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STRATEGIC MANAGEMENT OF STOCKPILED TOPSOIL GENERATED BY LARGE INFRASTRUCTURE PROJECTS: EVIDENCE FROM THE AKHURYAN RESERVOIR, ARMENIA

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Abstract

Large infrastructure projects frequently require the removal of the fertile topsoil layer during construction activities. Although this material represents a valuable natural resource, it is often treated as a temporary by-product and remains unused for long periods, resulting in quality degradation and economic losses. This study evaluates the volume, quality, and management potential of stockpiled topsoil accumulated during the construction of the Akhuryan Reservoir in Armenia.

The research combines UAV-based topographic surveying, cadastral data analysis, soil sampling, laboratory determination of humus content using the Tyurin method, and assessment of legal demand for fertile soil. The results indicate that approximately 212,532 m³ of topsoil has been accumulated within a designated storage area. Laboratory analyses revealed an average humus content of 3.54%, corresponding to high-quality agricultural soil. Comparative analysis showed a significant imbalance between the accumulated stockpile volume and the officially recorded demand for fertile soil.

The findings demonstrate that long-term storage of topsoil may lead to gradual degradation of soil quality and reduction of its agricultural value. The study proposes a strategic resource-management approach in which stockpiled topsoil generated by large infrastructure projects is considered a strategic environmental resource requiring systematic inventory, monitoring, and controlled redistribution.

The proposed approach may contribute to improved soil conservation, reduction of illegal soil extraction, and more efficient utilization of valuable land resources in Armenia and other countries facing similar challenges.

***Keywords*:** topsoil management; fertile soil; soil conservation; infrastructure projects; humus content; resource management; Akhuryan Reservoir; Armenia.

Introduction

Topsoil, the fertile upper layer of soil, is one of the most valuable natural resources within terrestrial ecosystems. Formed over thousands of years through complex physical, chemical, and biological processes, it provides the foundation for plant growth, biodiversity conservation, carbon sequestration, water regulation, and sustainable agricultural production. Unlike many other natural resources, fertile topsoil is renewed extremely slowly; therefore, its degradation or loss may result in long-term environmental, social, and economic consequences.

During recent decades, the implementation of large-scale infrastructure projects—including reservoirs, highways, industrial facilities, residential developments, mining operations, and energy infrastructure—has accelerated worldwide. Construction of such projects typically requires the removal of the fertile topsoil layer during site preparation. This material is generally stockpiled in designated storage areas for future reclamation or reuse following project completion.

Despite existing environmental regulations and engineering practices, stockpiled topsoil frequently remains unused for extended periods. Prolonged storage may lead to gradual deterioration of soil structure, reduction in biological activity, loss of active organic matter, compaction, and increased susceptibility to erosion, ultimately decreasing its agricultural and ecological value. At the same time, many regions continue to experience substantial demand for fertile soil for agricultural production, land reclamation, landscaping, and urban greening projects. This contradiction indicates that the principal challenge is not the availability of fertile soil itself, but the effectiveness of its management.

International scientific literature has devoted considerable attention to soil conservation, land degradation, and sustainable soil-resource management. However, the assessment and management of stockpiled topsoil generated by large infrastructure projects have received comparatively limited attention. Existing studies primarily focus on reclamation techniques, erosion control, and restoration practices, whereas relatively little emphasis has been placed on systematic inventory, quantitative assessment, quality preservation, demand–supply analysis, and strategic redistribution of accumulated topsoil resources. Consequently, significant methodological gaps remain regarding the integration of these aspects into a comprehensive resource-management framework.

In the Republic of Armenia, numerous large-scale water infrastructure, transportation, industrial, and urban development projects have generated substantial volumes of stockpiled topsoil. Simultaneously, both legal demand for fertile soil and cases of illegal soil extraction have been recorded, indicating deficiencies in existing management, accounting, and regulatory mechanisms. Under these conditions, accumulated topsoil should no longer be regarded merely as temporarily stored excavated material, but rather as a strategic environmental resource whose effective management can simultaneously contribute to soil conservation, sustainable agriculture, environmental protection, and more efficient utilization of national land resources.

The objective of this study is to evaluate the volume, quality characteristics, and management potential of the stockpiled topsoil accumulated during the construction of the Akhuryan Reservoir in Armenia by integrating UAV-based topographic surveying, cadastral analysis, laboratory soil testing, and demand assessment. Based on the obtained results, the study proposes a strategic management approach for stockpiled topsoil that may support sustainable resource utilization in Armenia and provide a practical framework applicable to other countries implementing large infrastructure projects.

Literature Review

Topsoil as a Strategic Natural Resource

Topsoil represents one of the fundamental components of terrestrial ecosystems, formed through long-term interactions among physical, chemical, and biological processes. Classical soil formation theory demonstrates that soil development depends on the combined influence of parent material, climate, topography, biota, and time, making fertile topsoil a slowly renewable and highly vulnerable natural resource [40]. Contemporary soil science further recognizes topsoil not only as the foundation of agricultural production but also as a provider of essential ecosystem services, including water regulation, carbon sequestration, nutrient cycling, and biodiversity conservation [35,39].

During the last decade, soil conservation has become a global priority. Assessments published by the United Nations Convention to Combat Desertification (UNCCD), the Food and Agriculture Organization (FAO), the Intergovernmental Panel on Climate Change (IPCC), and the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (IPBES) consistently identify soil degradation as one of the major threats to food security, climate resilience, and ecosystem restoration [1,10,32,33]. The loss of fertile soil or deterioration of its quality is particularly critical in countries with limited land resources, where agriculture continues to play a significant socio-economic role. Consequently, the conservation of topsoil should be regarded not only as an environmental issue but also as a strategic resource-management challenge.

Recent international policy documents increasingly recognize soil as a form of natural capital. The European Union Soil Strategy for 2030 emphasizes the importance of healthy soils for climate-change mitigation, biodiversity conservation, and food security [2]. Similar approaches are reflected in the strategic frameworks developed by FAO and the Global Soil Partnership, which highlight the necessity of sustainable soil management, systematic monitoring, and continuous assessment of soil quality [3,4,34]. These initiatives demonstrate a transition from viewing soil conservation as a purely technical issue toward considering it an integral component of national and international environmental policy.

Scientific research likewise emphasizes the need for integrated soil-health assessment. Modern studies evaluate soil quality using not only physicochemical parameters but also biological activity, soil organic carbon, microbial diversity, and ecosystem functionality [11–13]. Such an integrated perspective is particularly relevant for topsoil because it contains the highest concentrations of humus, root biomass, microorganisms, and plant nutrients that determine soil fertility and ecological performance.

Nevertheless, the majority of existing studies concentrate on agricultural soil conservation, land degradation, erosion control, and ecological restoration. Comparatively little attention has been devoted to fertile topsoil removed during the implementation of large-scale infrastructure projects. Under such conditions, topsoil enters an intermediate state: it is no longer functioning within its natural ecosystem while simultaneously remaining unused for agricultural production, ecological restoration, or landscape rehabilitation. This transitional condition creates a distinct resource-management challenge that has received limited attention in the international scientific literature.

Topsoil Management in Infrastructure and Construction Projects

The implementation of large-scale infrastructure projects is frequently accompanied by the removal of the fertile topsoil layer. During the construction of reservoirs, highways, industrial facilities, mining operations, and urban developments, topsoil is stripped from the construction site to facilitate engineering activities. International guidelines consistently recommend that fertile topsoil should be removed separately from subsoil materials, stored in designated stockpiles, and subsequently reused during land reclamation and ecological restoration [25,26,31].

