ASSESSMENT OF INFRASTRUCTURAL CHANGES IN THE TERRITORIES OF TSKHINVALI REGION OF GEORGIA (2007–2023) USING GEOINFORMATION SYSTEMS

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Abstract

This study examines the spatial and quantitative changes to infrastructure and settlements in the Tskhinvali region of Georgia between 2007 and 2023, caused by armed conflict and prolonged occupation. Using high-resolution aerial imagery, satellite data and geographic information systems (GIS), the research identifies and quantifies infrastructural losses across four municipalities: Tskhinvali, Java, Znauri and Akhalgori. Multi-temporal image analysis and digitization were performed using Google Earth Pro and ArcMap software. The results reveal a significant decrease in the number and area of infrastructure objects. Tskhinvali municipality experienced the most pronounced decline, with a 13.4% decrease in building areas and an 18.0% reduction in the number of infrastructure objects. The municipalities of Java and Znauri recorded infrastructure losses of 12.8% and 6.6%, respectively, while Akhalgori showed a modest 1.2% reduction. The spatial analysis also revealed patterns of degradation in specific settlements. These findings emphasize the long-lasting effects of conflict on built environments and highlight the importance of geospatial tools in post-conflict assessments. The study provides a detailed geodatabase to support future reconstruction, regional planning and peacebuilding initiatives. Furthermore, the methodology demonstrates the value of integrating temporal satellite imagery with GIS for monitoring changes in conflict-affected territories.

Keywords: geospatial analysis, GIS, infrastructure degradation, Tskhinvali region, Georgia

I. Introduction

Armed conflicts and occupations leave enduring physical and socio-economic impacts. Beyond immediate casualties, they damage or transform essential infrastructure—roads, bridges, power grids, settlements, and public facilities—reducing economic activity and quality of life [1,2].

Assessing these impacts is vital not only to document destruction but also to inform reconstruction planning, peacebuilding, and long-term regional development strategies [3].

Modern geospatial technologies—particularly high-resolution aerial imagery, satellite data, and geographic information systems (GIS)—provide powerful means to analyze territorial changes in conflict, occupied zones. Unlike ground surveys, which often rely on indirect or secondhand evidence, satellite imagery offers direct, verifiable information about spatial patterns and their evolution over time. The consistent temporal coverage of satellite archives also enables comparative studies of past and present conditions. These capabilities are crucial for understanding conflict dynamics, planning humanitarian interventions, and supporting reconstruction [4–7. Following the 2008 Russia–Georgia war, the Russian Federation recognized the independence of the self-proclaimed "Republic of South Ossetia," a move later followed by Nicaragua, Venezuela, and Nauru. However, the vast majority of the international community—including the European Union, NATO, the United Nations, and most UN member states—continues to regard these territories (Tskhinvali region) as part of Georgia's sovereign territory. While this issue has complex geopolitical, legal, and humanitarian dimensions [8–10], the present study addresses exclusively the infrastructural aspects of the changes observed in the occupied territories. Under the influence of hostilities and after the occupation of the Tskhinvali region in 2008, infrastructural facilities and settlements in the territories have changed. This article studies and analyzes these changes based on orthophotos derived from processing satellite and aerial images.

Knowing what infrastructural changes are taking place in the occupied territories of the Tskhinvali region after the occupation, what infrastructural facilities were destroyed and where they are being developed, where new settlements are being formed, etc., will help us to develop plans for the peaceful resolution of the conflict; also, when restoring territorial integrity, we will be ready to see how the existing infrastructure should be developed in the future.

This study uses multi-temporal, high-resolution aerial imagery and GIS-based digitization techniques to analyze settlement changes in the occupied territories of the Tskhinvali region between 2007 and 2023. Its objectives are to:

1. Quantify the scale and spatial distribution of infrastructure losses.
2. Identify the areas most affected by conflict and occupation.
3. Build an information database to support future reconstruction planning and conflict resolution initiatives.

