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GEOSPATIAL TECHNOLOGIES IN POST-WAR RECONSTRUCTION: CHALLENGES AND INNOVATIONS IN UKRAINE

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Abstract. *TUkraine's post-war reconstruction requires effective strategies to transform war-torn areas into resilient, smart cities, with geospatial technologies playing a pivotal role. Several key scientific methods were employed for the study, including data extraction and analyses, system modeling, and complexity decomposition. This study explores the challenges and innovations in applying geospatial technologies to Ukraine's reconstruction efforts. It examines data accuracy and availability, and the integration of ecological and urban planning within GIS frameworks. Key challenges identified include data inaccuracy, technological limitations, and a shortage of skilled professionals. Innovations such as the development of the GIS for Regional Development and integration with the Digital Restoration Ecosystem for Accountable Management (DREAM) aim to address these issues. A sustainable economic reconstruction model is presented, emphasizing geospatial data integration. Enhancing legislation on geospatial data infrastructure and implementing capacity-building initiatives are essential. Effective integration of advanced geospatial technologies and improved legislation will enable Ukraine to meet reconstruction demands, fostering sustainable urban environments and serving as a model for other nations.*

Keywords: *urban renovation, GIS, restoration economy, sustainable development, innovation technology, urban economics.*

Introduction

The reconstruction of cities and lands devastated by war presents a critical and multifaceted challenge for any nation. Ukraine, currently enduring a full-scale conflict, has witnessed extensive destruction, impacting numerous cities, villages, and essential infrastructure such as bridges. This war has not only caused significant physical damage but has also led to severe ecological

consequences. As part of Ukraine's digital restoration and development toolkit, an essential phase of implementing GIS will be its integration with the Digital Restoration Ecosystem for Accountable Management (DREAM). DREAM aims to digitize the entire reconstruction process, making it fully public, transparent, and more efficient. It provides a unique mechanism for collecting systematic information about reconstruction projects at all implementation stages and ensures transparent and accountable use of reconstruction funds.

By integrating modern digital solutions, such as GIS and DREAM, Ukraine aims to ensure transparency and accountability throughout the reconstruction process, making it an exemplar of efficient and effective post-war recovery. This article explores the multifaceted role of geospatial technologies in the post-war reconstruction of Ukraine, focusing on the challenges and innovations essential for transforming war-torn areas into smart cities. It examines the current state of geospatial data accuracy and availability, the integration of ecological and urban planning within GIS frameworks, and the technological advancements required to overcome existing limitations. Furthermore, it discusses capacity-building strategies to enhance local expertise in geospatial technologies, ensuring that reconstruction efforts are informed, effective, and sustainable.

The Ministry of Community Development, Territories, and Infrastructure of Ukraine has started developing the GIS for Regional Development (Fig. 1), which will serve as a single geoinformation system to monitor every stage of development and restoration of Ukraine's regions and communities. The GIS system, administered by the Agency for Restoration and owned by the Ministry, will identify common community problems, assess the effectiveness of local and regional recovery plans, evaluate the social and economic situation in each community, and monitor the development and recovery stages of Ukraine's regions and communities.

The GIS system will feature functionalities for collecting and processing data on socio-economic development indicators of communities and territories, monitoring regional development and recovery status at the local level based on these indicators, and providing geo-analytics and data visualization for decision-making by communities, regions, and the state. The system is set to be operational in a test environment by the end of the year, with funding for its

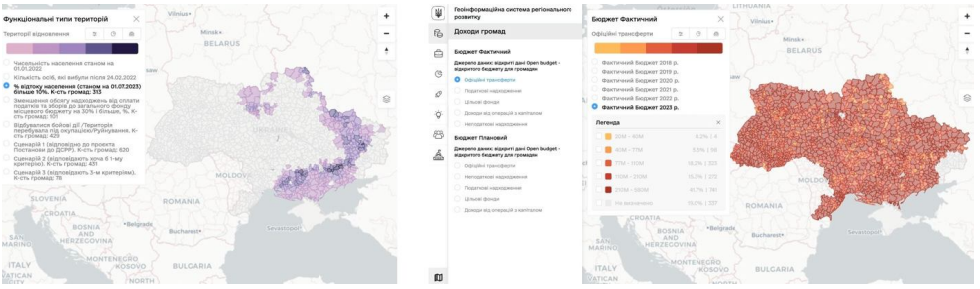

Fig. 1. Web interface of the GIS for Regional Development presented by the Ministry of Infrastructure of Ukraine on March 14, 2024 (prepared by: Martyn A. based on [1])

development provided by international technical assistance.