Technical guidance documents addressing sustainable soil use in construction projects emphasize several key principles for topsoil preservation. These include preventing the mixing of topsoil with underlying materials, limiting stockpile height, minimizing soil compaction, and ensuring proper surface-water management during storage [25,27]. Although these recommendations provide valuable technical guidance, they primarily focus on construction practices and do not establish comprehensive long-term strategies for managing accumulated topsoil resources.

Research conducted in mining and land-reclamation contexts demonstrates that stockpiling may substantially influence the future usability of topsoil. Recent investigations have shown that prolonged storage can alter soil geochemical properties, microbial community composition, biological integrity, and restoration potential [17–23]. These findings are particularly relevant because they indicate that stockpiled topsoil should not be regarded as a stable resource whose quality remains unchanged throughout the storage period.

Despite these advances, the existing literature remains largely focused on mining and post-mining reclamation. Considerably less attention has been devoted to the accumulated topsoil generated during reservoir construction, transportation infrastructure, and urban development projects. In particular, limited research has addressed the quantitative inventory of accumulated topsoil, its legal circulation, demand assessment, and integration into long-term resource-management systems. These shortcomings become especially significant in countries where fertile soil resources are limited and where uncontrolled or illegal soil extraction creates additional environmental and governance challenges.

Therefore, the international experience in topsoil management demonstrates that while technical requirements for soil preservation are relatively well established, considerably less progress has been achieved in developing systematic approaches for inventory, valuation, monitoring, and controlled redistribution of accumulated topsoil as a strategic environmental asset. This research seeks to address this gap by examining the stockpiled topsoil generated during the construction of the Akhuryan Reservoir as a representative case of strategic topsoil resource management.

Effects of Long-Term Topsoil Stockpiling on Soil Quality

The effectiveness of topsoil conservation depends not only on the removal and storage of the fertile soil layer but also on the duration and conditions of storage. Numerous studies published in recent years have demonstrated that even when stockpiles are established in accordance with technical guidelines, prolonged storage may result in gradual deterioration of the physical, chemical, and biological properties of topsoil, thereby reducing its suitability for subsequent reuse [17–24].

Contemporary research indicates that the principal factors affecting the quality of stockpiled topsoil include storage duration, stockpile height, soil compaction, restricted aeration, and alterations in the soil moisture regime [19–23]. The combined influence of these factors reduces soil porosity, disrupts gas exchange, suppresses aerobic biological processes, and gradually decreases microbial activity. Simultaneously, changes occur in the mineralization of organic matter, accompanied by losses of active humus fractions and reduced bioavailability of essential plant nutrients [13,17,19]. These findings demonstrate that the quality of stockpiled topsoil continuously evolves during storage rather than remaining constant over time.

Particular attention has recently been devoted to changes in soil microbial communities. Fischer et al. demonstrated that increasing stockpile height significantly alters both the composition and diversity of microbial communities, directly affecting soil functionality and ecological resilience [21]. Similar conclusions were reported by Bordez et al., who observed substantial modifications in microbial diversity, enzymatic activity, and biochemical processes even after relatively short storage periods [23]. These studies suggest that evaluating topsoil quality should extend beyond conventional physicochemical analyses to include biological indicators that better reflect the functional condition of the soil ecosystem.

Structural changes within stockpiled topsoil have also been identified as an important consequence of prolonged storage. Ledesma et al. reported that extended stockpiling leads to pronounced vertical heterogeneity within soil piles, resulting in considerable differences in moisture content, soil organic carbon, nutrient availability, and microbial activity between upper and lower layers [20]. Such heterogeneity may substantially reduce the effectiveness of subsequent reclamation activities and negatively influence vegetation establishment following soil redistribution.

Similarly, Valliere et al. demonstrated that long-term stockpiling disrupts the biological integrity of topsoil even when major physicochemical properties remain relatively stable [17]. Their findings indicate that the loss of biological integrity may become one of the principal limiting factors affecting ecological restoration success. Comparable conclusions were reached by D'Agui et al., who showed that different methods used to evaluate soil biological properties exhibit varying sensitivity to storage-induced changes, emphasizing the importance of applying comprehensive assessment approaches when evaluating stockpiled topsoil quality [18].

Although considerable progress has been achieved in understanding the effects of stockpiling on soil quality, the existing literature remains strongly focused on post-mining reclamation and mine-site restoration [17–23]. Comparatively few studies have examined topsoil stockpiles generated during reservoir construction, transportation infrastructure, or other large-scale civil engineering projects. Furthermore, most available investigations concentrate on individual physical, chemical, or biological indicators rather than integrating soil quality changes with stockpile volume, storage duration, legal demand, and long-term management strategies.

Consequently, the international scientific literature provides compelling evidence that long-term topsoil stockpiling is not a neutral process. Rather, storage time itself should be regarded as an independent factor influencing soil quality and, therefore, should be explicitly considered in reclamation planning and resource management. Nevertheless, no comprehensive methodological framework has yet been proposed to integrate stockpile-induced soil quality changes with quantitative inventory, demand assessment, and strategic redistribution of accumulated topsoil resources. Addressing this methodological gap constitutes one of the principal objectives of the present study.

International Approaches to Topsoil Reuse and Resource Management

During the last two decades, international approaches to topsoil management have evolved considerably. While earlier practices primarily focused on the technical aspects of topsoil conservation and land reclamation, contemporary approaches increasingly emphasize sustainable resource utilization, circular economy principles, and the efficient management of natural capital [2–10, 27–36].

According to current international concepts, topsoil removed during the implementation of large-scale infrastructure projects should not be regarded as waste or merely as temporarily excavated material but rather as a valuable natural resource suitable for subsequent reuse. Policy frameworks and technical guidelines developed by the European Union, the Food and Agriculture Organization (FAO), the United Nations Environment Programme (UNEP), and the World Bank consistently recommend preserving fertile topsoil, preventing its degradation during storage, and returning it to productive use through ecological restoration, land reclamation, urban greening, and agricultural development whenever possible [2–10,25,26,31,34].

The scientific literature identifies several principal directions for the reuse of stockpiled topsoil, including post-mining reclamation, restoration of construction sites, landscape rehabilitation along transportation corridors, urban green infrastructure development, rehabilitation of degraded lands, and improvement of agricultural soil fertility [11–18,24,27]. Numerous studies further demonstrate that topsoil reuse not only reduces the need for extracting fertile soil from undisturbed areas but also contributes to resource conservation, ecosystem restoration, and the reduction of greenhouse gas emissions associated with land disturbance [10–16,32,33].

Recent research has increasingly highlighted the importance of systematic soil governance. The proposed European Soil Monitoring Law, together with initiatives developed within the framework of the European Union Soil Observatory (EUSO) and the EJP SOIL programme, aims to establish harmonized systems for soil monitoring, quality assessment, and long-term evaluation of soil health across Europe [5,28,29,36]. These initiatives demonstrate a gradual transition from project-specific soil management toward integrated national and regional strategies for sustainable soil governance.

Despite these advances, analysis of the international literature indicates that existing approaches remain largely focused on technical preservation measures, soil quality monitoring, and reclamation practices. Comparatively limited attention has been devoted to situations where large volumes of fertile topsoil accumulate as a consequence of infrastructure development projects and remain stockpiled for extended periods without systematic inventory, continuous quality monitoring, or coordinated redistribution mechanisms. Existing publications rarely address accumulated topsoil stockpiles as resources requiring strategic management at regional or national scales [21,25–31].