II. Study area

The Tskhinvali region is located on the southern slopes of the Greater Caucasus range. Its northern border runs along the main watershed range of the Caucasus, and the eastern border runs along the Alevi range; the western border of the region crosses the Likhi, Racha, and Shoda-Kedela ranges, the valleys of the Dzirula, Kvirila, Jejora, and Gharula rivers, and ends directly at Mamisoni Pass; the southern border follows the northern periphery of the Shida Kartli plain. In the north, the Tskhinvali region borders the Republic of North Ossetia of the Russian Federation - Alania, and on the other three sides - the administrative units of Georgia: in the east - Kazbegi and Dusheti municipalities, in the south - Kaspi, Gori, Kareli, and Khashuri municipalities, and in the west - Sachkhere and Oni municipalities (see Fig. 1) [11].

The territory of the Tskhinvali region occupies 3,800 km². In the Tskhinvali region, Tskhinvali city, 4 townships - Akhalgori (former Leningori), Kornisi (former Znauri), Kvaisa, and Java, and about 300 villages are located [12].

The so-called Tskhinvali region (formerly South Ossetia Autonomous Region until 1991). The northernmost point of the region is the Caucasus Range, Mount Chanchakhi, at 4,461 m above sea level; the southernmost point is the valley of the river Tortla (a tributary of Mejuda), north of

Tbilisi-Senaki-Leselidze highway, south of Orchosani village at 725 m above sea level; the westernmost point is the gorge of the Gharula River (the left tributary of Rioni), northeast of Oni's village of Kvedi, 3 km, 1,300 m above sea level; and the easternmost point is the Lomisa-Alevi range, the area of Kartolisi, 4 km east of the village of Monasteri, at 1,839 m above sea level.

