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GEOLOGY AND TECHNICAL SCIENCES**

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*The scientific journal News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences has been indexed in the international abstract and citation database Scopus since 2016 and demonstrates stable bibliometric performance.*

*The journal is also included in the Emerging Sources Citation Index (ESCI) of the Web of Science platform (Clarivate Analytics, since 2018).*

*Indexing in ESCI confirms the journal's compliance with international standards of scientific peer review and editorial ethics and is considered by Clarivate Analytics as part of the evaluation process for potential inclusion in the Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), and Arts & Humanities Citation Index (AHCI).*

*Indexing in Scopus and Web of Science ensures high international visibility of publications, promotes citation growth, and reflects the editorial board's commitment to publishing relevant, original, and scientifically significant research in the fields of geology and technical sciences.*

*«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық реферативтік және ғылымиметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.*

*Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық реферативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.*

*ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылмды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.*

*Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.*

*Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.*

*Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).*

*Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).*

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## CONTENTS

<b>Abetov A.E., Seitzhanov A.K., Samenov Y.R., Zhassymbek S.A.</b> Machine learning and neural networks for lithofacies mapping and reservoir property evaluation of core samples.....	8
<b>Aitkaliyev A.K., Pak Y.N., Kolmakov Y.V., Pak D.Y., Matishev T.V.</b> Application of the X-Ray radiometric method to improve the operational quality control of copper ores during geological testing.....	26
<b>Altay Y.A., Karymsakova N.T., Fedorov A.V., Absadykov D.B., Ismagul G.K.</b> Predictive control of diagnostically significant parameters of acoustic emission using machine learning: new data.....	41
<b>Astanakulov K.D., Kodirova M.G., Saydumarov B., Nersesyan D.V., Kurashkin S.O.</b> Resource potential of ecological and geological systems of allocated soil masses.....	58
<b>Avazov Sh.B., Yodgorov Sh.I., Mukhammadkulov N.M., Aktamov B.U., Khayriddinov B.B.</b> Instrumental seismometric assessment of the impact of technogenic seismic vibrations on the structural stability of historical objects.....	74
<b>Baskanbayeva D., Kalmaganbetov S., Sabirova L., Zholdybayeva G., Koptleuov K.</b> CFD analysis of screw compressor rotor geometry influence on gas compression efficiency in geology.....	92
<b>Borotov A.N., Karshiev F.U., Igamberdiyev A.A., Grigoryan A.G., Sarigo N.V.</b> Ecological aspects of resource conservation in the development of mineral deposits.....	107
<b>Gerasidi V.V., Lisachenko A.V., Apatenko A.S., Sevryugina N.S., Fomin A.Y.</b> Analysis of the application of non-destructive testing methods for assessing the technical condition of mining equipment motors based on vibration parameters.....	121
<b>Hajiyeva A.Z., Ibrahimova L.P., Humbatova Sh.Y., Jafarova F.M.</b> Ecological processes of vertical landscape transformation and their manifestation in the natural landscapes of Nakhchivan.....	135
<b>Jakiyayev D.K., Nussipali R.K.*, Malibekov A.K., Jakiyayev B.D., Zhashen S.Zh.</b> Statistical model of multi-cycle fatigue of steel structural elements under a complex non-uniform stress state.....	149
<b>Jumatov Y.K., Tashbulatov S.B., Pushanov A.N., Kozenkova G.L., Yarygina I.V.</b> Technological substantiation of sustainable mining reclamation of disturbed lands in open pit operations.....	169
<b>Kainenova T.S., Kosmbaeva G.T., Bissembayeva K.T., Otarbayeva A.T., Orazbek A.A.</b> Effectiveness of measures to regulate the development process at the Alibekmola field.....	185