Another important limitation of current research is its predominant focus on individual projects or specific restoration sites. Most investigations evaluate the condition of topsoil removed from a particular mine, construction site, transportation project, or urban development area, whereas considerably less attention has been paid to the integrated management of accumulated topsoil originating from multiple infrastructure projects. Consequently, issues such as quantitative inventory, assessment of legal demand, controlled redistribution, economic utilization, and national coordination remain largely unexplored. As a result, accumulated topsoil continues to be treated primarily as a project-specific engineering material rather than as an integral component of national natural capital [2–10,25–36].

Therefore, the international experience demonstrates that although technical methods for topsoil preservation and reuse have been developed to a relatively high level, considerably less progress has been achieved in establishing comprehensive frameworks for the long-term management of accumulated topsoil resources. Systematic inventory, continuous quality assessment, demand analysis, and controlled redistribution remain insufficiently addressed in the existing literature. These observations suggest that topsoil generated during large-scale infrastructure projects should be regarded not merely as material intended for future reclamation but as a **strategic environmental asset** whose effective management can substantially improve the efficiency of national soil resource utilization while reducing the need for additional extraction of fertile soils from natural landscapes.

Research Gap and Conceptual Framework

A comprehensive analysis of the international scientific literature demonstrates that substantial progress has been achieved in recent years regarding soil conservation, soil health assessment, land reclamation technologies, sustainable soil management, and soil monitoring systems [1–40]. Considerable advances have been made in the development of soil quality assessment methods, technical standards for topsoil preservation, and scientific understanding of soil ecosystem services and natural capital [2–10,13–18,25–36].

Despite these achievements, the comparative review reveals several fundamental limitations that remain insufficiently addressed. First, the majority of published studies examine topsoil within the context of individual construction or restoration projects without considering accumulated topsoil generated by multiple infrastructure developments as an integrated resource system [17–24]. Consequently, existing approaches provide only project-specific assessments and do not allow evaluation of the actual scale or strategic significance of accumulated topsoil resources at regional or national levels.

A second important limitation concerns the predominant focus on the physical, chemical, and biological characteristics of topsoil, whereas considerably less attention has been devoted to the organizational, economic, and institutional dimensions of accumulated topsoil management [17–31]. In particular, issues related to systematic inventory, legal demand assessment, resource allocation, controlled redistribution, and long-term governance of accumulated topsoil remain largely absent from the existing scientific literature.

The third limitation is associated with the scale of resource management. Most international studies focus on local or project-level investigations, evaluating topsoil generated during mining operations, transportation infrastructure, or urban development projects [17–31]. Comparatively little research has examined accumulated topsoil originating from multiple infrastructure projects as interconnected strategic resources requiring coordinated management at regional or national scales.

Furthermore, current scientific approaches are primarily designed to evaluate reclamation performance or preserve soil quality during storage. To date, no comprehensive methodological framework has been proposed that simultaneously integrates quantitative inventory of accumulated topsoil, assessment of soil quality, evaluation of storage duration effects, analysis of legal demand, and strategic resource management within a unified conceptual framework [17–31].

These limitations indicate that the existing body of knowledge lacks an integrated approach capable of evaluating accumulated topsoil generated during large-scale infrastructure projects not merely as a by-product of construction activities but as a valuable long-term natural resource. This observation highlights the necessity for a new conceptual perspective based on systematic inventory, continuous quality monitoring, demand assessment, and coordinated redistribution of accumulated topsoil resources.

The present study addresses this scientific gap by proposing an integrated resource-management approach using the stockpiled topsoil generated during the construction of the Akhuryan Reservoir as a representative case study. For the first time, quantitative assessment of accumulated topsoil, laboratory soil analyses, soil quality characteristics, cadastral and spatial information, and legal demand assessment are integrated within a single analytical framework. This integrated methodology enables accumulated topsoil to be considered not as temporarily excavated construction material but as a **strategic environmental asset** whose systematic management can contribute to soil conservation, more efficient utilization of national land resources, and the achievement of sustainable development objectives.

Accordingly, this study fills an important gap in the international scientific literature by introducing the **Strategic Topsoil Resource Management (STRM) framework**, an integrated resource-management framework for the systematic inventory, quality assessment, long-term monitoring, demand analysis, and controlled redistribution of topsoil stockpiles generated during large-scale infrastructure projects. Although demonstrated using the Akhuryan Reservoir case study, the proposed framework has broader applicability and may serve as a methodological basis for sustainable topsoil resource management in other countries implementing similar infrastructure projects.

Conflict Setting

Large-scale infrastructure projects require the removal of substantial volumes of fertile topsoil during site preparation. Although environmental regulations generally require this material to be separately stripped, preserved, and reused for reclamation or land restoration, in practice accumulated topsoil frequently remains stockpiled for prolonged periods without systematic inventory, continuous quality monitoring, or coordinated management. During long-term storage, the physical, chemical, and biological properties of topsoil may gradually deteriorate, reducing its agricultural and ecological value.

At the same time, many countries continue to experience increasing demand for fertile soil for agricultural production, ecological restoration, urban greening, and rehabilitation of degraded lands. Consequently, a practical contradiction arises: while significant quantities of high-quality topsoil remain unused in storage areas, growing sectors of the economy simultaneously face shortages of fertile soil resources. This imbalance indicates that the existing challenge is not limited to soil conservation itself but extends to the absence of effective mechanisms for managing accumulated topsoil resources.

Current management practices primarily address technical aspects of topsoil stripping, storage, and reclamation within individual construction projects. However, they rarely consider accumulated topsoil as a strategic resource requiring systematic inventory, quality assessment, demand analysis, and controlled redistribution beyond the boundaries of a single project. As a result, substantial environmental, economic, and resource-efficiency opportunities remain unrealized.

The present study addresses this practical conflict by introducing the **Strategic Topsoil Resource Management (STRM)** framework, which provides an integrated approach for the systematic inventory, quality assessment, long-term monitoring, demand analysis, and controlled redistribution of accumulated topsoil generated during large-scale infrastructure projects.

Materials and Methods

The methodology developed in this study was designed to provide a comprehensive framework for the assessment and strategic management of topsoil stockpiles generated during large-scale infrastructure projects. Unlike conventional approaches, which primarily focus on soil quality assessment or individual reclamation activities, the proposed methodology integrates field investigations, unmanned aerial vehicle (UAV) surveys, digital terrain modelling, laboratory soil analyses, spatial and cadastral data evaluation, and legal demand assessment within a unified analytical framework.

The methodological structure consists of a sequence of interconnected stages that collectively enable quantitative inventory of accumulated topsoil, comprehensive evaluation of soil quality, assessment of storage-related impacts, and identification of opportunities for subsequent resource utilization. To achieve these objectives, this study develops and applies the **Strategic Topsoil Resource Management (STRM)** framework, an integrated methodological approach that considers accumulated topsoil not merely as a by-product of construction activities but as a strategic natural resource requiring systematic inventory, continuous monitoring, and science-based management. The overall research methodology is presented in **Fig. 2**, while the individual methodological stages are described in the following subsections.

Study Area

The present study was conducted within the accumulated topsoil stockpile area formed during the construction of the Akhuryan Reservoir in Shirak Province, Republic of Armenia.

