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QGIS ile Kamulaştırma Yönetiminin İyileştirilmesi: Kuzey Makedonya'da SWOT Tabanlı Dijital Bir Yaklaşım

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ÖZET

Bu çalışma, kamulaştırma yönetiminin geleneksel, kağıt tabanlı iş akışlarından entegre bir dijital çerçeveye dönüşümünü kolaylaştırmak için açık kaynaklı coğrafi teknolojilerin potansiyelini araştırmayı amaçlamaktadır. Kuzey Makedonya da dahil olmak üzere birçok gelişmekte olan ülkede, kamulaştırma süreçlerini destekleyecek kapsamlı dijital sistemlerin bulunmaması, verimsizliklere, veri tutarsızlıklarına, idari darboğazlara, prosedür gecikmelerine ve şeffaflık eksikliğine yol açmıştır. QGIS, Google Earth Pro ve ulusal E-Hizmetler Portalı (E-Uslugi Katastar) kullanılarak yapılan araştırma, kamulaştırma prosedürlerinin verimliliğini, şeffaflığını ve erişilebilirliğini artırmayı amaçlayan bir dijital dönüşüm modeli önermektedir. Kuzey Makedonya'nın Polog Bölgesi'ne özel atıfta bulunan temsili bir kamulaştırma vaka çalışması kullanılarak yapılan analiz, açık kaynaklı coğrafi çözümlerin benimsenmesinin fizibilitesini ve stratejik etkilerini eleştirel bir şekilde değerlendirmek için hem SWOT (Güçlü Yönler, Zayıf Yönler, Fırsatlar ve Tehditler) hem de TOWS (Tehditler, Fırsatlar, Zayıf Yönler ve Güçlü Yönler) Matrisi metodolojilerini içermektedir. Sonuçlar, bu araçların gelişmiş uzamsal analizi destekleme, yüksek çözünürlüklü uydu görüntüleri aracılığıyla kartografik görselleştirmeyi iyileştirme ve kadastro veri setlerine gerçek zamanlı erişim sağlama kapasitesini vurgulamakta ve böylece kamulaştırma yönetiminin operasyonel çerçevesini güçlendirmektedir. Çalışma, Kuzey Makedonya'da tam entegre bir Kamulaştırma Bilgi Sisteminin kurulmasını savunmakta ve Coğrafi Bilgi Sistemlerini (GIS) arazi yönetiminin daha geniş bağlamında dijital dönüşümü ilerletmek için temel bir araç olarak konumlandırmaktadır.

Improving Expropriation Management via QGIS: A SWOT-based Digital Approach in North Macedonia

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ABSTRACT

This study aims to investigate the potential of open-source geospatial technologies to facilitate the transformation of expropriation management from traditional, paper-based workflows to an integrated digital framework. In many developing countries, including North Macedonia, the absence of comprehensive digital systems to support expropriation processes has resulted in inefficiencies, data inconsistencies, administrative bottlenecks, procedural delays, and a lack of transparency. By employing QGIS, Google Earth Pro, and the national Portal for E-Services (E-Uslugi Katastar), the research proposes a digital transformation model aimed at enhancing the efficiency, transparency, and accessibility of expropriation procedures. Utilizing a representative expropriation case study, with specific reference to the Polog Region of North Macedonia, the analysis incorporates both SWOT (Strengths, Weaknesses, Opportunities, and Threats) and TOWS (Threats, Opportunities, Weaknesses and Strengths) Matrix methodologies to critically assess the feasibility and strategic implications of adopting open-source geospatial solutions. The results highlight the capacity of these tools to support advanced spatial analysis, improve cartographic visualization through high-resolution satellite imagery, and provide real-time access to cadastral datasets, thereby strengthening the operational framework of expropriation management. The study advocates for the establishment of a fully integrated Expropriation Information System in North Macedonia and positions Geographic Information Systems (GIS) as a pivotal instrument for advancing digital transformation within the broader context of land governance.

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INTRODUCTION

Effective and efficient Land Administration System and Land Management System serve as fundamental pillars of sustainable development, enabling equitable resource allocation, promoting transparent governance, and fostering economic growth [1-3]. Land is a fundamental territorial resource, which constitutes one of the primary natural assets and serves as a critical factor of production that drives economic development and expansion [4]. It is a crucial factor of production that plays a fundamental role in enhancing the living conditions of people globally [5]. Access to land encompasses both the physical availability of land and the authority to make decisions concerning its use or the exercise of the rights inherent to it [6, 7]. Land expropriation is an inevitable process within the context of rapid urbanization [8-10] and the rapid growth of the economy [11]. Within this context, the expropriation process plays a pivotal role in acquiring land for public purposes, including infrastructure development and urban evolution. This development process and economic growth generate a significant demand for modern services as well as geospatial data management tools [12]. Recently there has been a growing application of geospatial data in the development of geoinformatics and decision support systems aimed at achieving sustainable land management [13-16].

However, in numerous developing countries, particularly in the countries of the Balkan Peninsula, such as Albania, Kosovo, Montenegro, Serbia, and Bosnia and Herzegovina, the absence of digital systems significantly hampers expropriation procedures, resulting in inefficiencies and challenges that obstruct progress and undermine developmental goals. In North Macedonia, the expropriation management process entails intricate administrative procedures. Despite these measures, significant challenges persist, largely due to the lack of comprehensive digital systems. This deficiency results in inefficiencies that hinder the effectiveness and progress of the expropriation management process. Expropriation addresses or resolves holdout issues among landholders who are unwilling to sell their properties at market value [17]; thus, by utilizing the power of expropriation, the time and costs associated with intended projects are significantly reduced, as property owners are compelled to transfer their land to the public at a fair and equitable price [12]. The dependence on paper-based workflows in expropriation management processes poses substantial challenges. Manual record-keeping and data management are inherently vulnerable to errors, inconsistencies, and data loss. This absence of digitization undermines the accurate tracking of expropriation cases, leading to delays, disputes, and a pervasive lack of transparency. Furthermore, the lack of integrated digital systems complicates coordination among diverse stakeholders, such as government agencies, landowners, and developers, thereby intensifying the difficulties associated with land expropriation for public projects.

Open-source technology can enhance and accelerate the processes of implementing, aggregating, categorizing, and symbolizing geospatial data, thereby facilitating more effective mapping [18]. Geographic Information System (GIS) serves as an effective tool for capturing, storing, analyzing, and disseminating land related information [19]. In this context, GIS technology, with a particular focus on QGIS (Quantum Geographic Information System), an open-source GIS platform, presents itself as a practical and effective solution. QGIS provides advanced tools for spatial data integration, spatial analysis, and cartographic visualization [20], to develop a land management system based on GIS technology [21] and thus facilitating the creation of comprehensive Expropriation Information Systems. GIS, leveraging their potential to disseminate geographic information, consists of modular software components designed to perform specific GIS operations, including the visualization of maps [22]. GIS, with the capability to capture, store, analyze, and display geographically referenced information, proves to be an effective tool in addressing the current demands of the field [23]. The open-source framework of QGIS further positions it as a cost-effective option for developing countries, aligning with budgetary limitations while offering a scalable platform for achieving digital transformation. In recent decades, many developing countries around the world have experienced rapid urbanization [24, 25]. Information

technology enables the development of land use systems through the simulation of dynamic and interactive land use processes [26]. QGIS as an open-source software offers comprehensive functionalities for the analysis of spatial phenomena and provides virtually limitless possibilities for customization and extension [27]. Using QGIS with other open-source solutions or open geospatial sources, such as Google Earth Pro and the Portal for E-Services (E-Uslugi Katastar), can significantly enhance the visualization capabilities of expropriation management.