<b>Koishiyeva G.Zh., Yerimova A.Zh., Kurbaniyazov S.K., Agaidarova K.H., Abdraimova K.T.</b>	
Radiological properties and stratigraphic significance of glauconite-bearing formations: implications for paleoenvironments and geochemical zonation.....	203
<b>Kondratiev V.V., Bryukhanova N.N., Kononenko R.V., Gladkikh V.A., Matasova I.Y.</b>	
Environmental and technological assessment of beneficiation tailings reprocessing based on mechanical activation and non-ferrous metals leaching.....	223
<b>Kuldeyev Ye., Negmatov S., Nurpeissova M., Kirgizbaeva D., Donenbayeva N.</b>	
Geodynamic Polygon of the Zhilandy Ore Field: Results and Prospects.....	237
<b>Madibekov A., Christian Opp., Karimov A., Ismukhanova L., Zhadi A.</b>	
Regularities of distribution and accumulation factors of heavy metals in soils of the Zhetysu region (Kazakhstan).....	253
<b>Malikov G.I., Musayeva S.A., Mammadov K.S., Jabiyeva U.M., Jafarova K.V.</b>	
Effects of hydrocarbon fuel quality fluctuations on energy generation efficiency, economic viability, and environmental footprint.....	272
<b>Narbaev M.T., Ismailova G.K., Narbaeva K.T., Burlibayeva D.M., Groll M.</b>	
Assessment of ecological and water management parameters of the Syrdarya River.....	290
<b>Nurmagambetov A.</b>	
On seismic hazard of Almaty and tectonic faults in the city.....	309
<b>Permana A.P., Kasim M., Hutagalung R., Uno D.A.N., Sandi I.N.</b>	
petrographic, provenance, and tectonic setting of Dolokapa formation sandstone, North Gorontalo.....	319
<b>Ratov B.T., Khomenko V.L., Yavorska O.O., Koroviaka Ye.A., Akhmetova N.S.</b>	
Analytical and structural justification of a wellhead sealing device for large-diameter drilling operations.....	335
<b>Skrobala V.M., Popovych V.V., Kopylov V.P., Popovych N.P.</b>	
Comprehensive assessment of heavy metal pollution of a river within a large city.....	355
<b>Sunakbaeva D.Kh., Yuldashbek D.Kh., Aitekova K., Seitbayev K.Zh.</b>	
Monitoring heavy metals in soils and waters of the City of Turkestan: geoecological aspect.....	371
<b>Zakirov M.M., Agzamova I.A., Ochilov G.E., Gulyamov G.D., Xudayberdiyev T.M.</b>	
Analysis of the results of changes in the gas and isotopic composition of groundwater during the period of earthquake preparation.....	385
<b>Zhanbatyrov A.A., Tukhfatov Zh.K., Bektay E.K., Turisbekova G.S., Zhanbatyrov N.A.</b>	
Current state of potash ore development in the Caspian lowlands of the Republic of Kazakhstan: problems and solutions.....	399

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## RESOURCE POTENTIAL OF ECOLOGICAL AND GEOLOGICAL SYSTEMS OF ALLOCATED SOIL MASSES

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**Abstract. Relevance.** The formation of dredged soil massifs as a result of hydraulic and mining operations leads to the accumulation of large volumes of technogenic material that influences environmental safety while simultaneously representing a potential mineral resource for industry. Insufficient knowledge of their engineering geological and ecological properties limits the efficiency of

their economic involvement and secondary industrial utilization. *Objective.* To summarize and systematize the patterns of formation, material composition, and engineering behavior of dredged soil massifs and to substantiate directions for their rational industrial development from the standpoint of resource conservation and environmental safety. *Methods.* The study employed field surveys, drilling and sampling, laboratory determination of granulometric and mineral composition, strength and filtration characteristics, geoecological contamination assessment, and mathematical modeling of engineering properties. *Results and conclusions.* The conducted research demonstrated that dredged soil massifs are characterized by a specific granulometric composition dominated by sandy and sandy-loam fractions, which determines their favorable engineering-geological properties and technological suitability for industrial use. Laboratory investigations confirmed satisfactory density, strength, and deformation parameters, allowing these soils to be considered a promising secondary geomaterial for the construction and mining industries. It was established that the values of internal friction, cohesion, and deformation modulus provide sufficient bearing capacity for the use of these soils as foundation materials for engineering and infrastructure facilities after standard engineering preparation. Geoecological assessment revealed that the concentrations of mobile heavy metals and other potentially hazardous contaminants remain within permissible limits established for industrial territories. This confirms the environmental acceptability of involving dredged soils in economic circulation and indicates the absence of significant risks of secondary environmental contamination during their industrial utilization. The feasibility of applying dredged soils in the construction sector, mining industry, and hydraulic engineering has been substantiated, including their use in foundation engineering, the formation of artificial platforms, and land reclamation projects. The study also emphasizes the importance of integrated management of technogenic soil resources as a key factor in improving resource efficiency, environmental sustainability, and rational use of geological materials.