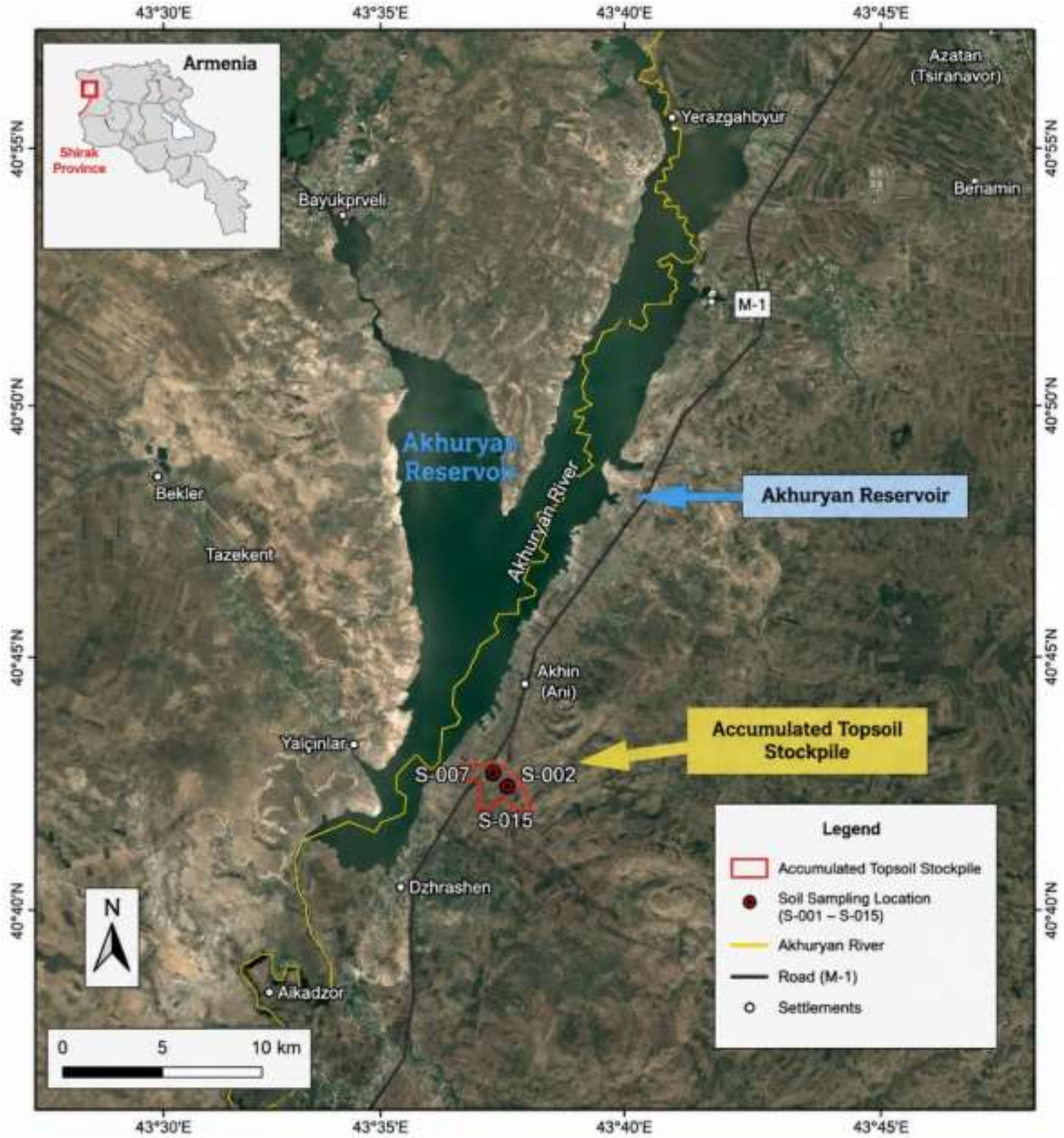

Fig. 1 Location of the Study Area and the Accumulated Topsoil Stockpile

The study area was selected as a representative case study for evaluating the accumulation, quality, and strategic management potential of topsoil generated during large-scale infrastructure projects.

Location of the Akhuryan Reservoir and the accumulated topsoil stockpile investigated in the present study. The figure illustrates the geographical position of the study area within Shirak Province, Republic of Armenia, and identifies the location of the accumulated topsoil stockpile selected for detailed field investigation and subsequent implementation of the Strategic Topsoil Resource Management (STRM) framework.

Fig. 2 Overall Research Methodology and the Strategic Topsoil Resource Management (STRM) Framework

Fig. 2 illustrates the overall methodological structure of the present study together with the integrated Strategic Topsoil Resource Management (STRM) framework. The methodology comprises five interconnected stages: (1) definition of the study area and accumulated topsoil stockpile, (2) multi-source field data acquisition, including UAV surveys, GPS observations, soil sampling, cadastral information, and field investigations, (3) integrated data processing involving digital terrain modelling, volume estimation, laboratory soil analyses, spatial analysis, soil quality assessment, and demand evaluation, (4) implementation of the Strategic Topsoil Resource Management (STRM) framework based on systematic inventory, quality assessment, long-term monitoring, demand analysis, and controlled redistribution of accumulated topsoil resources, and (5) generation of strategic outputs supporting sustainable topsoil management, environmental protection, evidence-based decision-making, and efficient resource governance.

Data Acquisition

A comprehensive data acquisition strategy was adopted to collect field, unmanned aerial vehicle (UAV), laboratory, and spatial information required for the quantitative and qualitative assessment of accumulated topsoil stockpiles. The data acquisition process included field investigations, soil sampling, high-resolution UAV imagery, geographic positioning, and the collection of cadastral and engineering documentation.

The UAV-derived imagery was used for digital terrain modelling, delineation of topsoil stockpile boundaries, and subsequent volume estimation. Field investigations also included soil sampling for laboratory analyses aimed at evaluating the principal physicochemical properties of the accumulated topsoil. In addition to primary field data, spatial, cadastral, and engineering datasets were incorporated to support the integrated analysis and implementation of the Strategic Topsoil Resource Management (STRM) framework. The integrated data acquisition strategy adopted in the present study and the relationships among the principal data sources are illustrated in Fig. 3.