Several studies have been conducted on the GIS-based digital transformation of land management processes. Smajić et al., (2020) [28], assert that the application of GIS in the analysis of contemporary landscape topographic transformations is imperative, emphasizing the pivotal role of digital elevation models and satellite imagery in such analyses. Given that land management constitutes a critical function of local governance, the availability and quality of spatial data, particularly in the form of transactional spatial data and metadata, represent an indispensable resource that must be systematically developed and maintained [29]. GIS serve not only as tools for enhancing governmental functions but also as catalysts for institutional transformation [30]. In Bosnia and Herzegovina, the integration of GIS into governance frameworks contributes significantly to improving the efficiency and effectiveness of core administrative processes. This includes enhanced information control at the highest levels of government, improved public communication, streamlined internal communication systems, and more informed decision-making through the management of both information flows and accumulated institutional knowledge [29, 31]. Kuka et al. (2014) [32], emphasizes that the transition from a communist regime to a democratic system characterized by both private and state ownership has significantly increased the demand for land expropriation within the territory of Kosovo. In this context, the development of a GIS-based model or application is recognized as a timely necessity, as it would enable a more efficient, rapid, and accurate resolution of expropriation-related issues. The establishment of a dedicated GIS application for the management and administration of expropriated properties is therefore deemed essential [32]. The spatial decision-making process is widely recognized as a complex and multifaceted challenge, as it necessitates the selection of the most optimal alternative among numerous possible scenarios to effectively achieve a defined objective [33]. According to Meha et al., (2011), the development of a GIS for settlements offers a comprehensive overview of on-the-ground realities relevant to economic analyses. GIS facilitates the identification and evaluation of various relationships and influencing factors, including the estimation of expropriation costs and the time required for potential relocation of affected settlements. The processes of expropriation, along with their associated social impacts, exert a significant influence on both temporal and financial dimensions of project implementation [34]. In the context of Croatia, the digitalization of processes related to land administration, spatial planning, and construction law represents a specific dimension of the broader digital transformation of public administration, which has its foundations in the development of electronic governance (e-administration). However, the digitalization of spatial planning and the construction sector constitutes a significantly more complex undertaking than it may initially appear. Although terms such as "planning," "space," and "area" are commonly understood, even by non-specialists, their practical implementation within a digital governance framework involves intricate legal, institutional, and technical considerations [35]. Lisjak et al. (2021) [36], emphasizes the necessity of employing GIS techniques for both the development and visualization of spatial data and processes. Pejović et al. (2014) [27], highlight in their study that a pilot land expropriation project demonstrates the potential of the QGIS platform for conducting analytical evaluations of designated expropriation zones in Serbia. In the Republic of Serbia, public interest is defined in accordance with the provisions of the Law on Expropriation, which serves as the legal framework for the acquisition of state assets. This legislation ensures that fair compensation is granted for the expropriation of agricultural arable land, either through the allocation of alternative land of equivalent type and quality or by providing

monetary compensation equivalent to the land's value within the same geographic vicinity. In cases where the expropriation beneficiary is unable to offer suitable replacement agricultural land, compensation is determined based on the appraised market value of comparable land within the designated area [37, 38].

Accordingly, the principal objective of this study is to develop and demonstrate a technically robust, cost-effective, and policy-relevant digital workflow for expropriation management, leveraging QGIS alongside other open-source geospatial tools. In contrast to prior research predominantly centered on cadastral registration or broader land administration, this investigation specifically targets the underdeveloped and operationally sensitive domain of expropriation, emphasizing practical implementation within resource-constrained contexts such as North Macedonia. The originality of this study resides in its synthesis of an applied real-world case study, a comprehensive SWOT (Strengths, Weaknesses, Opportunities, and Threats) - TOWS (Threats, Opportunities, Weaknesses and Strengths) strategic analysis, and alignment with international frameworks, including ISO standards and the United Nations Sustainable Development Goals (SDGs), propose a replicable roadmap for digital transformation in land governance. This research contributes both theoretically and pragmatically by:

a) Introducing a replicable and cost-effective technical framework based on open-source GIS technologies tailored for expropriation workflows.

b) Offering implementation-focused strategies attuned to the legal, institutional, and technical realities not only for North Macedonia but also for various developing countries facing similar problems.

c) Advancing the global discourse on digital land governance through bridging geospatial technological capabilities with expropriation policy reform.

Problem Statement and Research Objectives

In North Macedonia the expropriation process remains constrained by fragmented, paper-based administrative systems that lead to inefficiencies, procedural delays, limited transparency, and inadequate inter-institutional coordination. The prevailing cadastral and administrative infrastructures lack real-time data integration and spatial analysis functionalities, thereby impeding the accurate identification, evaluation, and management of parcels subject to expropriation. This study seeks to address these systemic limitations by introducing an open-source, GIS-based digital workflow designed to enhance spatial precision, legal verification, and institutional coordination in expropriation procedures. The research emphasizes the application of QGIS due to its advanced spatial analysis capabilities, high degree of customizability, alignment with international standards, and cost-effectiveness, rendering it particularly suitable for resource-constrained environments. The deliberate selection of exclusively open-source platforms, including Google Earth Pro and the Portal for E-Services, reflects a strategic commitment to promoting affordability, scalability, and autonomy from proprietary software constraints. The primary objectives of this study are as follows:

a. To evaluate the role of open-source geospatial technologies in the modernization of expropriation workflows.
b. To design and implement a GIS-based digital framework utilizing QGIS and complementary platforms.
c. To conduct a SWOT and TOWS analysis to assess the strengths, weaknesses, opportunities, and threats associated with the proposed approach.
d. To propose a strategic roadmap for integrating open-source geospatial solutions into national expropriation policy and operational practice.

MATERIALS AND METHODS

Methodology

This study employs a conjunctive methodology to examine the role of open geospatial sources, underlining QGIS in enhancing expropriation management processes in North Macedonia. The approach combines geospatial analysis techniques to evaluate QGIS's capabilities in improving expropriation management and to develop a scalable framework. Additional spatial and cadastral information was verified using complementary tools, including Google Earth Pro and the Portal for E-Services platform. Data processing and spatial analysis were performed using QGIS Desktop version 3.34.13 (Prizren), incorporating workflows such as the organization of cadastral data, spatial overlays, and buffer analyses to evaluate cadastral parcels impacted by expropriation case study. The primary dataset consists of cadastral parcel information provided by a private cadastral-surveying and engineering office, derived from the Cadastral Department of the Agency for Real Estate Cadastre (AREC). This dataset includes detailed records of parcel boundaries, unique identifiers, ownership, and legal attributes, forming the foundation for spatial analysis. The data were processed and analyzed using a multi-stage workflow centered on QGIS. Spatial analyses included overlaying cadastral layers with proposed project boundaries to identify affected parcels, conducting spatial queries to classify cadastral parcels. To authorize precision and guarantee reliability, the assessment and quality assurance involves the combination of spatial and institutional data to visualize the results of the cadastral parcels affected by the expropriation process with the sole purpose of providing authentic, clear and easily accessible results for all interested parties.

Open geospatial tools

QGIS - is a well-established, universally recognized and widely used open-source GIS application [39-41]. It is recognized for its flexibility, ease of use and powerful capabilities in managing, analyzing and visualizing spatial or geospatial data [42, 43]. The QGIS platform supports an extensive range of various formats, including raster and vector data, thus enabling seamless integration with different spatial datasets. With up-to-date geoprocessing tools, customizable plugins and scripting functionalities developed, the QGIS platform is highly adaptable for use in different fields and operations. Among them, the inclusion and adoption of the QGIS software with other open-source solutions, improves data quality and encourages the combination of capabilities. In the realm of governing expropriation management, QGIS facilitates a comprehensive set of tools for visualizing cadastral parcels, analyzing spatial relationships, and thus generating related maps to support decision-making in this direction.