Analysis of recent researches and publications

The destruction of the Kakhovka Dam, for instance, has profoundly affected the southern Ukrainian ecosystem, while the Black Sea has suffered from pollution due to military activities. Furthermore, the conflict has displaced approximately 2 million people, forcing them to seek refuge in other countries [1-4]. These factors underscore the urgent need for a comprehensive and integrated post-war reconstruction plan that addresses both urban renewal and ecological restoration [5-7].

In this context, geospatial technologies, including Geographic Information Systems (GIS) and advanced cartographic methods, emerge as pivotal tools for planning and implementing effective post-war reconstruction strategies [8-10]. These technologies offer comprehensive solutions for assessing damage, planning redevelopment, and ensuring sustainable growth, thereby playing a crucial role in transforming devastated areas into modern, resilient, and smart cities [11-12].

Purpose. By highlighting the critical role of geospatial technologies in post-war reconstruction and detailing the framework established by the Ukrainian government, this article aims to contribute to developing resilient, smart, and sustainable urban environments in Ukraine.

Methods and research data

In line with this need, the Ukrainian government has created a unified geoinformation system for monitoring and evaluating the development of regions and territorial communities, as approved by the Cabinet of Ministers of Ukraine on May 23, 2023 (Resolution No. 522). This system, known as the GIS for Regional Development, is designed to provide analytical processing of information to support decision-making in the restoration and development of regions and communities and to monitor and evaluate the implementation of these processes.

Creating a Geographical Information System (GIS) for use in wartime and post-war reconstruction presents a multitude of challenges. These challenges stem from the unique and often severe conditions created by conflict, including infrastructure destruction, displacement of populations, and the complex logistics of coordinating reconstruction efforts. Below, we delve into some of the most significant problems encountered in developing and implementing GIS under these circumstances (Table 1).

Results

In the context of post-war reconstruction, the requirements for GIS extend far beyond those of peacetime topographic maps. The unique and complex challenges presented by a war-torn environment necessitate the inclusion of new and atypical data sets to effectively support recovery and redevelopment efforts. These data sets must capture a wide range of factors, from infrastructure damage to environmental degradation and socio-economic impacts, providing a comprehensive foundation for informed decision-making (Table 2 and 3).

Post-war reconstruction necessitates that the GIS industry accumulates and collects new types of data with corresponding accuracy and represents these data within cadastral systems and re-

1. Key problems faced in creating and implementing a GIS during wartime and post-war reconstruction and the potential solutions for overcoming these challenges*

Problem	Description	Solution
Data Accuracy and Availability	Destruction of data collection systems, restricted access to areas, and outdated/incomplete datasets.	Use drones and satellite imagery for real-time data collection; leverage crowd-sourced data and remote sensing.
Integration of Ecological and Urban Planning	Need for advanced GIS capabilities to balance urban redevelopment with ecological conservation.	Develop multi-layered GIS maps integrating urban and environmental data; involve environmental experts in planning.
Technological Limitations	Current GIS tools may not fully address the specific requirements of war-damaged environments.	Invest in advanced GIS technology tailored to post-war needs; incorporate high-resolution mapping and real-time data integration.
Capacity Building and Skilled Workforce	Disruption of educational and training programs leading to a shortage of qualified professionals.	Implement targeted training programs; establish partnerships with universities and international organizations for capacity building.
Coordination and Data Sharing	Difficulty in establishing a unified GIS platform for multiple stakeholders with varying data formats/standards.	Develop standardized data formats and protocols; create centralized GIS platforms for shared access and collaboration.
Security and Data Protection	Need for robust cybersecurity measures to protect sensitive information from unauthorized access.	Implement strong cybersecurity measures; ensure compliance with data protection regulations; use encryption and secure access controls.
Funding and Resource Allocation	Challenges in securing sufficient financial resources and managing international aid and technical assistance.	Secure international aid and technical assistance; ensure transparency and accountability in the use of funds.
Environmental Monitoring and Assessment	Requirement for sophisticated GIS tools to monitor and manage ecological damage in post-war environments.	Use advanced remote sensing technologies; establish continuous environmental monitoring systems integrated with GIS.
Public Engagement and Transparency	Ensuring GIS platforms are user-friendly and transparent to foster public trust and support.	Develop user-friendly GIS interfaces; ensure open access to relevant data; engage the public through transparent communication strategies.

* prepared based on the research data [1-11]

covery GIS frameworks. The unique challenges of conflict-affected environments require detailed damage assessment data, including building and infrastructure damage, hazard mapping of minefields and unexploded ordnance, and environmental degradation. Accurate socio-economic impact data, health and epidemiological information, and continuous environmental monitoring are also essential. These data sets provide a comprehensive understanding of the multifaceted impacts of war and are crucial for effective planning and execution of reconstruction strategies.