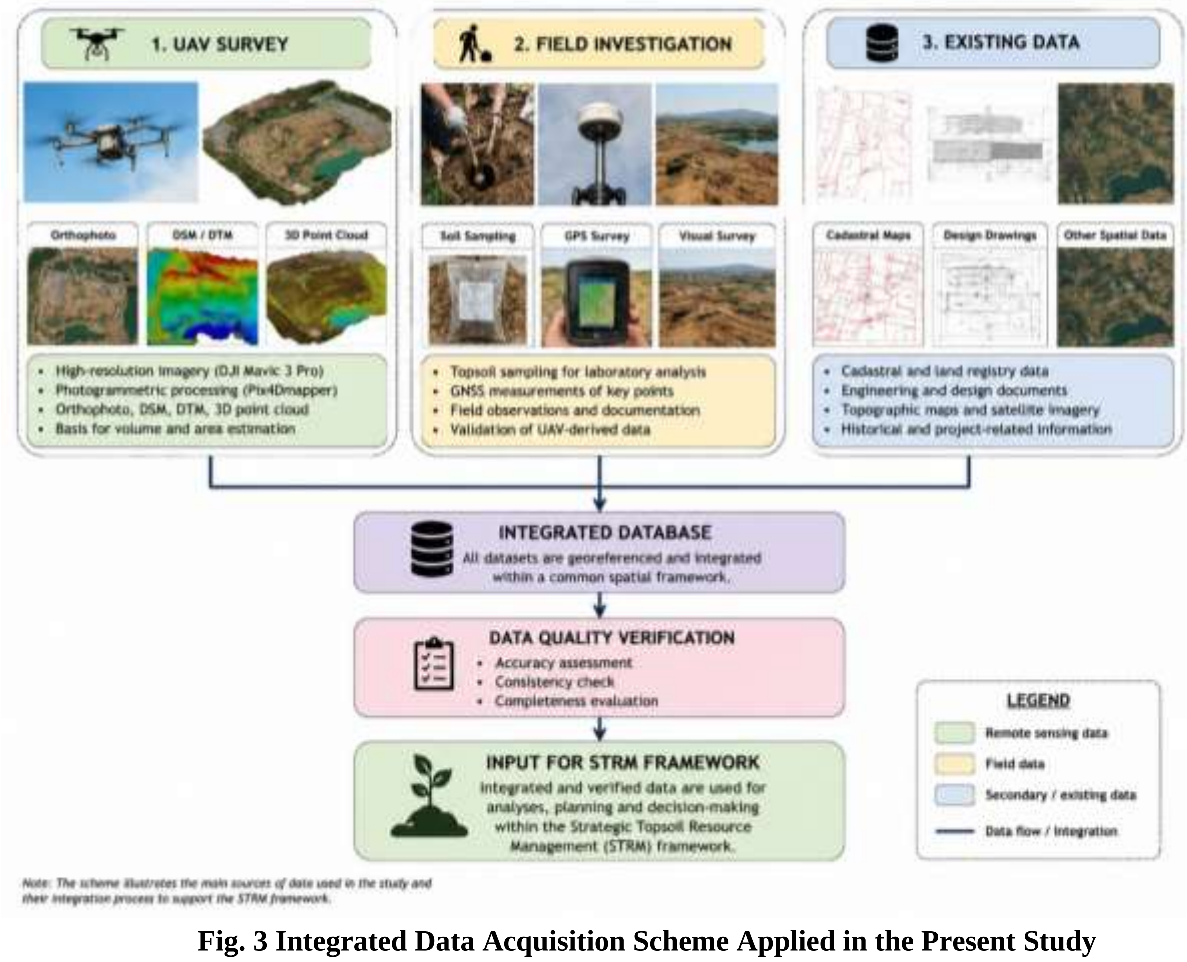

Fig. 3 Integrated Data Acquisition Scheme Applied in the Present Study

Integrated data acquisition was performed through the combined use of unmanned aerial vehicle (UAV) surveys, field investigations, and existing spatial and engineering datasets. UAV-derived products included orthophotos, digital surface models (DSM), digital terrain models (DTM), and three-dimensional spatial data. Field investigations comprised soil sampling, GPS measurements, and visual site inspections, while secondary information was obtained from cadastral maps, engineering documentation, and other spatial datasets. Following quality verification, all datasets were integrated into a common spatial database and subsequently utilized for the implementation of the Strategic Topsoil Resource Management (STRM) framework, supporting comprehensive analysis and evidence-based decision-making.

Research Results

Inventory and Spatial Characteristics of the Accumulated Topsoil Stockpile

The combined analysis of unmanned aerial vehicle (UAV) survey data, field investigations, and spatial datasets enabled the comprehensive inventory of the accumulated topsoil stockpile formed during the construction of the **Akhuryan Reservoir**. The inventory established the spatial extent, distribution pattern, geometric characteristics, and current condition of the accumulated topsoil stockpile. As shown in Fig. 1, the accumulated topsoil stockpile occupies a clearly delineated area that served as the principal study object for subsequent quantitative assessment, soil quality evaluation, and implementation of the Strategic Topsoil Resource Management (STRM) framework.

Quantitative Assessment of the Accumulated Topsoil Stockpile

The quantitative assessment of the accumulated topsoil stockpile was carried out using an integrated analysis of high-resolution unmanned aerial vehicle (UAV) imagery, digital terrain models (DTM), and three-dimensional spatial data. Processing of the acquired datasets enabled the determination of the geometric characteristics of the stockpile and the calculation of its principal quantitative parameters, including occupied area, total volume, relative elevation, and spatial distribution.

The application of digital terrain modelling minimized the influence of the surrounding terrain and ensured a high level of accuracy in estimating the volume of the accumulated topsoil stockpile. These results constitute the quantitative basis for determining the actual topsoil resource available within the study area and evaluating its potential for subsequent strategic management.

The accumulated topsoil stockpile occupies an area of 25,201 m² (2.52 ha) and contains 212,532 m³ of accumulated topsoil.

The principal quantitative characteristics of the accumulated topsoil stockpile are summarized in Tab. 1, while the three-dimensional spatial representation derived from digital terrain modelling is presented in Fig. 4.

Table 1.

Principal Quantitative Characteristics of the Accumulated Topsoil Stockpile

Parameter	Unit	Value
Total stockpile area	m²	25,201
Total stockpile area	ha	2.52
Total accumulated topsoil volume	m³	212,532

Three-dimensional digital terrain model illustrating the surface morphology, geometric configuration, and elevation variability of the accumulated topsoil stockpile. The model served as the basis for quantitative estimation of the stockpile area and accumulated topsoil volume.

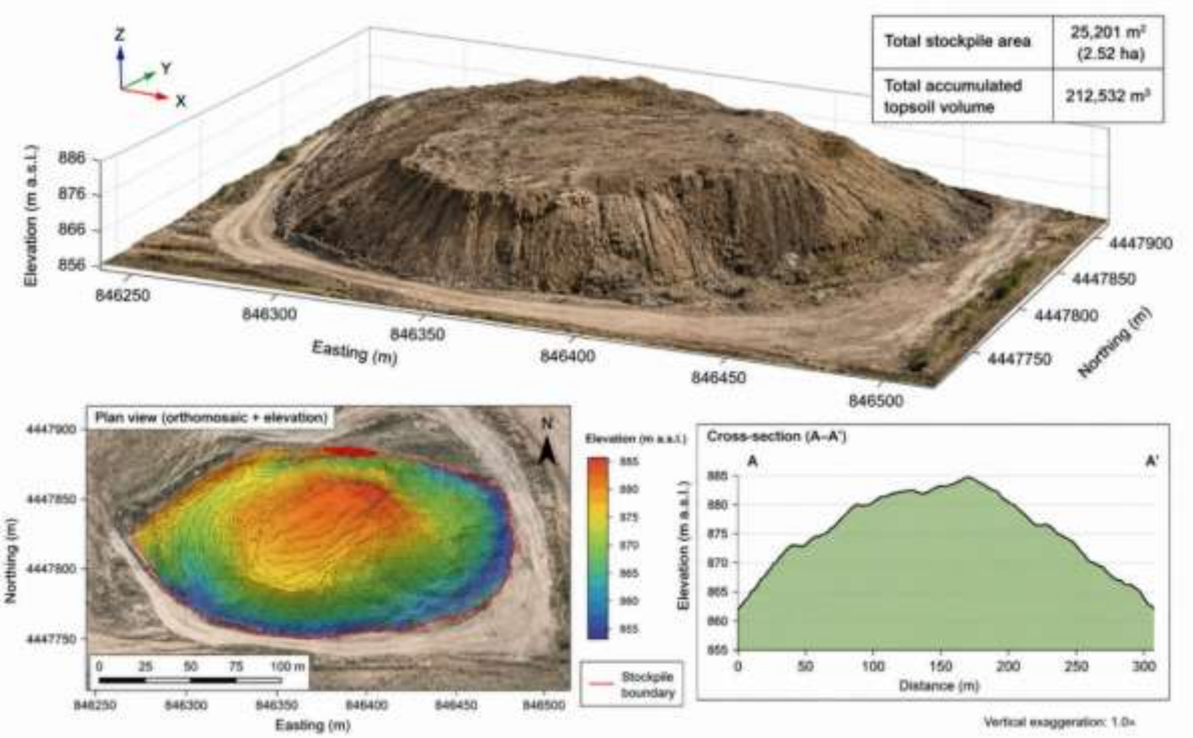

Fig. 4. Three-Dimensional Spatial Representation of the Accumulated Topsoil Stockpile

Soil Quality Assessment

The quality of the accumulated topsoil was evaluated through laboratory analysis of soil samples collected from the stockpile and from undisturbed background locations surrounding the study area. The assessment focused on the principal physicochemical properties that determine soil fertility and its suitability for future agricultural, ecological, and land restoration applications.

