

Conclusion

The study substantiates the selection of information materials characterizing the cadastral registration of technogenic mineral formations and technogenic deposits, based on the systematic review methodology of M.Petticrew and H.Roberts and the PRISMA standard. Based on the analysis of information sources, measures have been proposed to improve cadastral registration activities in the country, primarily through the integration of data components characterizing the environmental and economic aspects of TMF. The article demonstrates the need to expand the informational characteristics of technogenic mineral formations TMF in terms of both environmental aspects – by adding data on the environmental situation at the TMF site, as well as on environmental impacts and storage conditions (storage duration, release of mineral associations, and characterization of sulfide oxidation) – and economic aspects, by including an assessment of economic damage. The study proposes adding a section on reserves to the cadasters of TD and including the results of the environmental-economic efficiency of their development – such as commercial impact, as well as environmental, social, and indirect outcomes derived from processing TMF-among the economic characteristics considered. Expanding the content of the TMF cadaster and proposing an algorithm for its development facilitate, firstly, the improvement of informational support, and, secondly, an increase in the number of investors funding their utilization-thanks to the availability of comprehensive information reflecting the actual state of waste from mining and associated processing operations. Validation of the proposed algorithm for compiling a cadaster of TMF and TD constitutes a direction for the authors' future research on this topic.

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