To effectively utilize GIS in its post-war recovery efforts, Ukraine must enhance its national legislation concerning geospatial data infrastructure. This enhancement should mandate the collection and accumulation of new datasets and implement innovative approaches to public accessibility, all while considering the challenges posed by wartime conditions and cybersecurity concerns. Strengthening the legal framework will

2. New GIS Data Sets for Post-War Reconstruction GIS: Beyond Peacetime Topographic Maps *

Data Set Category	Description	Responsible Authorities	Scale of Maps
Damage Assessment Data	Building Damage: Categorizing buildings by their level of damage (e.g., minor, major, destroyed) and identifying those requiring demolition or repair. Infrastructure Damage: Mapping the extent of damage to roads, bridges, utilities, and other critical infrastructure. Environmental Damage: Documenting areas affected by pollution, deforestation, or other ecological impacts resulting from the conflict.	Ministry of Infrastructure, Local Governments, State Environmental Inspection	1:1,000 to 1:10,000
Hazard Mapping and Minefields	Minefields: Detailed maps of known and suspected minefield locations, including types of mines and clearance status. UXO Locations: Information on the locations of unexploded ordnance, including the types and estimated quantities.	Ministry of Defense, Mine Action Operators, Local Authorities	1:2,500 to 1:10,000
Refugee and Displacement Data	IDP Camps and Refugee Settlements: Locations, capacities, and conditions of temporary settlements. Population Movement: Patterns of population displacement and return, including origin and destination points.	Ministry of Social Policy, UNHCR, Local Governments	1:10,000 to 1:50,000
Environmental Monitoring Data	Pollution Levels: Data on air, water, and soil pollution levels, including sources and affected areas. Natural Resource Depletion: Information on the status of natural resources such as forests, water bodies, and wildlife.	Ministry of Environment, State Environmental Inspection	1:5,000 to 1:50,000
Cultural Heritage and Preservation	Cultural Heritage Sites: Locations and conditions of cultural heritage sites, including those damaged or at risk. Preservation Efforts: Information on efforts to protect and restore cultural heritage.	Ministry of Culture, UNESCO, Local Heritage Organizations	1:1,000 to 1:50,000

* prepared based on the Martyn A. research data and public available materials

ensure that GIS technologies can support transparent, accountable, and efficient reconstruction efforts, while also addressing the security issues inherent in such a volatile context.

Figure 2 illustrates a generalized sustainable economic reconstruction model, which integrates settlements and population, nature, and land (top diagram), alongside a sample smart-city application layer service model (bottom diagram). In the future, smart-city application services will be integral to sustainable reconstruction as part of a framework that leverages technology to create resilient and efficient urban systems. This system can be employed during and after recovery from disruptions such as natural disasters, economic shifts, or infrastructure degradation, thereby enhancing the overall resilience and efficiency of urban environments.

3. New Socio-Economic Data Sets for Post-War Reconstruction GIS: Beyond Peacetime Topographic Maps*

Data Set Category	Description	Responsible Authorities	Scale of Maps
Socio-Economic Impact Data	Employment and Income Levels: Information on employment rates, income levels, and economic activities in affected areas. Public Services Availability: Status of essential services like healthcare, education, and social services. Housing Needs: Data on housing availability, conditions, and needs.	Ministry of Economy, Local Governments, Statistical Agencies	1:10,000 to 1:50,000
Health and Epidemiological Data	Health Facilities: Locations and operational status of hospitals, clinics, and other health facilities. Disease Outbreaks: Information on the incidence and spread of diseases, including any outbreaks related to the conflict.	Ministry of Health, WHO, Local Health Departments	1:5,000 to 1:50,000
Environmental Monitoring Data	Pollution Levels: Data on air, water, and soil pollution levels, including sources and affected areas. Natural Resource Depletion: Information on the status of natural resources such as forests, water bodies, and wildlife.	Ministry of Environment, State Environmental Inspection	1:5,000 to 1:50,000
Reconstruction Progress Tracking	Project Status: Information on the status of reconstruction projects, including timelines, budgets, and responsible entities. Resource Allocation: Details on the allocation and expenditure of funds for reconstruction activities.	Ministry of Infrastructure, Local Governments, International Donors	1:1,000 to 1:50,000
Community Engagement and Feedback	Community Surveys: Data from surveys and consultations with local communities regarding their needs and priorities. Public Feedback: Mechanisms for collecting and mapping feedback from the public on reconstruction efforts and outcomes.	Local Governments, NGOs, Community Organizations	1:10,000 to 1:50,000
Legal and Land Ownership Data	Land Ownership Records: Up-to-date information on land ownership, including any changes resulting from the conflict. Legal Disputes: Data on ongoing legal disputes over land and property.	Ministry of Justice, StateGeoCadastre, Local Governments	1:1,000 to 1:10,000