The laboratory analyses included determination of soil organic matter (humus), soil reaction (pH), mechanical composition, bulk density, carbonate content, and other relevant soil quality indicators. Comparative evaluation of stockpiled and background soils enabled assessment of the degree to which long-term storage affected the physical and chemical characteristics of the accumulated topsoil.

The analytical results indicate that, despite prolonged storage, the accumulated topsoil generally retained the fundamental properties required for subsequent beneficial use. Variations observed in several soil quality indicators remained within acceptable ranges and did not significantly reduce the potential suitability of the material for future reclamation, landscaping, or agricultural applications.

Table 2

Principal Soil Quality Characteristics of the Accumulated Topsoil and Background Soil

Parameter	Unit	Accumulated Topsoil	Background Soil
Number of samples	No.	12	3
Soil moisture	%	17.21	17.91
Humus content	%	3.54	4.54
Dry residue	mg/l	113.22	126.97
Soil fertility classification	–	High	High

The principal laboratory results and comparative soil quality indicators are summarized in Tab. 2**,** while the spatial distribution of the investigated sampling locations is presented in Fig. 5**.**

Comparative Analysis of Soil Quality Indicators

Comparative analysis of the laboratory results demonstrated that the accumulated topsoil generally preserved the principal physicochemical properties associated with soil fertility during long-term storage. Differences were observed between the accumulated topsoil and the undisturbed background soils; however, most of these variations remained within ranges that do not substantially limit the future utilization of the accumulated material.

The comparative evaluation of humus content, soil moisture, and other investigated soil quality indicators suggests that the observed changes primarily reflect natural physical and biochemical processes occurring during storage rather than significant degradation of the accumulated topsoil.

Interpretation of Laboratory Results

The integrated evaluation of the laboratory results indicates that, despite prolonged storage, the accumulated topsoil has largely preserved the principal properties associated with soil fertility. Although slight reductions in humus content and variations in several physicochemical indicators were observed, these changes do not indicate substantial soil degradation and remain within the range of natural variability.

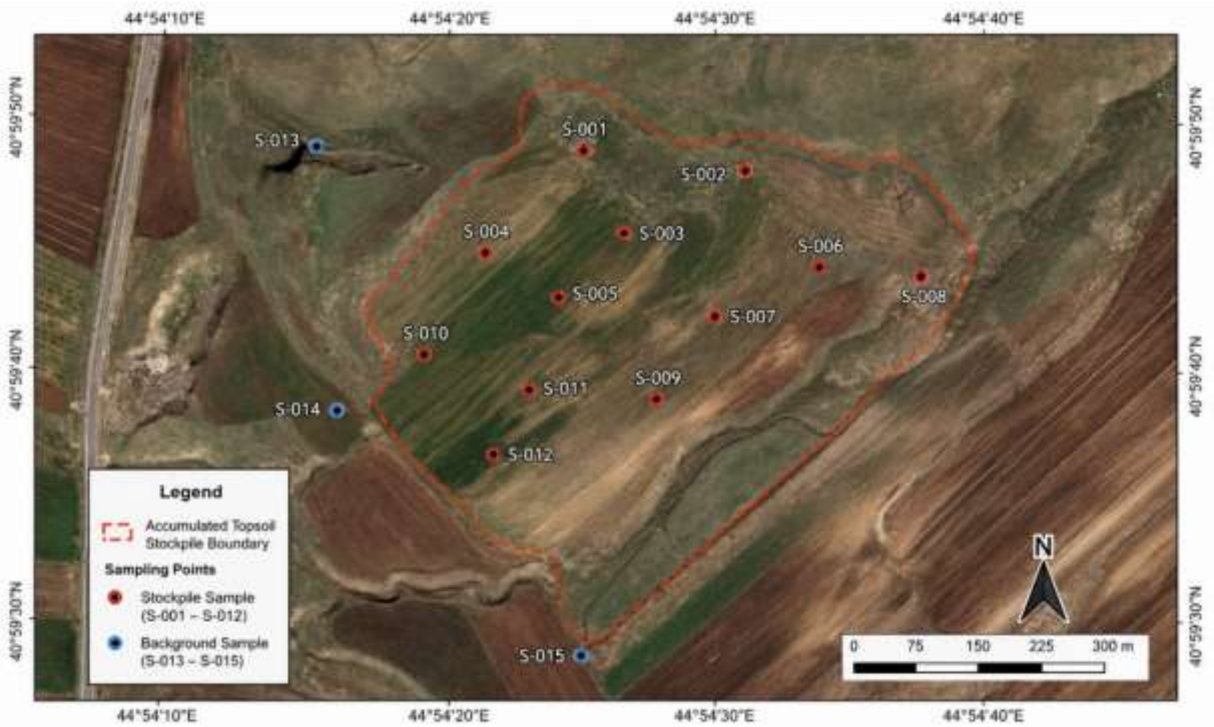

Fig. 5. Spatial Distribution of Soil Sampling Locations

Spatial distribution of soil sampling locations established for laboratory assessment of the accumulated topsoil stockpile. Twelve sampling points (S-001–S-012) were distributed throughout the stockpile to characterize its physicochemical properties, whereas three background reference samples (S-013–S-015) were collected from adjacent undisturbed soils to provide comparative baseline conditions.

Comparison with the background soils demonstrates that the accumulated topsoil continues to retain characteristics that make it suitable for subsequent beneficial utilization. The obtained results suggest that long-term stockpiling, when accompanied by appropriate storage conditions, does not necessarily result in a significant loss of soil quality or fertility.

These findings provide scientific evidence supporting the consideration of accumulated topsoil not as construction waste, but as a strategic natural resource that can be effectively utilized in land reclamation, landscape restoration, agricultural development, and other environmental management applications.

Spatial distribution of soil sampling locations established for laboratory assessment of the accumulated topsoil stockpile. Twelve sampling points (S-001–S-012) were distributed throughout the stockpile to characterize its physicochemical properties, whereas three background reference samples (S-013–S-015) were collected from adjacent undisturbed soils to provide comparative baseline conditions.

Strategic Evaluation of Accumulated Topsoil Resources

The integrated evaluation of the quantitative and qualitative results demonstrates that the accumulated topsoil investigated in the present study represents a valuable natural resource whose effective management may provide substantial environmental, economic, and social benefits. The considerable volume of accumulated topsoil together with the preservation of its principal soil fertility characteristics indicates that the material can substantially reduce the need for extracting new topsoil resources for future reclamation, landscaping, and infrastructure development projects.