GOOGLE EARTH PRO - is a sophisticated, freely accessible geospatial visualization platform developed by Google. It is distinguished by enabling comprehensive exploration, analysis, and presentation of spatial data within a three-dimensional virtual globe environment. The platform provides access to outrageous-resolution satellite imagery [44] and elevated-quality [45] aerial photographs, while incorporating various advanced geospatial measurement tools for several calculations. The software demonstrates notable interoperability through its support for multiple geospatial data formats, including KML, KMZ, and GIS shapefiles, facilitating efficient integration with external spatial datasets. A relatively coherent advantage is also the analysis of time-lapse images, thus enabling valuable insights on land use in varying time periods. In the circumstances of expropriation administration, Google Earth Pro offers a variety of essential advantages. Facilitating the visualization of cadastral parcels and the evaluation of physical terrain critical to expropriation, makes Google Earth Pro more suitable in decision making.

PORTAL FOR E-SERVICES - advanced by the AREC as an online platform, mainly conveys digital cadastral services to citizens, businesses, government institutions and other parts. By providing

a broad range of solutions, including approach to cadastral maps, property sheets, thus examination of ownership information, and other geodetic data, Portal for E-Services constitutes as an indispensable tool in the realm of expropriation management, offering accurate, reliable, and up-to-date cadastral data necessary for identifying and assessing cadastral parcels subject to expropriation. The possibility of conjunction with GIS capabilities enables users to visualize original cadastral parcel boundaries and analyze spatial relationships of cadastral parcels and nearby infrastructure subject of expropriation, thereby supporting related decision-making. Additionally, this platform is easily accessible and vastly transparent with fostering improved collaboration among institutions engaged in the expropriation management process.

The linking relationship between QGIS, Google Earth Pro, and Portal for E-Services is methodically investigated and introduced in Table 1. This structure clarifies how these supportive geospatial tools can grant the expropriation workflow, while highlighting their individual functional capacities and limitations.

Table 1
Respective advantages and disadvantages of utilized open geospatial tools.

Applications	Advantages	Disadvantages
QGIS	a. Free and open-source software. b. Supports various data formats (e.g., vector, raster). c. Extensive spatial analysis tools. d. Highly customizable with a variety of plugins.	a. Requires manual updates and maintenance. b. Performance issues with very large datasets. c. Steep learning curve for beginners.
GOOGLE EARTH PRO	a. Provides high-quality satellite imagery. b. Allows 3D visualization of the terrain and properties. c. User-friendly interface and easy navigation. d. Simple to import/export data (e.g., KML/KMZ files).	a. Requires internet connection for accessing real-time imagery. b. No direct integration with cadastral data systems (e.g., Portal for E-Services). c. Limited spatial analysis tools compared to QGIS.
PORTAL FOR E-SERVICES	a. Direct integration with national property databases. b. Provides accurate and up-to-date property information for cadastral data. c. Centralized, government-backed system for cadastral data.	a. User interface might be less intuitive. b. Limited visualization capabilities compared to QGIS or Google Earth Pro. c. Missing advanced spatial analysis tools. d. Requires internet connection for access.

SWOT analysis and TOWS matrix

The SWOT analysis is one of the most respected [46], well established and widely utilized strategic tools globally, typically structured in a 2x2 matrix format, assessing internal strengths and weaknesses, as well as external opportunities and threats within its operating environment [47-50]. SWOT analysis remains highly relevant and has matured to the extent that it can be regarded as a comprehensive strategic theory, particularly in response to the growing emphasis on holistic strategic thinking [51-54]. SWOT analysis, as a fundamental strategic tool [55, 56], is widely applied across various sectors and methodological approaches. It serves to bridge knowledge gaps within the strategic planning domain and provides valuable insights for enhancing decision-making processes [46]. This qualitative analytical approach [58-60] was selected to assess both internal capabilities and external factors that influence the effectiveness of these applications in facilitating digital transformation within expropriation procedures.

The TOWS Matrix was initially introduced as a strategic formulation tool for businesses and later adapted as a conceptual framework for a systematic analysis [61]. The TOWS Matrix methodology

facilitates the generation and development of multiple strategic alternatives [62, 63]. It generates four distinct sets of strategic alternatives [64], while serving as a complementary tool to SWOT analysis for the development and implementation of strategic initiatives [65]. TOWS Matrix enhances the systematic deployment of strategies by considering the interrelationships and consequences of internal and external factors [66]. The TOWS matrix is a strategic tool utilized to assess the sustainability of various components [67]. It identifies four conceptually distinct strategic groups (Table 2): Strength-Opportunity (SO), Strength-Threat (ST), Weakness-Opportunity (WO), and Weakness-Threat (WT) [68].

Table 2
TOWS matrix [50], represented with a Table.

TOWS Matrix	Strengths (S) (Internal, Positive)	Weaknesses (W) (Internal, Negative)
Opportunities (O) (External, Positive)	Strategies to peer internal strengths with external opportunities from the environment.	Strategies to terminate internal weaknesses by exploiting external opportunities.
Threats (T) (External, Negative)	Strategies to annihilate external threats by operating internal strengths.	Strategies to abolish internal weaknesses by utilizing external threats.

The SWOT analysis and TOWS matrix were employed in a sequential and complementary manner to address both the analytical and strategic dimensions of this study. Initially, the SWOT analysis was conducted to systematically identify and classify the internal and external factors influencing the implementation of open-source geospatial technologies, within the context of expropriation management. This diagnostic phase yielded a structured evaluation of institutional SWOT, informed by expert consultations, scholarly literature, and empirical field observations. Drawing upon the insights generated through the SWOT analysis, the TOWS matrix was subsequently applied as a strategic planning instrument, translating identified factors into actionable strategies. Whereas the SWOT framework serves primarily a diagnostic function, the TOWS matrix is prescriptive and forward-looking, offering targeted strategic responses through the systematic pairing of internal and external variables. The integration of these tools facilitates a coherent progression from situational analysis to strategic formulation: SWOT clarifies the current institutional landscape, while TOWS delineates potential future directions and implementation pathways.

Study area

The study area encompasses the boundaries of the Polog Region, one of the eight administrative regions in North Macedonia, situated in the northwest of the country. It includes two major cities, Tetovo and Gostivar. The region holds strategic importance due to its geographic location, economic potential, and cultural significance within the national framework. Given its strategic geographical positioning, this region holds significant potential for infrastructural development. The case study includes cadastral parcels from two cadastral municipalities under the jurisdiction of the Cadastral Department of Tetovo (Figure 1-3).

Study Framework

The methodological framework illustrated in Figure 4 is structured around five core stages: Data Collection, Data Preparation, Data Analysis, Data Visualization, and Decision Support. In the Data Collection phase, cadastral parcel data and foundational spatial layers were obtained from a private cadastral-surveying office and subsequently verified through the National Portal for E-Services. During the Data Preparation stage, the acquired spatial datasets were subjected to cleaning, reprojection, and systematic organization within the QGIS environment to ensure consistency in coordinate reference systems and attribute schema. The Data Analysis phase involved the application of advanced geospatial

Figure 1
Study area map – map of Republic of North Macedonia.