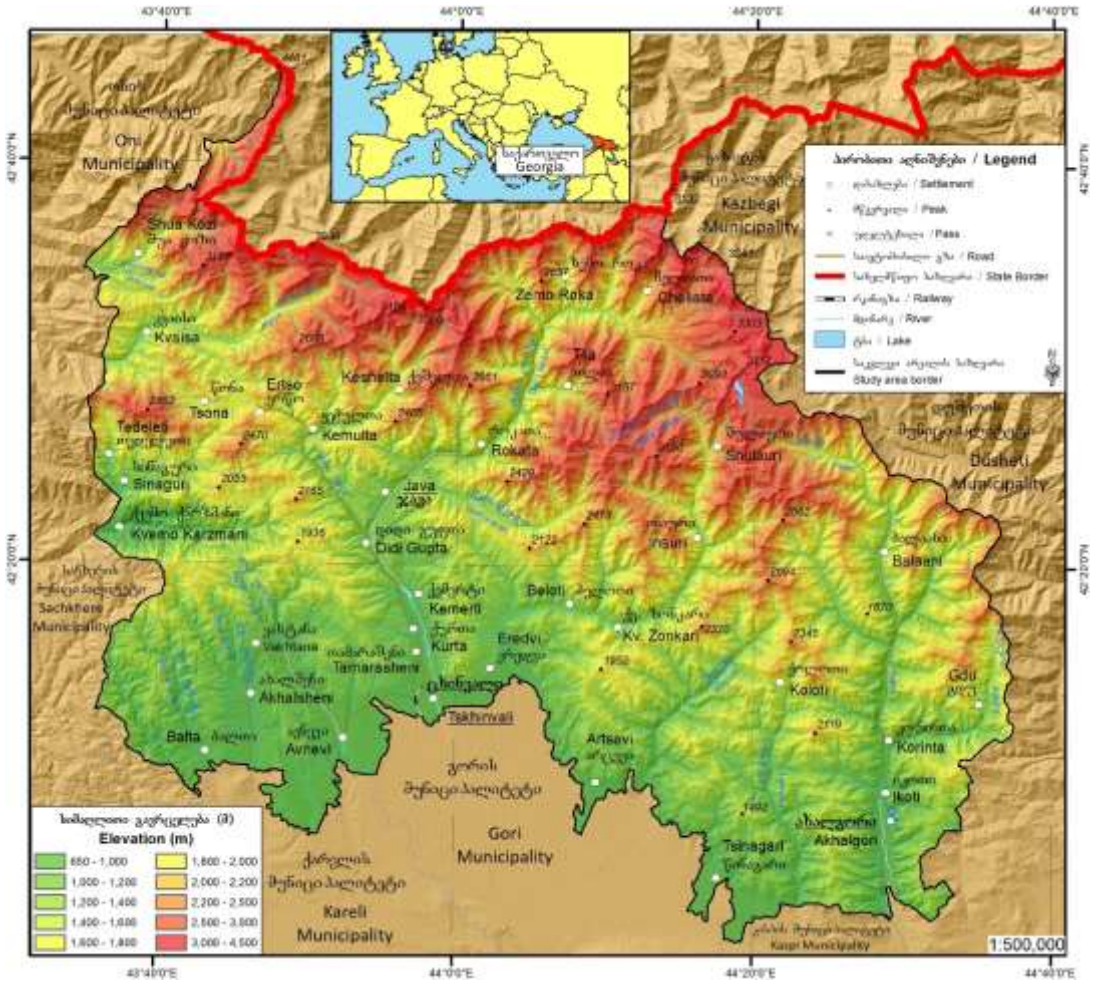


Figure 1: *A map of the study area*

Java Municipality (former South Ossetia Autonomous District until 1991). The northernmost point of the municipality is Mount Chanchakhi, the Caucasus Range, at 4,461 m above sea level; The southernmost point is the area of Nacherala, the watershed of Kekhura and Itrapuli (Didi Liakhvi river basin), at 1,751 m above sea level; The westernmost point is the gorge of the Gharula River (a left tributary of the Rioni river), 3 km northeast of the Oni village of Kvedi, at 1,300 m above sea level, and the easternmost point is the Keli volcanic mountain range, south of Kelitsadi Lake, at 3,409 m above sea level [12,13].

The so-called Znauri Municipality (within the former South Ossetia Autonomous District until 1991). The northernmost point of the municipality is the Likhi range, Mount Rustavi, the watershed of the Aghmosavletis Prone and Patsa rivers, at 1,936 m above sea level; the southernmost point is the gorge of the Ghaghuri River (the left tributary of the Dasavletis Prone River), south of Shua Kvatetri village, at 760 m above sea level; the westernmost point is the Likhi range, Mt. Kaprebi hill, at 1,183 m above sea level; and the easternmost point is the basin of the Aghmosavletis Prone River, the Saltani channel, 3 km east of the village of Didmukha, at 845 m above sea level [12,13].

Akhalgori region (former South Ossetia Autonomous District until 1991 - Leningori Region). The northernmost point of the municipality is the Keli highland, west of the Archvebi

Lake, at 3,310 m above sea level. The southernmost point is the gorge of the river of Tortla (a tributary of Mejuda), north of the Tbilisi-Senaki-Leselidze highway, south of the village of Orchosani, at 725 m above sea level; the westernmost point is the Shida Kartli plain, 4 km southwest of Tsinagari village, at 728 m above sea level. The easternmost point is the Lomisa-Alevi range, an area of Kartolisi, 4 km to the east of the village of Monasteri, at 1,839 m above sea level [12,13].

III. Methods and materials

The following activities were carried out within the study area: historical data collection, generalization, and analysis. The main information of the research was analyzed in geoinformation systems, where images of different resolutions and areas were processed based on aerial imagery and satellite data of different periods.

Aerial images of different periods and Google Earth Pro software were used as the main base data, where photos of different periods were collected within the study area. The main part included information from the year 2007 and 2023. Digitization of infrastructural objects was carried out using ArcMap software. In the first stage, the photos of 2023 were converted into digital format and grouped according to municipalities. In the next stage, similar activities were conducted based on the data from 2007 [4,14]. In the final stage of the research, the analysis of existing infrastructural objects in the first and second stages in different periods and the preparation of the relevant database were carried out (see Fig. 2).

Figure 2: *Study area database*

III. Results and discussion

The results obtained based on the analysis of infrastructural objects using the mentioned methodology are presented below, according to municipalities (see Fig. 3).

2007 2023

Figure 3: *Distribution of infrastructural objects by municipalities (2007-2023)*

Tskhinvali municipality

Based on the data of 2023 within the study area, it was determined that 11,098 different types of infrastructural objects were quantitatively fixed within the municipality in the mentioned year. Particularly large number of infrastructural facilities are located in the territories of the Tskhinvali city and nearby settlements, such as villages of Tamarasheni, Kurta, Kekhvi, Kemerti, and Eredvi. Regarding the 2007 data, an analysis of aerial imagery from different areas revealed that 13,546 distinct types of infrastructural objects were recorded in the temporarily occupied territory of the municipality. From 2007 to 2023, the number of infrastructure facilities decreased by 18.0% (see Fig. 4).