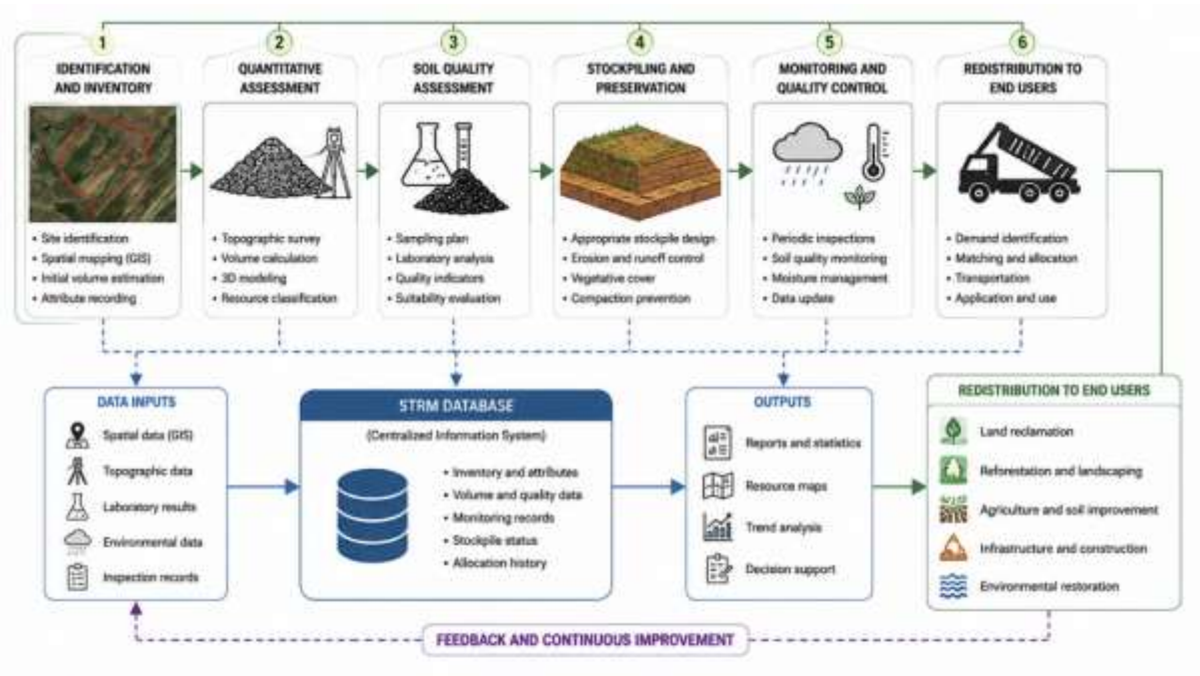

Fig. 6. Strategic Topsoil Resource Management (STRM) Framework

The framework illustrates the integrated management cycle of accumulated topsoil resources, including inventory, quantitative and qualitative assessment, preservation, monitoring, and demand-oriented redistribution to support sustainable land use and environmental restoration.

The obtained findings demonstrate that accumulated topsoil should not be regarded merely as temporarily stored material but rather as a strategic natural resource requiring long-term management. This concept is fully consistent with the proposed **Strategic Topsoil Resource Management (STRM)** framework, which emphasizes systematic inventory, continuous quality assessment, and demand-oriented redistribution of accumulated topsoil resources.

Practical Application of the STRM Framework

Strategic Topsoil Resource Management (STRM) framework developed in the present study was applied to the accumulated topsoil stockpile formed during the construction of the Akhuryan Reservoir. The application of the STRM framework enabled the integration of spatial information, quantitative assessment, laboratory analyses, and management-oriented decision-making within a unified methodological system.

Implementation of the framework provided a comprehensive inventory of the accumulated topsoil resource, quantitative estimation of its volume, evaluation of soil quality, and assessment of its potential for subsequent beneficial utilization. The integrated approach demonstrated that accumulated topsoil should be regarded not merely as material generated during construction activities but as a strategic natural resource requiring long-term management.

Application of the STRM framework further demonstrated that systematic inventory, continuous monitoring, and demand-oriented redistribution of accumulated topsoil resources can substantially improve resource utilization efficiency, reduce environmental impacts, and establish a scientifically justified system for the sustainable reuse of topsoil.

The obtained results indicate that the proposed STRM framework is applicable not only to the Akhuryan Reservoir case study but also to large-scale infrastructure, mining, transportation, and other engineering projects involving extensive earthworks and the generation of significant quantities of accumulated topsoil.

Discussion

The results of the present study demonstrate that accumulated topsoil generated during large-scale infrastructure projects should be regarded as a strategic natural resource rather than merely as temporarily stored construction material. The combined evidence obtained from quantitative assessment, laboratory soil analyses, and application of the Strategic Topsoil Resource Management (STRM) framework demonstrates that accumulated topsoil can retain its functional properties during long-term storage and can subsequently be utilized in a wide range of environmental, agricultural, and infrastructure-related applications.

Previous studies have primarily focused on topsoil stripping techniques, stockpile preservation, erosion control, or evaluation of individual soil quality parameters. In contrast, the present study proposes an integrated management framework that combines resource inventory, quantitative assessment, soil quality evaluation, continuous monitoring, demand analysis, and redistribution mechanisms within a unified Strategic Topsoil Resource Management (STRM) system.

This integrated approach enables accumulated topsoil to be considered as a form of natural capital requiring long-term management rather than as surplus construction material. Consequently, the proposed framework contributes to improved resource efficiency, reduced environmental impacts, and practical implementation of circular economy principles in large-scale engineering projects.

Advantages of the STRM Framework Compared with Existing Approaches

Most existing approaches address topsoil management as a sequence of separate activities, primarily focusing on topsoil stripping, storage, or subsequent reuse. Such approaches generally do not provide comprehensive resource inventory, long-term monitoring, or demand-oriented redistribution of accumulated topsoil resources.

In contrast, the Strategic Topsoil Resource Management (STRM) framework integrates the entire process within a unified management system. The proposed framework combines spatial inventory, quantitative assessment, soil quality evaluation, centralized database management, continuous monitoring, and end-use planning into a single decision-support framework. This integrated approach enables data-driven management decisions and promotes more efficient utilization of accumulated topsoil resources.

The principal advantage of the STRM framework lies in its transformation of the conventional perception of accumulated topsoil. Rather than considering it as temporarily stored construction material, the framework recognizes accumulated topsoil as a strategic natural resource whose value should be preserved and managed throughout its entire life cycle.

Practical Implications and Future Applications of the STRM Framework

The findings of the present study demonstrate that the proposed **Strategic Topsoil Resource Management (STRM)** framework is applicable not only to the accumulated topsoil stockpile investigated at the Akhuryan Reservoir but also to a wide range of large-scale infrastructure projects involving extensive earthworks and the generation of substantial topsoil stockpiles.

Implementation of the STRM framework enables the establishment of a centralized system for topsoil inventory and management that integrates spatial mapping, continuous quality assessment, demand evaluation, and efficient redistribution of accumulated topsoil resources among different projects. Such an approach has the potential to reduce the need for additional topsoil extraction, conserve natural soil resources, and improve the environmental sustainability of infrastructure development.

Future research should focus on digital implementation of the STRM framework, integration with Geographic Information Systems (GIS), development of national topsoil inventory databases, and the application of artificial intelligence for demand forecasting and optimized resource allocation. These developments could facilitate the establishment of next-generation topsoil management systems and promote broader implementation of circular economy principles in infrastructure development.

Conclusion

1. This study developed and applied, for the first time, the **Strategic Topsoil Resource Management (STRM)** framework for the systematic inventory, assessment, preservation, and beneficial utilization of accumulated topsoil generated during large-scale infrastructure projects.