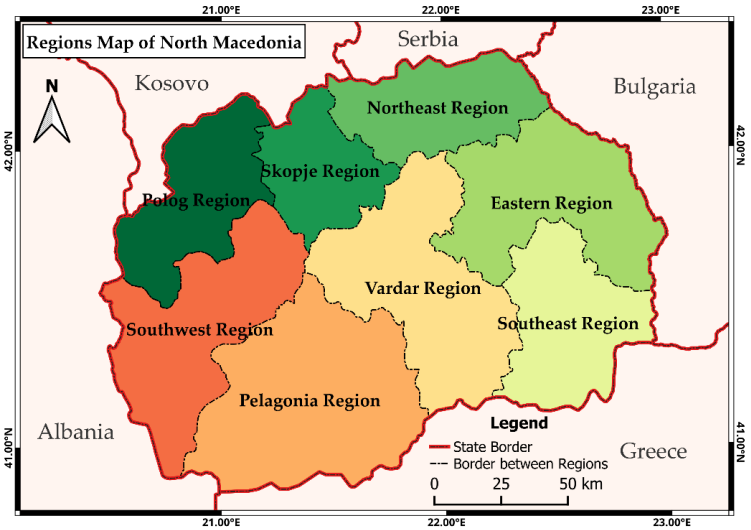

Figure 2
Study area map – map of Regions in Republic of North Macedonia.

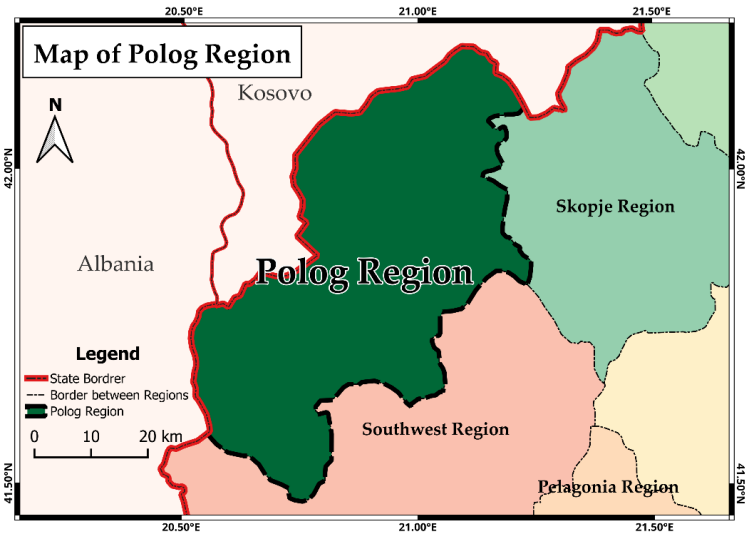

Figure 3
Study area map – map of Polog Region in Republic of North Macedonia.

operations, such as spatial queries, buffer analysis, and overlay functions, within QGIS to delineate parcels affected by the proposed infrastructure development. In the Data Visualization stage, identified parcels were symbolized, labeled, and exported for rendering in both QGIS and Google Earth Pro, with outputs cross-validated against official cadastral records. Finally, in the Decision Support stage, the analytical and cartographic outputs were consolidated into thematic maps, tabular summaries, and interactive geospatial layers, serving as decision-support tools for institutional stakeholders. This structured methodological approach not only ensures technical precision but also promotes transparency, replicability, and accessibility within the expropriation decision-making process. Each phase of the proposed workflow, comprising data collection, preparation, analysis, and decision support, is systematically structured to align with the principles of quality management and transparency ISO standards and SDGs. This alignment ensures that the methodology conforms to internationally recognized standards, thereby enhancing institutional reliability, fostering innovation, and improving overall organizational performance.

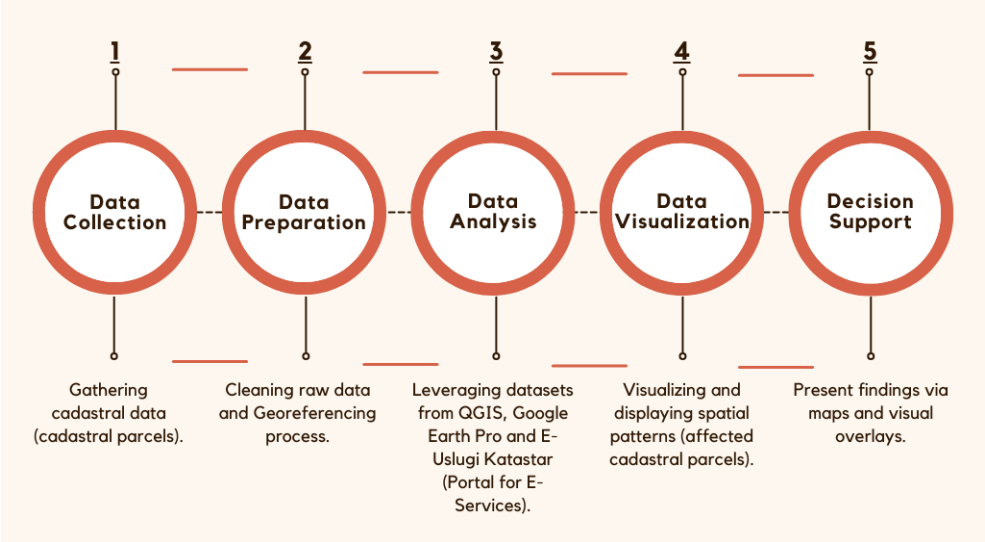

Figure 4
Designed flowchart with five key stages representing the workflow of the employed process.

RESULTS

As an expropriation case study, a total of 20 cadastral parcels has been analyzed, all of which belong to two cadastral municipalities under the jurisdiction of the Cadastral Department of Tetovo. The selected parcels are entirely state-owned, with no privately owned properties included, ensuring the protection of privacy and preventing the misuse of sensitive information. The spatial and legal datasets utilized in this study were primarily obtained from a private cadastral surveying office, complemented by data accessed through the official online platform of Cadastral Department, maintained by the Agency for Real Estate Cadastre (AREC) of North Macedonia. Although the data are of high quality and appropriate for geospatial analysis, minor inconsistencies, such as overlapping polygons were identified and subsequently rectified using QGIS geoprocessing tools. Accordingly, the finalized dataset satisfies the requisite standards for spatial accuracy and legal validity, thereby ensuring its suitability for integration within digital expropriation workflows.

Expropriation case study

Visualization with QGIS - The visualization of cadastral parcels and areas subject of expropriation were conducted in QGIS using a structured GIS-based methodology to ensure spatial accuracy, and

effective data representation. The process began with the acquisition of cadastral data from a private cadastral-surveying office in shapefile (.shp) format, containing essential attributes such as parcel ID, area, land classification and ownership type. These shapefiles were subsequently imported into QGIS for preprocessing and refinement. To maintain geospatial consistency, the Coordinate Reference System (CRS) was verified and, when necessary, reprojected from the Macedonian State Coordinate System (EPSG:6316) to WGS 84 (EPSG:4326) to ensure compatibility. Topological integrity checks were performed to identify and rectify geometric inconsistencies, including overlapping polygons, self-intersections, duplicate vertices, and invalid geometries, which could otherwise compromise spatial analysis. To enhance visualization, a symbology framework was applied: original cadastral parcels were rendered in neutral tones (Figure 5), while cadastral parcels object of expropriation was highlighted in distinct colors (Figure 6, Figure 7).