**Keywords:** dredged soils, resource potential, industrial utilization, engineering geological properties, environmental safety, construction and mining industry

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## ЖУЫЛАТЫН ТОПЫРАҚ МАССИВТЕРІНІҢ ЭКОЛОГИЯЛЫҚ- ГЕОЛОГИЯЛЫҚ ЖҮЙЕЛЕРІНІҢ РЕСУРСТЫҚ ӘЛЕУЕТІ

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**Аннотация.** *Өзектілігі.* Гидромеханизацияланған және тау-кен өнеркәсібі жұмыстарының нәтижесінде жуылатын топырақ массивтерінің қалыптасуы аумақтардың экологиялық қауіпсіздігіне әсер ететін және сонымен бірге өнеркәсіп үшін әлеуетті минералдық-шикізат ресурсын білдіретін техногендік материалдың едәуір көлемінің жинақталуымен қатар жүреді. Олардың инженерлік-геологиялық және экологиялық қасиеттерінің жеткіліксіз зерттелуі шаруашылық тартудың және қайта өнеркәсіптік пайдаланудың тиімділігін шектейді. *Мақсат.* Жуылатын топырақ массивтерінің қалыптасуының, материалдық құрамы мен инженерлік мінез-құлқының заңдылықтарын жалпылау және жүйелеу және оларды ресурстарды

үнемдеу және экологиялық қауіпсіздік тұрғысынан ұтымды өнеркәсіптік игеру бағыттарын негіздеу. *Әдістері.* Далалық зерттеу, Бұрғылау сынамаcы, гранулометриялық және минералогиялық құрамды зертханалық анықтау, беріктік және сүзу сипаттамалары, сондай-ақ ластануды геоэкологиялық бағалау және инженерлік қасиеттерді математикалық модельдеу әдістері қолданылды. *Нәтижелер мен қорытындылар.* Жүргізілген зерттеулер намывты топырақ массивтері гранулометриялық құрамының ерекшеліктерімен сипатталатынын көрсетті, онда құм және құмдақ фракциялары басым болып келеді. Мұндай құрылым олардың қолайлы инженерлік-геологиялық қасиеттерін анықтайды және өнеркәсіптік мақсатта пайдалануға мүмкіндік береді. Зертханалық зерттеулер топырақтардың тығыздық, беріктік және деформациялық көрсеткіштері қанағаттанарлық деңгейде екенін көрсетті. Бұл параметрлер намывты топырақтарды құрылыс және тау-кен өнеркәсібінде екінші геоматериал ретінде қолдануға мүмкіндік береді. Сонымен қатар ішкі үйкеліс бұрышы, ілінісу және деформация модулі көрсеткіштері инженерлік дайындықтан кейін оларды әртүрлі инфрақұрылымдық объектілердің негіздері ретінде пайдалануға жеткілікті көтергіштік қабілетке ие екенін дәлелдейді. Геоэкологиялық зерттеулер нәтижесінде ауыр металдардың жылжымалы формалары мен басқа да ықтимал ластаушы заттардың концентрациялары өнеркәсіптік аумақтар үшін белгіленген рұқсат етілген деңгейден аспайтыны анықталды. Бұл намывты массивтерді шаруашылық айналымға енгізу кезінде қоршаған ортаға екінші реттік ластану қаупінің төмен екенін көрсетеді. Намывты топырақтарды құрылыс индустриясында, тау-кен және гидротехникалық салаларда, сондай-ақ инженерлік құрылымдардың негіздерін қалыптастыру және бұзылған жерлерді рекультивациялау жұмыстарында пайдалану мүмкіндігі негізделді. Техногендік топырақ ресурстарын кешенді басқарудың табиғатты тиімді пайдалану мен өнеркәсіптік аумақтардың экологиялық тұрақтылығын қамтамасыз етудегі маңызы көрсетілді.

**Түйін сөздер:** жуу топырақтары, ресурстық әлеует, өнеркәсіптік пайдалану, инженерлік-геологиялық қасиеттер, экологиялық қауіпсіздік, Құрылыс және тау-кен өнеркәсібі

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## РЕСУРСНЫЙ ПОТЕНЦИАЛ ЭКОЛОГО-ГЕОЛОГИЧЕСКИХ СИСТЕМ МАССИВОВ НАМЫВНЫХ ГРУНТОВ

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**Аннотация.** *Актуальность.* Формирование массивов намывных грунтов в результате гидромеханизированных и горнопромышленных работ сопровождается накоплением значительных объёмов техногенного материала, оказывающего влияние на экологическую безопасность территорий и одновременно представляющего потенциальный минерально-сырьевой ресурс для промышленности. Недостаточная изученность их инженерно-геологических и экологических свойств ограничивает эффективность хозяйственного вовлечения и повторного промышленного