2. Investigation of the accumulated topsoil stockpile formed during the construction of the Akhuryan Reservoir demonstrated that it occupies **25,201 m² (2.52 ha)** and contains **212,532 m³** of accumulated topsoil, indicating the formation of a substantial natural resource.
3. The integrated application of quantitative assessment, three-dimensional digital terrain modelling, and laboratory soil analyses enabled comprehensive characterization of the accumulated topsoil resource and established a reliable basis for evidence-based management.
4. Comparative soil quality assessment demonstrated that the accumulated topsoil largely preserved the principal physicochemical properties associated with soil fertility during long-term storage, confirming its suitability for future reclamation, environmental restoration, and other beneficial applications.
5. The proposed STRM framework integrates spatial inventory, quantitative assessment, soil quality evaluation, monitoring, and demand-oriented redistribution within a unified management system, representing a substantial advancement over conventional fragmented approaches.
6. The findings demonstrate that accumulated topsoil should be regarded not as a by-product of construction activities but as a strategic natural resource requiring long-term management throughout its entire life cycle.
7. The proposed STRM framework is applicable not only to reservoir construction projects but also to transportation infrastructure, mining operations, and other large-scale engineering projects, thereby supporting natural resource conservation, circular economy implementation, and environmentally sustainable infrastructure development.

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ԽՈՇՈՐ ԵՆԹԱԿԱՌՈՒՑՎԱԾՔԱՅԻՆ ԾՐԱԳՐԵՐԻ ԱՐԴՅՈՒՆՔՈՒՄ ԿՈՒՏԱԿՎԱԾ ՀՈՂԱԲՈՒՍԱԿԱՆ ՇԵՐՏԻ ՌԱԶՄԱՎԱՐԱԿԱՆ ԿԱՌԱՎԱՐՈՒՄԸ՝ ԱԽՈՒՐՅԱՆԻ ՋՐԱՄԲԱՐԻ ՕՐԻՆԱԿՈՎ

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Ակադեմիկոս Ի.Վ. Եղիազարովի անվան ջրային հիմնահարցերի և հիդրոտեխնիկայի ինստիտուտ

Խոշոր ենթակառուցվածքային ծրագրերի իրականացման ընթացքում հաճախ անհրաժեշտ է լինում հեռացնել հողի բերրի վերին շերտը: Չնայած այդ շերտը հանդիսանում է արժեքավոր բնական ռեսուրս, այն հաճախ դիտարկվում է որպես ժամանակավոր նյութ և երկար ժամանակ մնում է չօգտագործված, ինչը հանգեցնում է որակի վատթարացման և տնտեսական կորուստների: Սույն ուսումնասիրության նպատակն է գնահատել Ախուրյանի ջրամբարի կառուցման ընթացքում կուտակված հողաբուսական շերտի ծավալը, որակը և կառավարման ներուժը:

Հետազոտության շրջանակներում կիրառվել են անօդաչու թռչող սարքով իրականացված չափագրումներ, կադաստրային տվյալների վերլուծություն, հողի նմուշառում, հումուսի պարունակության լաբորատոր որոշում Տյուրինի մեթոդով, ինչպես նաև հողի պահանջարկի գնահատում: Արդյունքները ցույց են տվել, որ կուտակված հողաբուսական շերտի ծավալը կազմում է մոտ 212 532 մ³: Լաբորատոր հետազոտությունների համաձայն՝ հումուսի միջին պարունակությունը կազմել է 3.54%, ինչը համապատասխանում է բարձր որակի գյուղատնտեսական հողերին: Համեմատական վերլուծությունը բացահայտել է էական անհամապատասխանություն կուտակված պաշարների և պաշտոնապես գրանցված պահանջարկի միջև:

Հետազոտության արդյունքները ցույց են տալիս, որ հողաբուսական շերտի երկարատև պահեստավորումը կարող է հանգեցնել դրա որակի աստիճանական նվազման և գյուղատնտեսական արժեքի կորստի: Աշխատանքում առաջարկվում է ռեսուրսների ռազմավարական կառավարման մոտեցում, որի համաձայն խոշոր ենթակառուցվածքային ծրագրերի արդյունքում կուտակված հողաբուսական շերտը պետք է դիտարկվի որպես ռազմավարական բնապահպանական ռեսուրս, որը ենթակա է հաշվառման, մոնիթորինգի և վերահսկվող վերաբաշխման:

Առաջարկվող մոտեցումը կարող է նպաստել հողերի պահպանության բարելավմանը, ապօրինի հողի տեղահանման կրճատմանը և արժեքավոր հողային ռեսուրսների առավել արդյունավետ օգտագործմանը Հայաստանում և նմանատիպ խնդիրներ ունեցող այլ երկրներում:

Բանալի բառեր. հողաբուսական շերտ, սևահող, հողի պահպանություն, ենթակառուցվածքային ծրագրեր, հումուս, ռեսուրսների կառավարում, Ախուրյանի ջրամբար, Հայաստան:

СТРАТЕГИЧЕСКОЕ УПРАВЛЕНИЕ НАКОПЛЕННЫМ ПЛОДОРОДНЫМ ПОЧВЕННЫМ СЛОЕМ, ОБРАЗУЮЩИМСЯ ПРИ РЕАЛИЗАЦИИ КРУПНЫХ ИНФРАСТРУКТУРНЫХ ПРОЕКТОВ: ОПЫТ АХУРЯНСКОГО ВОДОХРАНИЛИЩА В АРМЕНИИ

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При реализации крупных инфраструктурных проектов часто возникает необходимость снятия плодородного верхнего слоя почвы. Несмотря на то, что данный слой представляет собой ценный природный ресурс, на практике он нередко рассматривается как временно изымаемый материал и длительное время остается невостребованным, что приводит к ухудшению его качественных характеристик и снижению хозяйственной ценности. Целью настоящего исследования является оценка объема, качества и потенциала управления запасами плодородного почвенного слоя, накопленного в процессе строительства Ахурянского водохранилища в Республике Армения.

В рамках исследования были использованы данные топографической съемки с применением беспилотного летательного аппарата, результаты кадастрового анализа, материалы почвенного опробования, лабораторные исследования содержания гумуса по методу Тюрина, а также сведения о существующем спросе на плодородный почвенный слой. Результаты показали, что объем накопленного почвенного материала составляет около 212 532 м³. Лабораторные исследования установили среднее содержание гумуса на уровне 3,54 %, что соответствует категории высококачественных сельскохозяйственных почв. Сравнительный анализ выявил существенный дисбаланс между объемом накопленных запасов и официально зарегистрированным спросом на плодородную почву.

Полученные результаты свидетельствуют о том, что длительное хранение плодородного почвенного слоя может приводить к постепенной деградации его свойств и снижению сельскохозяйственной ценности. В работе предлагается подход к стратегическому управлению данным ресурсом, согласно которому почвенный слой, образующийся при реализации крупных инфраструктурных проектов, должен рассматриваться как стратегический экологический ресурс, подлежащий систематическому учету, мониторингу и контролируемому перераспределению.

Предлагаемый подход может способствовать повышению эффективности охраны почв, сокращению случаев незаконного перемещения плодородного грунта и более рациональному использованию ценных земельных ресурсов как в Армении, так и в других странах, сталкивающихся с аналогичными проблемами.

***Ключевые слова*:** плодородный почвенный слой; гумус; охрана почв; управление почвенными ресурсами; инфраструктурные проекты; экологические ресурсы; Ахурянское водохранилище; Армения.

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