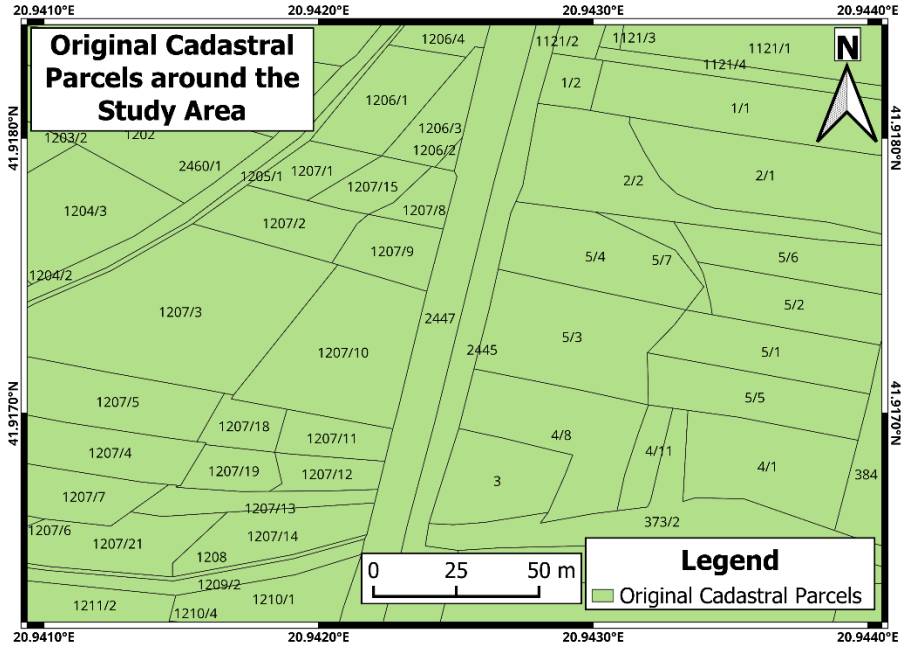

Figure 5
Cadastral parcels of the area where the study was conducted, obtained from a private office for cadastral-surveying services and engineering (original data).

In QGIS, a suite of spatial analysis tools was employed to overlay proposed infrastructure corridors onto existing cadastral boundaries, enabling the identification of land parcels directly impacted by the project. Buffer analysis was utilized to delineate the impact zone, thereby verifying that no adjacent public facilities or environmentally protected areas fell within a critical proximity. Additionally, the use of symbology and labeling functionalities facilitated the creation of visually distinct classifications between expropriated and unaffected parcels, thereby enhancing the clarity of spatial outputs for communication with policymakers and stakeholders. Attribute table filtering and field calculator operations were further applied to extract parcels based on ownership classification and area thresholds, thereby optimizing the prioritization and sequencing of expropriation procedures.

To improve data readability, cadastral parcel labels displaying key attributes (e.g., cadastral parcel numbers, expropriation status, and administrative codes) were generated. The processed dataset was then exported as a new shapefile, ensuring the retention of only relevant features (Figure 7).

In QGIS, a range of core geoprocessing and spatial analysis tools were systematically applied to support the digital workflow. The “Buffer” tool was employed to generate proximity zones around proposed infrastructure alignments, facilitating the identification of adjacent and potentially impacted

cadastral parcels. The “Select by Location” function was subsequently used to extract cadastral parcels intersecting these buffer zones. To perform spatial merging and delineation of the affected area, the

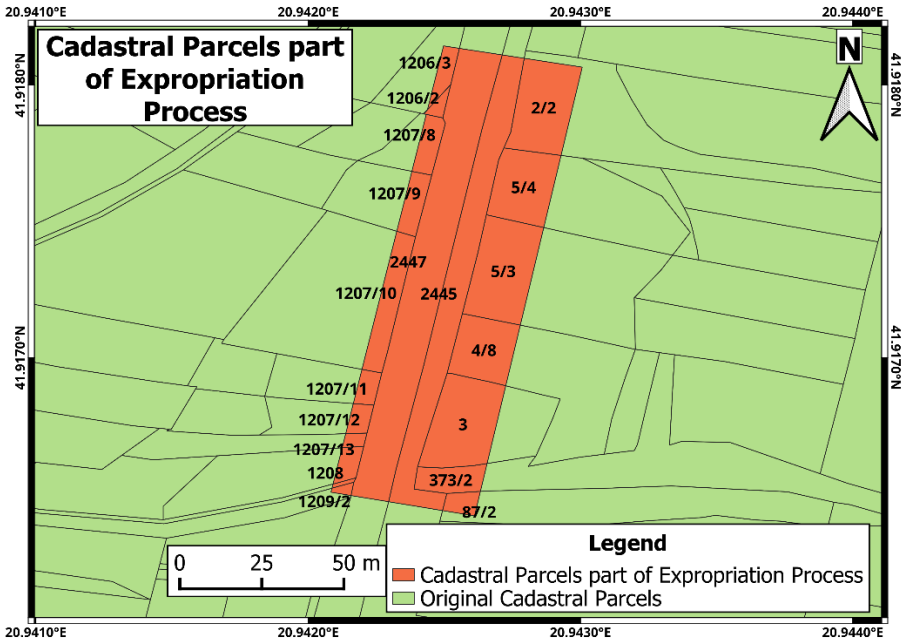

Figure 6
Cadastral parcels of the area where the study regarding expropriation was Conducted.

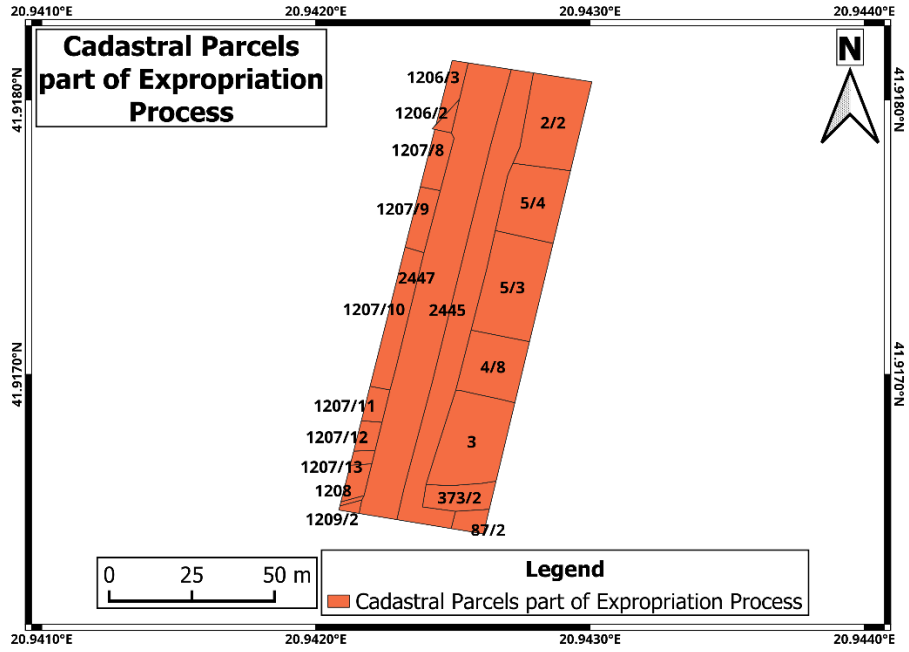

Figure 7
Sections of cadastral parcels designated for expropriation.