The change in the spatial distribution of buildings was also analyzed for the territory of the Tskhinvali municipality. As a result, it was identified that in the period from 2007 to 2023, the areas of buildings in the occupied territory of the municipality decreased by 13.4% (see Fig. 5).

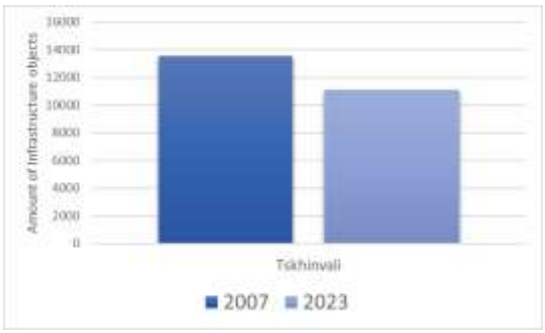


Figure 4: *Change in the quantity of infrastructural objects in the occupied territory of the Tskhinvali municipality (2007-2023)*

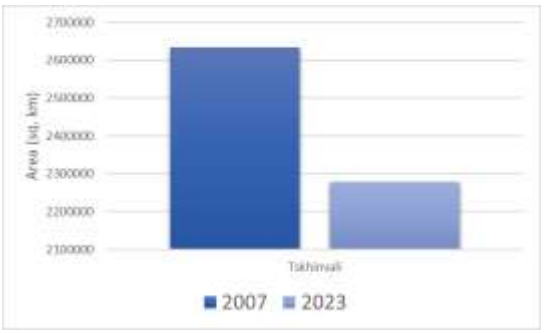


Figure 5: *Change of buildings by area in the occupied territory of the Tskhinvali municipality (2007-2023)*

Changes in the quantity and area of some settlements within the Tskhinvali municipality are demonstrated below (see Fig. 6).

Tamarasheni village (2007-2023)

Zemo Achabeti village (2007-2023)

Kekhvi village (2007-2023)

Kemerti village (2007-2023)

Figure 6. *Changes in the quantity and area of several settlements within the Tskhinvali municipality (2007-2023)*

Java municipality

Based on the data of 2023, within the study area, it was determined that 4,353 different types of infrastructural objects were quantitatively recorded within the municipality in the mentioned year. Particularly, a large number of infrastructural facilities are located in the territories of the Java township and nearby settlements - the village of Didi Gupta, Sakire, Mskhlebi, and Buzala. As for the data of 2007, based on the analysis of aerial imagery data of different areas, it was identified that according to the 2007 data, 4,991 different types of infrastructural objects were recorded in the temporarily occupied territory of the municipality. From 2007 to 2023, the number of infrastructure facilities decreased by 12.8% (see Fig. 7).

The change in the spatial distribution of buildings was also analyzed for the territory of the Java municipality. As a result, it was identified that in the period from 2007 to 2023, the areas of buildings in the occupied territory of the municipality decreased by 7.8% (see Fig. 8).

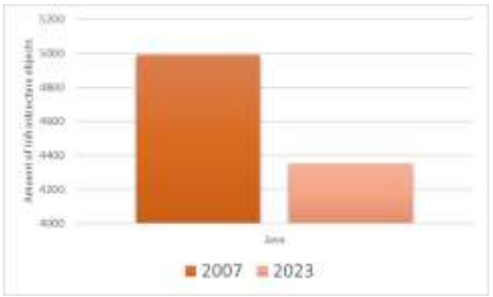


Figure 7: *Quantitative change of infrastructural objects in the occupied territory of the Java municipality (2007-2023)*

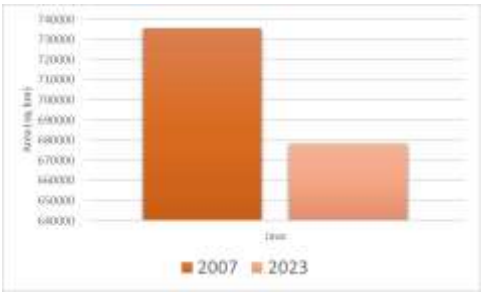


Figure 8: *Change of buildings by area in the occupied territory of the Java municipality (2007-2023)*

Changes in the quantity and area of several settlements within the Java municipality are demonstrated below (see Fig. 9).