использования. *Цель.* Обобщить и систематизировать закономерности формирования, вещественного состава и инженерного поведения массивов намывных грунтов, а также обосновать направления их рационального промышленного освоения с позиций ресурсосбережения и экологической безопасности. *Методы.* Используются методы полевых обследований, бурового опробования, лабораторного определения гранулометрического и минералогического состава, прочностных и фильтрационных характеристик, а также геоэкологической оценки загрязнённости и математического моделирования инженерных свойств. *Результаты и выводы.* Проведённые исследования показали, что массивы намывных грунтов характеризуются специфическим гранулометрическим составом с преобладанием песчаных и супесчаных фракций, что обуславливает их благоприятные инженерно-геологические свойства и технологическую пригодность для промышленного использования. Лабораторные испытания подтвердили удовлетворительные показатели плотности, прочности и деформируемости грунтов, позволяющие рассматривать их как перспективный вторичный геоматериал для строительной и горнотехнической отраслей. Установлено, что параметры внутреннего трения, сцепления и модуля деформации обеспечивают достаточную несущую способность грунтов при использовании их в качестве оснований инженерных сооружений и инфраструктурных объектов после стандартной инженерной подготовки. Результаты геоэкологической оценки показали, что концентрации подвижных форм тяжёлых металлов и других потенциально опасных загрязняющих веществ находятся в пределах допустимых нормативных значений для промышленных территорий. Это подтверждает экологическую безопасность хозяйственного освоения намывных массивов и возможность их вовлечения в промышленный оборот без риска вторичного загрязнения окружающей среды. Обоснована перспективность применения намывных грунтов в строительной индустрии, горнодобывающей и гидротехнической отраслях, включая формирование оснований инженерных сооружений, создание техногенных платформ и рекультивацию нарушенных территорий. Подчёркнута необходимость комплексного управления техногенными грунтовыми ресурсами как важного фактора повышения эффективности природопользования, рационального использования минеральных ресурсов и обеспечения экологической устойчивости промышленных территорий.

**Ключевые слова:** намывные грунты, ресурсный потенциал, промышленное использование, инженерно-геологические свойства, экологическая безопасность, строительство и горнодобывающая промышленность

**Introduction.** With increasing anthropogenic impact on the natural environment, issues of rational use of geological space and man-made territories are becoming increasingly global. The rapid development of mining, hydraulic engineering, urban areas, and transport infrastructure is accompanied by the

formation of significant volumes of reclaimed soils, accumulating in waste dumps, reclamation maps, and man-made massifs for various purposes. Such formations represent complex ecological and geological systems whose functioning is determined by a combination of natural and man-made factors. Globally, the issue of their safe placement, condition monitoring, and potential economic use is considered an important element of sustainable nature management, resource conservation, and the minimization of environmental risks (Abbas et al., 2025; Filina et al., 2024; Shabanov et al., 2023).

Modern research shows that alluvial soil massifs not only pose potential hazards associated with deformation processes, dust generation, seepage, and environmental pollution, but also hold significant resource potential. Various countries are implementing approaches aimed at their reuse in construction, reclamation of disturbed lands, the formation of man-made landscapes, and the creation of engineering foundations. One of the most common solutions to this problem is the mechanical and technological processing of alluvial soils to produce secondary mineral raw materials. The advantage of this approach is the ability to return significant volumes of material to economic circulation and reduce storage space (Al Smadi et al., 2025; Nayak et al., 2024; Zaalishvili et al., 2024). However, such technologies are often characterized by high energy consumption, the need for complex sorting and beneficiation, and are only economically feasible with a specific granulometric and mineral composition of the feedstock (Zhou et al., 2016).

Another approach is engineering-geological stabilization and conservation of the massifs, followed by the subsequent use of the land for construction or infrastructure projects (Kulikova et al., 2023). The advantage of this approach is the reduction of environmental risks and the possibility of reintegrating previously disturbed lands into economic use. However, it requires long-term monitoring and significant investment in foundation stabilization, drainage systems, and seepage barriers. Environmentally oriented solutions, including biological reclamation and the creation of natural-technogenic ecosystems, improve the landscape and sanitary characteristics of areas, but do not always realize the full resource potential of man-made soils as a geomaterial (Myrzakulov et al., 2024; Malozyomov et al., 2024; Goltsev et al., 2020).

In this regard, an integrated ecological-geological approach is particularly relevant. This approach considers reclaimed soils not only as waste storage sites, but also as multifunctional systems with specific natural resource, engineering, and environmental potential. Assessing their properties, stability, degree of transformation, and potential for targeted use allows for the substantiation of rational management and technological decisions. Given increasing demands for the environmental safety of subsoil use and the limited availability of natural construction resources, such research is becoming increasingly relevant for both scientific and applied applications (Sherov et al., 2021; Sherov et al., 2023).