“Union” and “Intersect” tools from the Vector Overlay toolbox were utilized. Furthermore, the “Field Calculator” enabled the creation of new attribute fields, such as Parcel Type, Expropriation Status, and Buffer Distance, which enhanced the semantic structuring of the dataset. To ensure geometric consistency and spatial integrity, the “Topology Checker” and “Check Validity” tools were applied to detect and correct topological errors, including overlapping polygons, sliver gaps, and self-intersections. For visualization purposes, the “Labeling” tool facilitated the dynamic display of parcel identifiers and area measurements, while the Symbology panel was configured to enable thematic representation

distinguishing expropriated from unaffected parcels. All spatial layers were exported in shapefile format and reprojected using the "Reproject Layer" tool to conform to the coordinate reference system, thereby ensuring interoperability with other spatial data platforms. This structured sequence of tools provided an efficient, precise, and reproducible spatial analysis pipeline, fully aligned with the overarching objectives of digital transformation and improved governance within the expropriation domain.

Visualization with Google Earth Pro - The QGIS and Google Earth Pro in conjunction facilitates a deeper spatial understanding of expropriation zones in relation to real-world terrain and infrastructure. However, it is important to note that Google Earth Pro does not support advanced GIS operations or complex data management tasks. The visualization of cadastral parcels subject to expropriation case study was extended to Google Earth Pro to enhance spatial interpretation. The processed shapefiles from QGIS were converted into KML format and seamlessly incorporated into Google Earth Pro, ensuring compatibility with existing geospatial datasets. Upon import, cadastral parcels were accurately overlaid on satellite imagery, providing a real-world spatial context for expropriation assessments. The same visualization process can be achieved by directly importing shapefiles into Google Earth Pro. Upon import, parcels subject to expropriation can be visualized using customized color schemes and labels, replicating the approach employed in QGIS. To enhance interpretability, cadastral parcels which are subject of expropriation were visually distinguished using distinct color schemes and transparency settings (Figure 8), ensuring clear differentiation from unaffected land areas.

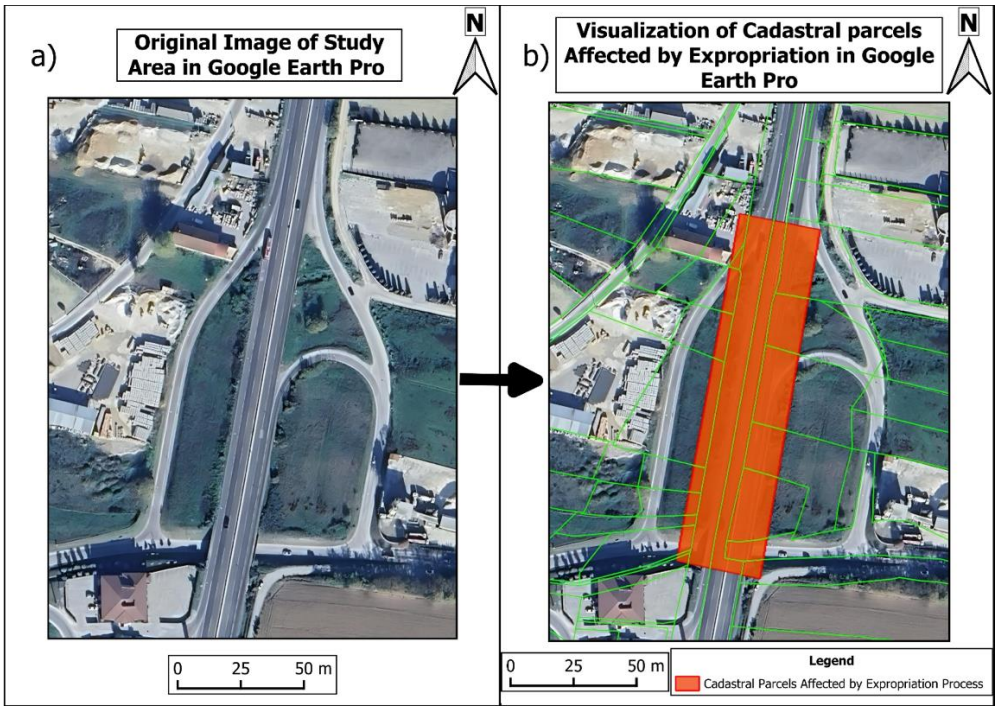

Figure 8
a) Original ımage of study area in Google Earth Pro (imagery date: 11/8/2024; source: Google Earth Pro) b) Visualization of cadastral parcels affected by expropriation in Google Earth Pro.

Google Earth Pro was employed primarily for three-dimensional terrain visualization and contextual land use interpretation, facilitating the assessment of topographical suitability within the designated project area. This application enabled the identification of potential physical constraints, such as steep slopes, dense vegetation, and water bodies, that are not readily discernible on conventional cadastral maps. The historical imagery function was further utilized to analyze temporal land cover changes, thereby providing supplementary justification for the selection of specific parcels. Transparent polygon overlays were applied to allow concurrent visualization of high-resolution satellite imagery and

project boundaries, thereby enhancing the spatial accuracy and reliability of decision-making processes.

Visualization with Portal for E-Services - To further enhance the accessibility and usability of the expropriation dataset, the data is transferred to Portal for E-Services. A similar process of visualization has been implemented in Portal for E-Services by importing shapefiles containing expropriation related cadastral parcel data (Figure 9). Once uploaded, the system enables users to overlay and analyze the designated expropriation parcels within the official cadastral platform over original cadastral parcels. This incorporation enhances data verification, ensures spatial accuracy, and provides direct access to authoritative cadastral records. Furthermore, the ability to cross-reference expropriation boundaries with existing cadastral data improves transparency and facilitates informed decision-making in the expropriation process.

The E-Uslugi Katastar portal functioned as a critical verification instrument within the digital workflow, facilitating the confirmation of the legal and administrative status of cadastral parcels previously identified through spatial analyses conducted in QGIS and Google Earth Pro. Following the delineation of expropriation-relevant parcels using geospatial tools, each parcel's unique identifier, ownership classification, surface area, and administrative coding were cross-referenced in real time against official cadastral records available on the portal. This verification procedure ensured the inclusion of only state-owned parcels devoid of mortgages, legal disputes, or administrative encumbrances, thereby safeguarding against the misuse of sensitive data and the unauthorized handling of private property records. Legal titles and property sheets were directly retrieved via the portal interface, allowing for the identification and correction of any discrepancies between the portal records and the QGIS dataset, such as outdated boundaries or missing metadata. Additionally, the portal enabled the overlay of official base maps with user-imported shapefiles, thereby enhancing spatial precision and enabling visual validation of parcel boundaries. Collectively, these procedures contributed to the creation of a legally robust, transparent, and institutionally valid dataset for the expropriation case study. Nevertheless, the limited availability of spatial analysis tools and occasional access delays within the portal were noted as technical constraints during the integration process.