Java township (2007-2023)

Chetari village (2007-2023)

Biteta village (2007-2023)

Tsru village (2007-2023)

Figure 9: *Changes in the quantity and area of several settlements within the Java municipality (2007-2023)*

Znauri municipality

Based on the data of 2023 within the study area, it was determined that 4,600 different types of infrastructural objects were quantitatively fixed within the municipality in that year. Particularly large number of infrastructural objects are located in the villages of Kornisi, Avnevi, Didi Tsikhiata, and Akhalsheni. As for the data of 2007, based on the analysis of aerial imagery data of different areas, it was determined that according to the 2007 data, 4,926 different types of infrastructural objects were recorded in the temporarily occupied territory of the municipality. From 2007 to 2023, the number of infrastructure facilities decreased by 6.6% (see Fig. 10).

The change in the spatial distribution of buildings was also analyzed for the territory of the Znauri municipality. As a result, it was established that in the period from 2007 to 2023, the areas of buildings in the occupied territory of the municipality decreased by 8.7% (see Fig. 11).

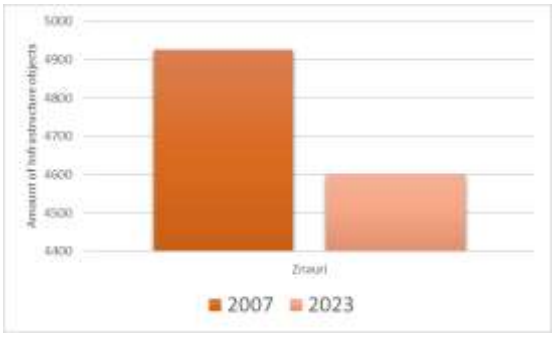


Figure 10: *Quantitative change of infrastructural objects in the occupied territory of the Znauri municipality (2007-2023)*

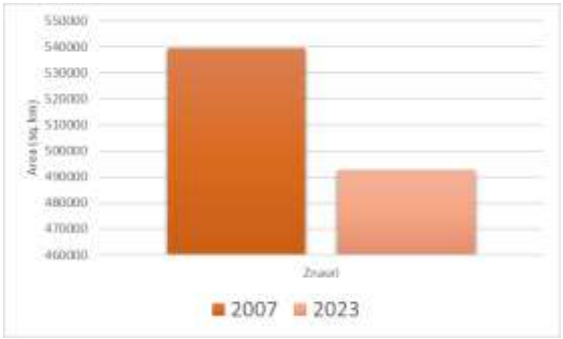
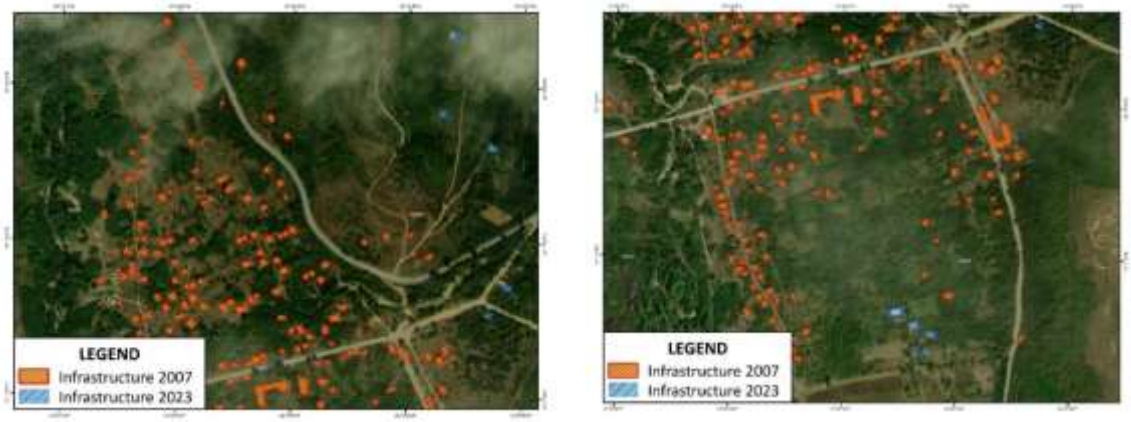


Figure 11: *Change of buildings by area in the occupied territory of the Znauri municipality (2007-2023)*

Changes in the quantity and area of several settlements within the Znauri municipality are demonstrated below (see Fig. 12).