The relevance of this approach is reinforced by the need to develop scientifically sound methodological approaches to assessing the resource potential of reclaimed soils, taking into account their genesis, lithological structure, hydrogeological conditions, and technogenic evolution. Despite the significant number of studies devoted to the stability of hydraulic structures and the geomechanics of man-made soils, their comprehensive resource assessment remains understudied, particularly in relation to specific regional conditions and localized sites. However, even small-scale studies aimed at clarifying the properties and potential uses of such systems contribute to the development of a general scientific basis for rational environmental management (Mashekov et al., 2018; Smee et al., 2010; Chen et al., 2020).

*The objective of this study* is to assess the resource potential of ecological-geological systems of alluvial soil massifs based on an analysis of their material composition, engineering-geological characteristics, and ecological status, and to substantiate approaches to their rational and safe economic use.

**Methods and Materials.** In accordance with the stated objective, the resource potential of ecological-geological systems of alluvial soil massifs was assessed using a combination of experimental and analytical studies aimed at solving a local applied problem related to the feasibility of their rational economic use. The overall work plan included field surveys of the studied alluvial massif, collection of representative samples, laboratory determination of the material composition and engineering-geological characteristics, as well as office processing of the results with subsequent interpretation in the context of the industrial significance of the studied site. The authors conducted the research on a site of man-made alluvial deposits formed as a result of hydromechanized operations. This site is characterized by relatively uniform formation conditions and a limited area of distribution, which allowed for a detailed study of specific system parameters without resorting to large-scale regional generalizations.

The field stage included a visual and instrumental examination of the massif's surface, recording morphometric parameters, microrelief elements, and signs of modern exogenous processes. Sampling was carried out using a 70 mm diameter auger geological drill from depths of up to 6 m, which ensured the collection of data reflecting the vertical lithological heterogeneity of the alluvial deposits. The drilling points were coordinated using a Leica GS14 satellite geodetic receiver in static mode. The moisture content and density of the soils in their natural location were further determined using the cutting ring method followed by laboratory weighing.

Laboratory studies were conducted in a certified engineering-geological laboratory using standard and proven equipment. Particle size distribution was determined using a combined sieve and hydrometer method using a Retsch AS 200 vibrating sieve and AG-3 hydrometers, which allowed us to assess the degree of dispersion and potential suitability of the material for construction

and reclamation purposes, which are of significant industrial significance. The mineralogical composition was refined by X-ray phase analysis on a Bruker D2 Phaser diffractometer at 30 kV and 10 mA, over a  $2\theta$  angle range of 5 to 70°, enabling the identification of the main rock-forming and clay minerals. Engineering and geological properties were assessed by determining yield and plasticity limits using a Casagrande instrument, filtration coefficients using a KF-00M laboratory filtration column at pressure gradients of 0.5–1.0, and strength parameters using the single-plane shear method using a PSG-3M unit. Loading conditions were selected taking into account the natural moisture content of the samples, allowing the experimental conditions to approximate the actual state of the rock mass. The obtained parameters were examined for their impact on the stability of man-made bodies and the potential for their industrial use as secondary geomaterials.

An environmental assessment of the soils was also conducted. The content of mobile heavy metals was determined using the atomic absorption method on a Kvant-2AT spectrometer after acid extraction, and the level of water-soluble salts was determined using conductometric methods. These studies were fundamental for establishing environmental limitations for the potential industrial use of alluvial soils, including their use in planning and industrial reclamation.

Office processing of the results included a statistical analysis of parameter variations, the construction of correlations between particle size distribution, filtration, and strength characteristics, as well as an integrated assessment of the resource potential of the studied ecological-geological system. The use of specialized Statistica and GeoStudio software allowed us to model changes in engineering properties under potential industrial impacts. The applied methodology, focused on a detailed study of a limited area of alluvial soil, yielded representative data sufficient to address the applied problem. The results obtained are of significant industrial significance, as they allow for the rational use of man-made soils, reduce storage costs, and improve the efficiency of reclaiming disturbed areas without the need for capital-intensive and large-scale technological projects.