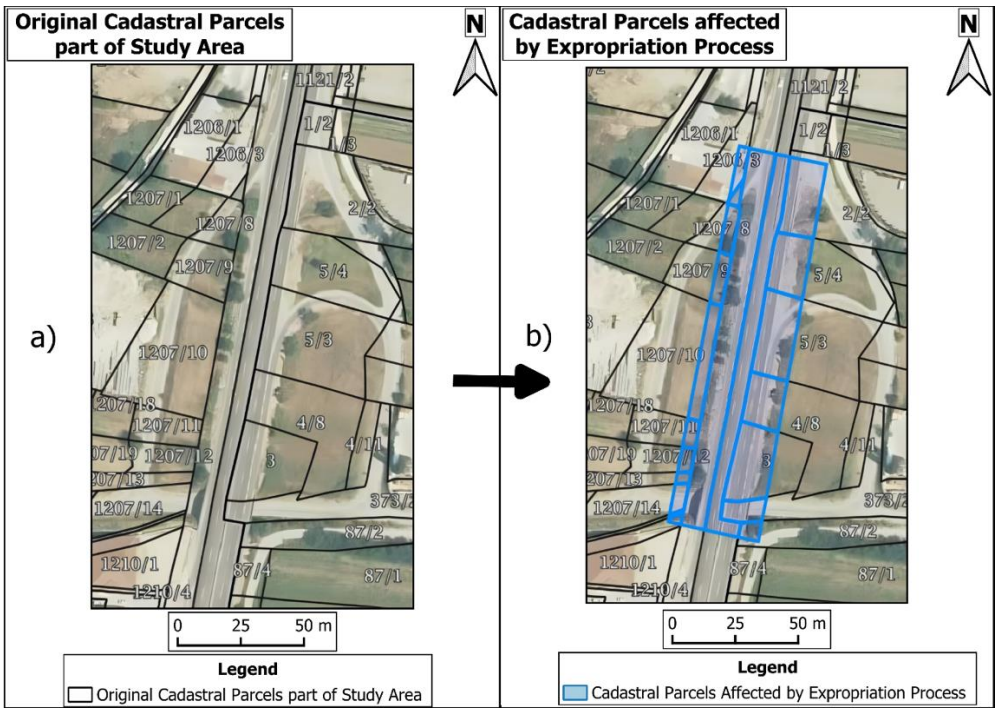

Figure 9

a) Original cadastral parcels of study area registered in portal for e-services b) Cadastral parcels affected by

Expropriation in Portal for E-Services (https://e-uslugi.katastar.gov.mk).

The Portal for E-Services served a pivotal function in the legal verification process. For each selected parcel, official records pertaining to ownership, cadastral status, and legal designations were accessed in real-time. This enabled the systematic cross-referencing of spatial datasets derived from QGIS with current legal information, thereby ensuring that the parcels identified for potential expropriation were not encumbered by litigation, mortgages, or administrative constraints. Moreover, the integration of attribute data from the portal supported the automated generation of formal documentation required for submission to the relevant municipal expropriation authorities. Furthermore, the incorporation of open geospatial sources is crucial in optimizing the expropriation management process, thus forming a comprehensive and synergistic system that supports the effective management and visualization of expropriation data.

SWOT analysis

To comprehensively assess the effectiveness and impact of utilizing these applications, a SWOT analysis is conducted to identify key factors influencing their implementation [69-71]. SWOT analysis is widely recognized as a conceptual framework and analytical tool that is extensively utilized in the strategic planning and development process [72]. This approach provides a clearer understanding of the system's overall feasibility and long-term sustainability. The study-related SWOT analysis is represented in Table 3 below:

Table 3
Strengths (S), Weaknesses (W), Opportunities (O) and Threats (T) of open geospatial tools in the expropriation management process.

S	1.	Cost-effective and open-source solutions
	2.	Global standardization and interoperability
	3.	Advanced spatial analysis and visualization
	4.	Enhanced data accuracy and visualization
	5.	Improved workflow and data sharing
W	1.	Data integration challenges
	2.	Learning curve and training
	3.	Limited real-time geospatial data
	4.	Performance issues with large datasets
	5.	Manual updates and maintenance required
O	1.	Digitalization and modernization of the expropriation process
	2.	Expansion to other geographic regions
	3.	Public engagement and transparency
	4.	Training and capacity-building initiatives
	5.	Improved coordination and collaboration among institutions, government agencies, policymakers, landowners, and developers
T	1.	Technological dependency and system vulnerabilities
	2.	Resistance to change from traditional paper-based systems
	3.	Legal and regulatory challenges
	4.	Institutional barriers
	5.	Software updates and compatibility issues

TOWS Matrix

The TOWS Matrix, as an extension of SWOT analysis, integrates external and internal factors [73], primarily through four distinct strategic combinations [68, 74]. The TOWS matrix can identify areas for improvement to enhance the system's sustainability [67]. The TOWS Matrix framework is employed to assess the organization's current position, establish strategic objectives, and inform

strategic decision-making processes [75]. A TOWS Matrix prepared as part of this study is represented in Table 4 below:

Table 4
TOWS matrix of open geospatial tools in the expropriation management process.

	Strengths (S) **(Internal, Positive)**	**Weaknesses (W)** **(Internal, Positive)**
Opportunities (O) **(External, Positive)**	S-O1: Leverage QGIS and Google Earth Pro to modernize expropriation processes in developing countries. S-O2: Use the real-time data-sharing capabilities of Portal for E-Services to enhance public engagement and transparency in expropriation processes. S-O3: Expand the use of QGIS and Google Earth Pro to other geographic regions facing similar challenges.	W-O1: Invest in training programs to improve institutional staff proficiency in QGIS and Google Earth Pro, enabling better data integration. W-O2: Develop formats and protocols to facilitate seamless integration between QGIS, Google Earth Pro, and Portal for E-Services. W-O3: Establish partnerships with GIS experts and institutions to provide technical support for digital transformation in expropriation.
Threats (T) **(External, Negative)**	S-T1: Use QGIS's advanced spatial analysis tools to mitigate the risks of outdated geospatial data from Google Earth Pro. S-T2: Promote the advantages of digital transformation to counter bureaucratic resistance in institutions. S-T3: Promote QGIS as a cost-effective solution to overcome resistance to change in traditional expropriation processes.	W-T1: Implement regular software updates and maintenance to address compatibility issues and reduce system vulnerability. W-T2: Develop user-friendly interfaces and simplified workflows to reduce the learning curve and encourage adoption. W-T3: Establish legal frameworks to recognize digital records, reducing regulatory challenges in expropriation processes.

DISCUSSION

Countries that lack advanced digital infrastructure, thus missing well-established and functional systems such as Expropriation Information System, Expropriation Database Systems, or Expropriation Digital Archive System, carry the potential of engagement open geospatial sources as a replacement method. This study aims to significantly contribute to the digitalization and transformation of the expropriation process, by incorporating open-source tools, thus highlighting the transformative role of geospatial solutions in improving the expropriation process in regions missing robust approaches. Facilitating efficient spatial analysis and data visualization, assembles QGIS as an invaluable asset for managing expropriation data. Nevertheless, challenges such as the steep learning curve remain as substantial obstacles to its adoption in developing countries [76, 77].

The TOWS Matrix developed within the scope of this study offers a systematic analytical framework through which institutional stakeholders can devise actionable strategies to facilitate digital transformation in the management of expropriation processes. Specifically, the S-O strategies, such as the utilization of QGIS and Google Earth Pro, highlight the potential of open-source geospatial technologies to support scalable modernization efforts. The W-O strategies, including targeted investments in staff capacity development and strategic collaborations with GIS-focused institutions, address critical barriers to effective digital adoption. Furthermore, the S-T strategies, exemplified by the promotion of QGIS as a cost-efficient digital alternative, are designed to mitigate institutional inertia and resistance to change. These strategic insights extend beyond theoretical

propositions; they provide a practical roadmap for policymakers seeking to implement incremental yet transformative reforms in existing expropriation workflows. The integration of such strategies holds significant potential to narrow the digital divide and to foster a more transparent, inclusive, and resilient land governance ecosystem within North Macedonia and comparable contexts.

A significant limitation of the present study is the exclusive reliance on state-owned cadastral parcels within the expropriation case study. This methodological decision was justified by the need to safeguard sensitive information related to private property rights and to adhere to ethical standards and data availability constraints. Expropriation processes involving privately owned parcels typically entail more intricate legal, socio-political, and compensation-related dynamics, which fall outside the scope of this research. Therefore, while the results and the proposed digital workflow are well-suited for implementation within institutional frameworks that manage public land, their application in contexts involving mixed ownership necessitates further refinement and contextual adaptation even in fully private cadastral parcels.