Avnevi village (2007-2023) Avnevi village (2007-2023)

Figure 12: *Changes in the quantity and area of several settlements within the Znauri municipality (2007-2023)*

Akhalgori municipality

Based on the data of 2023 within the study area, it was determined that 5,508 different types of infrastructural objects were quantitatively recorded within the municipality in the mentioned year. A particularly large number of infrastructural facilities are located in the territory of the Akhalgori city. Regarding the 2007 data, an analysis of aerial imagery from different areas revealed that 5,575 distinct types of infrastructural objects were recorded in the temporarily

occupied territory of the municipality. From 2007 to 2023, the number of infrastructure facilities decreased by 1.2% (see Fig. 13).

The change in the spatial distribution of buildings was also analyzed for the territory of the Akhalgori municipality. As a result, it was determined that the areas of buildings in the occupied territory of the municipality decreased by 1.3% in the period from 2007 to 2023 (see Fig. 14).

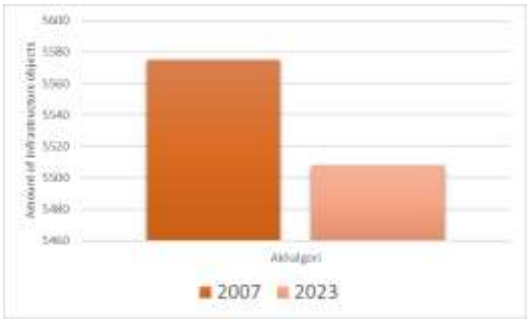


Figure 13: *Quantitative change of infrastructural objects in the occupied territory of the Akhalgori municipality (2007-2023)*