* prepared based on the Volodymyr N. research data and public available materials

Discussion

The recommendations presented in this article can serve as valuable guidance for the National Geospatial Data Infrastructure Council, relevant ministries, and agencies of Ukraine. By adopting these recommendations, Ukraine can develop resilient, smart, and sustainable urban environments, contributing to long-term recovery, stability, and prosperity. The effective integration of advanced geospatial technologies and improved legislative measures will enable Ukraine to meet the complex demands of post-war reconstruction and serve as a model for other nations facing similar challenges. The presented model focuses on integrating and managing digital services across key urban domains—such as land development, transportation cover network, natural resources management and support economic growth (revitalization). Using GIS-centered smart city service can assist with enhancing

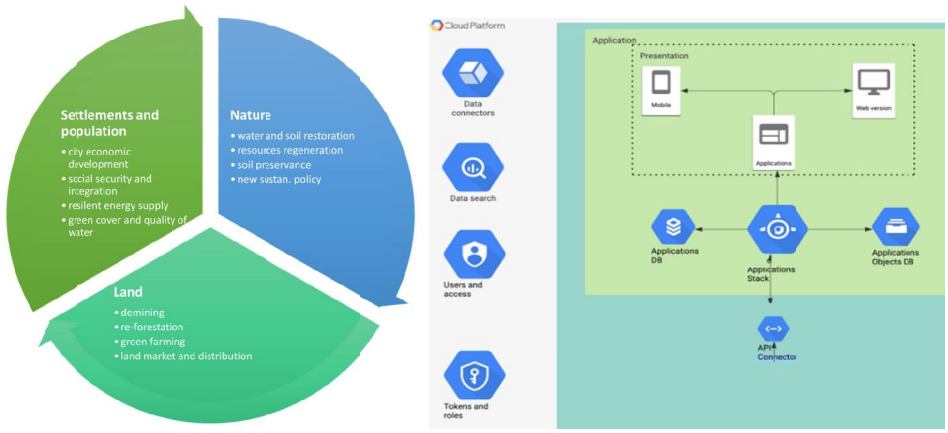

Fig. 2. Generalized sustainable economic reconstruction model (top) and sample smart-city application layer service model (bottom) (prepared by V.N. and A.M.)

sustainability, resource efficiency, and general population well-being. In future we plan to collect and group relevant spatial, economic and social data to create a real-time analytics web-service to support decision-making and response strategies for urban governance in areas of sustainable reconstruction..

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ГЕОПРОСТОРОВІ ТЕХНОЛОГІЇ У ПОВОЄННІЙ ВІДБУДОВІ: ВИКЛИКИ ТА ІННОВАЦІЇ В УКРАЇНІ

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Анотація. *Післявоєнна відбудова України вимагає ефективних стратегій перетворення зруйнованих війною районів на сучасні розумні міста, де геопросторові технології відіграють ключову роль. Для дослідження було використано кілька ключових наукових методів, включаючи збір та аналіз даних, моделювання систем та врахування їх складності. Це дослідження аналізує виклики та інновації у застосуванні геопросторових технологій для процесів, повязаних з відбудовою України. У ньому розглядається, аналізується точність та доступність даних, інтеграція екологічного та міського планування в рамках ГІС. Серед виявлених авторами ключових проблем слід зазначити: – мала або повна неточність даних, технологічні обмеження та нестача кваліфікованих фахівців. Такі інновації, як розробка ГІС для регіонального розвитку та інтеграція з Екосистемою цифрового відновлення для підзвітного управління (DREAM), спрямовані на вирішення цих питань. Представлено модель сталої економічної реконструкції, яка акцентує увагу на інтеграції геопросторових даних. Важливим є вдосконалення існуючого законодавства про інфраструктуру геопросторових даних та впровадження ініціатив з розбудови потенціалу. Ефективна інтеграція передових геопросторових технологій та вдосконаленого законодавства дозволить Україні знаходити шляхи для швидкої відбудови, сприяючи сталому міському середовищу та слугуючи прикладом для інших країн.*

Ключові слова: *повоєнне відновлення міст, ГІС, відновлювальна економіка, сталий розвиток, інноваційні технології, сучасні цифрові рішення, міська економіка.*