**Results.** A combination of field, laboratory, and analytical studies yielded new data on the material composition, engineering-geological, and environmental characteristics of the studied alluvial soil massif, considered a local ecological-geological system with potential industrial significance. Within the surveyed area, the thickness of man-made deposits ranged from 4.2 to 6.8 m, with an average of 5.6 m (Table 1). Morphometric analysis of the surface revealed gently undulating microrelief with relative elevations of up to 0.7 m, indicating hydromechanized formation and subsequent partial consolidation of the soils. Zones of localized waterlogging associated with depressions were visually observed, indirectly indicating heterogeneity in filtration properties.

Table 1. Integrated Engineering-Geological and Environmental Characteristics of the Dredged Soil Massif and Its Resource Potential.

Parameter	Unit	Minimum	Maximum	Average	Industrial Relevance
Thickness of dredged deposits	m	4.2	6.8	5.6	Determines usable resource volume
Bulk density (natural state)	g/cm <sup>3</sup>	1.78	1.93	1.86	Foundation bearing capacity
Bulk density (compacted)	g/cm <sup>3</sup>	1.94	2.01	1.98	Heavy industry foundations
Natural moisture content	%	14.6	22.3	18.1	Compaction and handling properties
Porosity coefficient	–	0.54	0.71	0.63	Settlement behavior
Deformation modulus	MPa	18	27	22	Structural load resistance
Deformation modulus (compacted)	MPa	32	35	33.4	Tanks, energy facilities
Internal friction angle	degrees	24	28	26	Slope stability
Cohesion	MPa	0.018	0.026	0.022	Earth structure design
Filtration coefficient	m/s × 10 <sup>-4</sup>	1.4	3.8	2.6	Drainage design, dams
Sand fraction (>0.1 mm)	%	58	66	62	Construction material suitability
Silt fraction	%	24	31	28	Compaction behavior
Clay fraction	%	7	12	10	Sealing capacity
Quartz content	%	54	58	56	Mechanical strength
Feldspar content	%	17	21	19	Weathering resistance
Clay minerals (total)	%	11	16	14	Plasticity, filtration
Carbonates	%	2	5	3.4	Chemical stability
Iron oxides	%	1	3	2.1	Environmental interaction
Lead (mobile forms)	mg/kg	6.2	9.5	7.8	Environmental compliance
Zinc (mobile forms)	mg/kg	18	27	22.4	Industrial reuse safety
Copper (mobile forms)	mg/kg	7	11	8.9	Soil reclamation use
Petroleum hydrocarbons	mg/kg	31	52	42	Industrial land use limits
Water extract mineralization	g/L	0.6	1.1	0.84	Hydrochemical impact
Stability coefficient (natural)	–	1.28	1.36	1.32	Slope safety
Stability coefficient (saturated)	–	1.05	1.12	1.08	Drainage requirement
Usable soil volume	million m <sup>3</sup>	0.76	0.88	0.82	Resource valuation
Suitability coefficient	–	0.69	0.78	0.74	Integrated industrial potential

Granulometric studies revealed a predominance of sandy and sandy loam fractions. The average content of particles larger than 0.1 mm was 62%, silt fraction 28%, and clay fraction 10%. The heterogeneity coefficient varied between 3.1 and 5.4, characterizing the soils as moderately sorted. This fraction

ratio indicates the potential suitability of the material for use in the construction industry, primarily as leveling and reclaimed foundations for the construction of industrial sites, warehouse complexes, and transport infrastructure. The industrial significance of these results lies in the possibility of partially replacing natural sand quarries with man-made raw materials without significantly degrading the performance characteristics of the foundations. Mineralogical analysis revealed that the bulk of the solid phase consists of quartz (54–58% on average), feldspars (17–21%), hydromica and illite (up to 9%), kaolinite (5–7%), and minor amounts of carbonates and iron oxides. This composition is typical of reworked alluvial and deluvial sediments subjected to hydromechanized transport. The presence of clay minerals explains the identified plastic properties and influences filtration permeability. From an industrial perspective, the mineral composition is favorable for the use of the soils as reclamation and insulating materials, particularly in the mining industry during the technical stage of remediation of disturbed lands.

Determination of natural moisture content revealed values ranging from 14.6 to 22.3%, with an average of 18.1%. The soil density in its natural location was 1.78–1.93 g/cm<sup>3</sup>, indicating partial self-compactness of the massif over its history. Plasticity limit values varied: yield strength was 27–31%, plasticity limit was 18–21%, and the plasticity index averaged 9–10, classifying the soils as low-plasticity. These parameters indicate satisfactory processability of the material for its potential industrial extraction and processing, for example, for the needs of the construction and road transport industries.