The findings of this study align with, and further substantiate, the established academic consensus regarding the transformative potential of GIS in land management and public administration. As emphasized by scholars across various national contexts, including Croatia, Serbia, Bosnia and Herzegovina, and Kosovo, the implementation of QGIS-based digital workflows has proven instrumental in modernizing institutional procedures and enhancing the efficiency and transparency of decision-making processes related to expropriation. The empirical evidence derived from the present case study reinforces the proposition that strategically deployed open-source GIS platforms possess the capacity to deliver spatially accurate and analytically robust outputs. Such capabilities are essential for addressing complex operational tasks, including cadastral parcel delineation, expropriation cost assessment, and the planning of property relocations.

The integration of open geospatial solutions into expropriation procedures aligns with broader socio-economic development goals, ensuring that land resources are managed effectively and sustainably. By providing a practical and cost-effective solution and enabling the creation of integrated digital platforms directly involved in the expropriation management process, QGIS and other open geospatial sources collectively form a leveraged digital ecosystem for efficient expropriation management, particularly in North Macedonia. Each platform part of this study contributes unique functionalities that enhance and streamline the expropriation management process, facilitating improved data accessibility, spatial analysis, and decision-making. The synergy between these tools empowers institutions in North Macedonia in modernizing the expropriation procedures. Expropriation management can evolve into a more data-driven and collaborative process by leveraging the unique strengths of each platform. Additionally, a critical and urgent necessity for the Republic of North Macedonia, is the establishment of a comprehensive Digital Expropriation Archive System and an Expropriation Information System as well. The development of such systems is a necessity and would mark a transformative advancement in the country's land management framework and workflow. Ensuring compliance with global standards, the deployment requisite adhering with ISO standards and the SDGs. The most appropriate SDGs related to our study are listed below:

a) SDG 8: Promoting inclusive and sustainable economic growth, ensuring efficient and standardized processes in expropriation management, supported by ISO 9001 [78].

b) SDG 9: Promoting innovation and building infrastructure, fostering technological advancements in data management, facilitated through ISO 56002 [79].

c) SDG 11: Promoting sustainable cities and communities, encouraging responsible urban

development and planning, addressed by ISO 37101 [80].

d) SDG 15: Promoting sustainable use of terrestrial ecosystems, sustainably managing forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss, strengthened by ISO 14055-1 [81] and ISO 38200 [82].

CONCLUSION

Bounded digital infrastructure, especially in underdeveloped and developing countries, often is a synonym of several obstacles and barriers to the progress of diverse processes. This study is a point of reference and capability for growth, as well as transformation, especially for countries that deficit a determined digital architecture, specifically for approach related to expropriation management. Through this research, an essential-needed solution and a transformative indicator tool is granted, through the features and specifications of QGIS, the advanced visualization of Google Earth Pro, as well as the designed E-Services Portal platform for real-time data control and distribution, and spatial analysis. However, despite the seemingly various advantages and benefits, the affiliation and the utilization of these tools as part of the expropriation management is extremely challenging and demanding. Among them, institutional obstacles and resistance, as well as inter-institutional inaction in this trend, are the far-reaching concerns.

Ultimately, from a progressive approach, open-source geospatial sources and their operational robustness demarcated in this study can and should move the walls that have been built until now. Progress towards effective, transparent, robust and well-structured systems support and contribute to the breaking of precedent management and governance expropriation process so far. Towards this evolutional pace and in executing this approach, on the way to the accommodation and assumption, initially of open-source geospatial tools, especially in QGIS, Google Earth Pro, and the Portal for E-Services, the tuition of institutional staff is indispensable. Increasing inter-institutional fraternization within government establishment, private parties and by engaging associated organizations, is undoubtedly an essential promoter. Continuous monitoring of the operations and systematic advice conjointly with user assessment clinch long-term functioning.

To operationalize the findings of this study and convert them into effective policy measures, a structured and strategic roadmap is proposed for governmental authorities and cadastral institutions in North Macedonia. As a first step, it is imperative to initiate the development of a centralized Digital Expropriation Archive System alongside an integrated Expropriation Information System, both underpinned by the quality management and sustainability principles outlined in ISO standards and SDGs. Second, targeted investments should be directed toward capacity-building initiatives aimed at enhancing institutional competencies in the use of QGIS, Google Earth Pro, and the national Portal for E-Services, thereby addressing digital literacy deficiencies identified through the SWOT analysis. Third, the establishment of inter-institutional coordination mechanisms is essential to facilitate seamless data exchange, enhance procedural transparency, and mitigate bureaucratic inefficiencies. Fourth, legal and regulatory frameworks should be reformed to formally recognize digital cadastral records and geospatial datasets as legally valid instruments within expropriation procedures.

As an initial step, institutional stakeholders are advised to adopt QGIS as the primary GIS platform for the management and visualization of cadastral datasets, owing to its extensibility, cost-effectiveness, and interoperability with open data standards. In the second phase, the establishment of a centralized PostgreSQL or PostGIS spatial database is recommended for the storage and management of real-time parcel data, associated legal documentation, and metadata, thereby ensuring scalability, data integrity, and multi-user accessibility. The third step involves utilizing the PyQGIS

scripting environment to automate spatial queries, streamline the generation of expropriation-related reports, and integrate external cadastral web services. In the fourth phase, a secure and user-friendly web-based GIS interface, developed using platforms such as QGIS Server or GeoServer in conjunction with client libraries like, should be deployed to facilitate multi-stakeholder access, including by municipal departments, landowners, and legal units. Finally, national authorities should prioritize the development of comprehensive technical documentation, user manuals, and training programs aligned with international standards. Collectively, these incremental strategies constitute a scalable and replicable framework for the establishment of a fully integrated system and may serve as a transferable model for implementation in other regions with comparable institutional and technical contexts.

In a digital era, is it justifiable for the monitoring and management of expropriation procedures to continue relying on traditional methods, such as paper-based records and printed documents? Consequently, does the Republic of North Macedonia require the establishment of a Digital Expropriation Archive System and a Digital Expropriation Information System to enhance productivity, transparency, and accessibility in expropriation processes?

Although the technical architecture for a fully integrated Digital Expropriation Information System is demonstrably feasible, its practical implementation is constrained by significant institutional barriers. The foremost challenges relate to the substantial financial investment required for server infrastructure and the recruitment of specialized personnel, particularly within the field of information technology. The strategic pathways delineated in the TOWS Matrix (Table 4), including targeted investment in training (W-O1) and the promotion of the benefits of digital transformation as a means of overcoming institutional resistance (S-T2), offer a structured roadmap for addressing these specific challenges.

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Author Contributions
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Research- Data Analysis- Validation (CRediT 3-4-6-11) E.J. (%30) – Ö.F.A. (%30) – H.Z.S. (%20) – S.S.D. (%20)
Writing the Article (CRediT 12-13) E.J. (%60) – Ö.F.A. (%40)
Revision and Improvement of the Text (CRediT 14) – H.Z.S. (%50) – S.S.D. (%50)

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Sustainable Development Goals (SDG)
Sustainable Development Goals: 8 Decent Work and Economic Growth
Sustainable Development Goals: 9 Industry, Innovation, and Infrastructure
Sustainable Development Goals: 11 Sustainable Cities and Communities
Sustainable Development Goals: 15 Life on Land

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