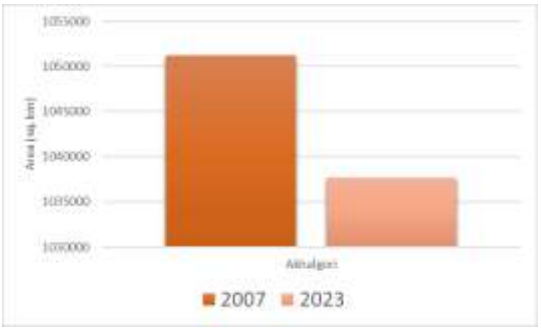
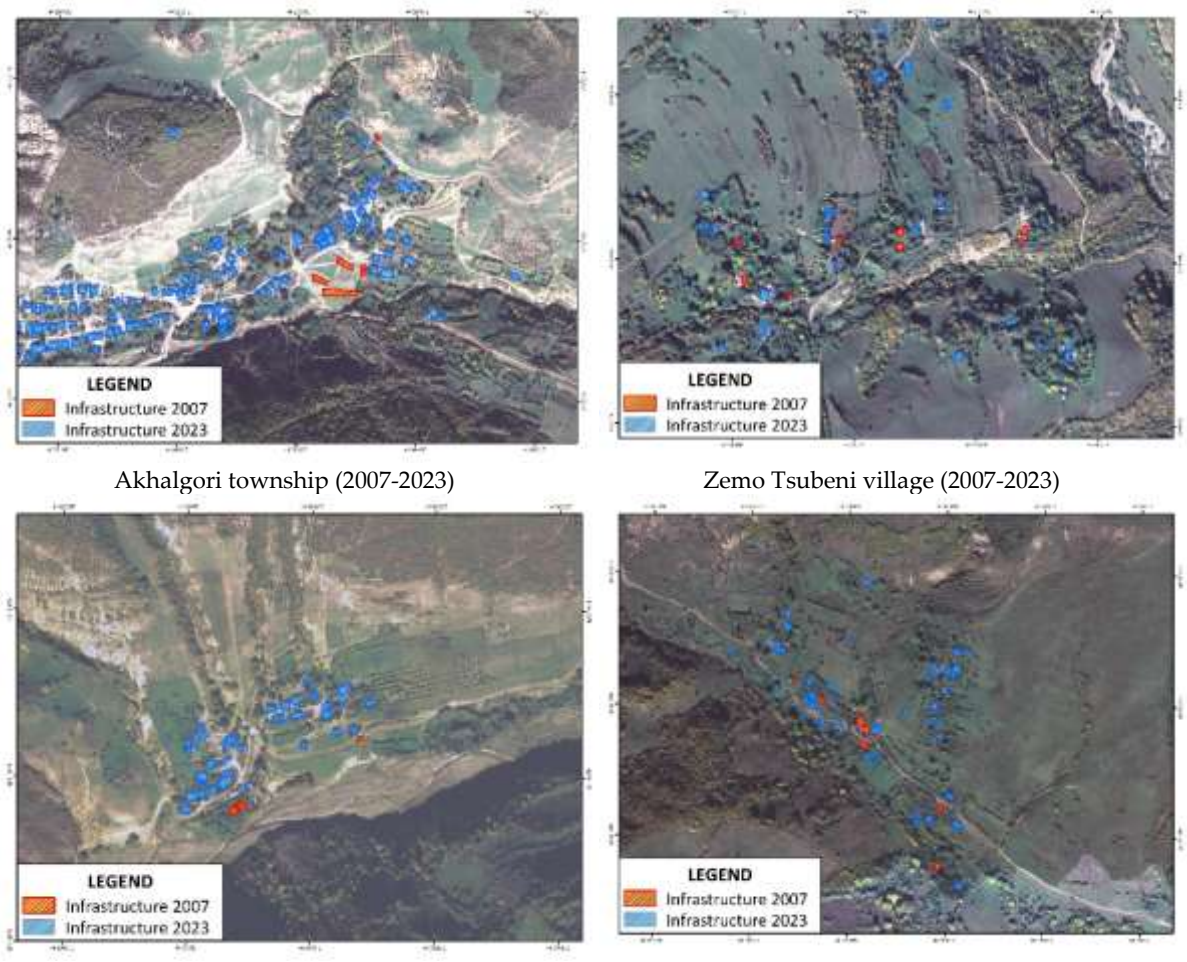


Figure 14: *Change of buildings by area in the occupied territory of the Akhalgori municipality (2007-2023)*

Changes in the quantity and area of several settlements within the Akhalgori municipality are demonstrated below (see Fig. 15).



Akhalgori township (2007-2023)

Zemo Tsubeni village (2007-2023)

Kvemo Alevi village (2007-2023)

Tsoldi village (2007-2023)

Figure 15: *Changes in the quantity and area of several settlements within the Akhalgori municipality (2007-2023)*

IV. Conclusion

This study provides a detailed geospatial analysis of the infrastructural and settlement changes in the Tskhinvali region of Georgia between 2007 and 2023. Aerial imagery, satellite data, and geographic information system (GIS) tools were utilized to digitize and measure changes in the number and spatial extent of infrastructural facilities across the territories of the four municipalities of Tskhinvali Region: Tskhinvali, Java, Znauri, and Akhalgori.

The findings indicate a significant decline in infrastructural assets and settlement areas, with the largest reductions marked in Tskhinvali municipality (18% decrease in infrastructure objects and 13.4% reduction in building areas) and smaller but measurable losses in other municipalities: Java – 12.8%, Znauri – 6.6%, Akhalgori – 1.2%. The spatial analysis also identified certain villages where infrastructural destruction or degradation was noticeable.

The conclusions reveal the enduring effects of hostilities and occupation on the infrastructure objects and settlements of the area. By creating this geodatabase, they provide a useful basis for planning reconstruction projects, territorial reintegration efforts, and settling disputes. In addition, the method used to incorporate multi-temporal imagery in GIS digitization can serve as a model for similar investigations conducted on other areas affected by conflict.

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CONFLICT OF INTEREST.
Authors declare that they do not have any conflict of interest.

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