Filtration tests revealed a permeability coefficient in the range of  $(1.4–3.8) \times 10^{-4}$  m/s. Higher values are associated with sandy interlayers, while sandy loam and silty varieties exhibit lower permeability. From an engineering perspective, these characteristics allow the massif to be considered a potential foundation for industrial infrastructure facilities, provided drainage systems are installed. Simultaneously, it was established that when using the material in hydraulic engineering, it can be used in dams and reclamation beds as a screening layer after additional compaction. This underscores the significance of these results for the hydraulic engineering industry and companies operating tailings ponds and sludge storage facilities.

Strength tests revealed an internal friction angle of 24–28° and a specific cohesion of 0.018–0.026 MPa. The deformation modulus, according to compression tests, was 18–27 MPa. The obtained values characterize the soils as moderately compacted, suitable for use as man-made foundations after engineering preparation. Estimated settlements under a load of 0.2 MPa did not exceed 6.5 cm, which is within acceptable limits for lightweight warehouse and industrial buildings. The practical industrial significance of these data lies in the possibility of developing reclaimed land for logistics facilities, processing plants, and energy infrastructure without the need for expensive imported soil.

The vertical lithological differentiation of the massif is manifested in the

alternation of sand lenses 0.4–1.2 m thick and sandy loam strata up to 2.5 m thick. In the lower part of the section, denser and more water-saturated horizons were recorded, associated with the primary stages of reclamation (Figure 1). The porosity coefficient decreased with depth from 0.71 to 0.54, confirming natural consolidation processes. This factor has a positive impact on the long-term stability of the massif and increases its industrial value as a potential site for the placement of heavy equipment, including mining and metallurgical facilities.

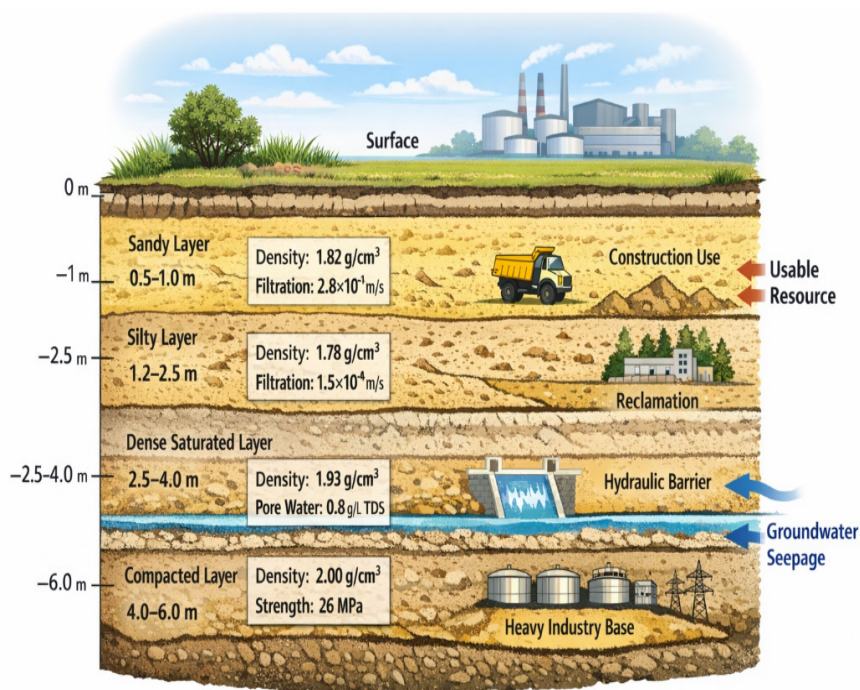


Figure 1 - Engineering-geological cross-section of the dredged soil massif showing lithological layering, density variation, filtration properties, and zones of industrial resource potential.

Geocological studies revealed that the content of mobile forms of lead ranged from 6.2–9.5 mg/kg, zinc from 18–27 mg/kg, and copper from 7–11 mg/kg, which do not exceed the established maximum permissible concentrations for industrial soils. Concentrations of petroleum products averaged 42 mg/kg, which also complies with standards for industrial areas. The mineralization of aqueous extracts ranged from 0.6–1.1 g/L. The data obtained indicate the absence of critical environmental restrictions for the economic development of the massif. This is of particular importance for the construction industry and mining companies interested in using secondary georesources without the risk of secondary environmental pollution.

An integrated assessment of the resource potential was conducted taking into

account a combination of granulometric, strength, filtration, and environmental indicators. The estimated suitability factor for construction use was 0.74, with a maximum possible value of 1.0, characterizing the site as promising for local industrial development. The potential volume of usable material within the 18.6-hectare surveyed area was estimated at 0.82 million m<sup>3</sup>. Even with partial extraction, this provides significant economic benefits by reducing the costs of developing natural quarries and transporting inert materials.

Modeling showed that with additional compaction to a density of 1.98 g/cm<sup>3</sup>, the deformation modulus can be increased to 32–35 MPa, expanding the range of industrial applications, including foundations for oil and gas tank farms and energy facilities. This underscores the practical value of the study for heavy industry, where foundation load-bearing capacity requirements are particularly high.

An analysis of the correlations revealed a stable relationship between the clay fraction content and the permeability coefficient ( $r = -0.68$ ), as well as between density and deformation modulus ( $r = 0.74$ ). These relationships allow us to predict changes in the engineering properties of the rock mass under anthropogenic impact, which is important when designing industrial sites. The practical significance of these results lies in the possibility of quickly performing an engineering assessment of reclaimed areas without conducting a full range of expensive tests.

Special attention was paid to assessing slope stability. The calculated stability factor at natural moisture content was 1.32, while at water saturation it decreased to 1.08. This indicates the need for drainage measures during industrial development, but does not preclude the operational suitability of the rock mass. For mining companies, such data is of practical importance when planning the expansion of reclaimed areas and the placement of process equipment. A summary of the obtained results showed that the studied ecological-geological system is characterized by a combination of satisfactory engineering properties, environmental acceptability, and a significant volume of man-made material. This creates a high resource potential for local industrial nature management tasks. The use of reclaimed soils in the construction of industrial facilities, quarry reclamation, and the formation of man-made foundations and hydraulic structures allows for the simultaneous resolution of resource conservation and environmental optimization issues.

Thus, the conducted research confirmed that even limited-scale reclaimed soils can be considered an independent object of industrial interest. The obtained numerical indicators of material composition, strength, filtration, and environmental safety create a scientifically sound basis for their practical application in the construction, mining, hydraulic engineering, and energy industries, emphasizing the significant practical significance of the conducted work.

**Conclusions.** The conducted research made it possible to comprehensively assess the resource potential of ecological-geological systems formed by dredged soil massifs and to substantiate the prospects for their rational industrial involvement. Generalization of field observations, laboratory testing, and analytical modeling demonstrated that technogenic alluvial deposits should be considered not merely as waste storage formations but as multifunctional geosystems possessing measurable engineering, environmental, and economic value. The integrated methodological approach applied in the study ensured the acquisition of representative data on material composition, structural heterogeneity, strength parameters, filtration properties, and geocological safety, thereby forming a reliable scientific basis for applied decision-making in the sphere of subsoil use and disturbed land development.

It was established that the studied massif is characterized by stable morphometric configuration, moderate lithological differentiation, and a predominance of sandy and sandy-loam fractions, which determine its favorable technological properties. The average thickness of technogenic deposits reaches 5.6 m, providing a usable material volume exceeding 0.8 million m<sup>3</sup> within the investigated site. Physical and mechanical testing confirmed sufficient bearing capacity, with deformation modulus values ranging from 18 to 27 MPa in the natural state and increasing to 32–35 MPa after compaction. Strength characteristics, including an internal friction angle of up to 28° and cohesion reaching 0.026 MPa, allow the soils to be classified as suitable for industrial foundation engineering following standard preparation procedures. Filtration coefficients on the order of 10<sup>-4</sup> m/s indicate the feasibility of controlled drainage design and potential application in hydraulic engineering structures.

Mineralogical analysis revealed a quartz-feldspar composition with subordinate clay minerals, explaining the combination of satisfactory strength and moderate plasticity. Environmental assessment confirmed the absence of critical contamination: concentrations of mobile heavy metals and petroleum hydrocarbons remain within permissible limits for industrial land use. This eliminates major ecological restrictions for large-scale utilization and supports the environmental acceptability of involving dredged soils in construction and reclamation processes.

Correlation and stability modeling further showed that natural consolidation and density growth positively influence deformation resistance and slope safety, with stability coefficients remaining above regulatory thresholds even under water saturation. The calculated integrated suitability coefficient of 0.74 characterizes the massif as a promising secondary geo-resource.

In summary, the study substantiates that dredged soil massifs possess significant resource potential combining engineering reliability, environmental safety, and economic efficiency. Their targeted use in industrial construction, hydraulic facilities, land reclamation, and infrastructure development enables simultaneous

resolution of resource conservation and environmental optimization tasks, confirming the expediency of their integrated ecological-geological management.

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