

Spatiotemporal Assessment of Infrastructure Destruction in the Gaza Strip from 2023 to 2026 Using Satellite Imagery and GIS

Osama R. Shaltami^{1,*}  , Mustafa A. Ben Hkoma²  , Kamal A. Almahdi³  , Firas K. Mohammed³  ,
Mansour A. Salem⁴  , Hala J. El-Khozondar^{5,6}  , Yasser F. Nassar⁷  

¹ Department of Earth Sciences, Faculty of Science, Benghazi University, Libya

² Sustainable Development Research Center, Ubari, Libya

³ Department of Earth Sciences, Faculty of Science, Omar Al-Mukhtar University, Libya

⁴ Department of Environmental Sciences, faculty of Environment and Natural Resources, Wadi Alshatti University, Brack, Libya

⁵ Department of Materials and London Centre for Nanotechnology, Imperial College London, UK

⁶ Electrical Engineering and Smart Systems Department, Islamic University of Gaza, P.O. Box 108, Gaza, Palestine

⁷ Department of Mechanical and Renewable Energy Engineering, Wadi Alshatti University, Brack, Libya

ARTICLE HISTORY

Received 12 August 2026

Revised 15 September 2026

Accepted 30 September 2026

Online 07 October 2026

KEYWORDS

Conflict;
Infrastructure;
Destruction;
Urban Change;
Remote Sensing;
GIS;
Gaza Strip;
Palestine.

ABSTRACT

The Gaza Strip has suffered significant damage to buildings, infrastructure, agriculture, and urban land since October 2023. This study evaluates the spatial and temporal pattern of infrastructure destruction in the Gaza Strip since October 2023 until 2026 using satellite imagery and geographic information system (GIS) techniques. The changes in the urban land cover and agricultural areas were evaluated utilizing the Landsat and Sentinel-2 satellite imagery. In turn, the changes in surface and infrastructure were assessed using the pre- and post-conflict Sentinel-1 synthetic aperture radar (SAR) imagery. The published UNOSAT damage assessments were integrated with GIS infrastructure data to ascertain the damage to buildings, roads, health facilities, educational institutions, water facilities, energy infrastructure, and transportation. The normalized difference vegetation index (NDVI) was employed to assess changes in the vegetation and agricultural lands. The study combined the various damage indicators to monitor the infrastructure destruction using the infrastructure damage index (IDI). The findings revealed a significant increase in damage to buildings as of the study period with damage concentration in the heavily urbanized areas. The study also revealed that the war resulted in extensive damage to road networks and infrastructures which affected services and accessibility of the region. The changes in the urban land cover and vegetation indicate additional environmental and agricultural disturbance. The study concludes that the combination of the temporal satellite imagery and GIS techniques offer a viable approach for assessing the destruction of infrastructure in large and inaccessible geographical areas and offers valuable insights for humanitarian assessments, emergency response, and reconstruction planning.

التقييم المكاني والزمني لدمار البنية التحتية في قطاع غزة خلال الفترة 2023-2026 باستخدام صور الأقمار الصناعية ونظم المعلومات الجغرافية

أسامة رحيل الشلطامي^{1,*}، مصطفى بن حكومة²، كمال أبراهيم المهدي³، فراس خميس محمد³، منصور اعويذات سالم⁴، هالة جارا الله الخزندار^{5,6}، ياسر فتحي نصار⁶

المخلص	الكلمات المفتاحية
تعرض قطاع غزة لأضرار جسيمة لحقت بالمباني والبنية التحتية والقطاع الزراعي والأراضي الحضرية منذ أكتوبر 2023. وتقيم هذه الدراسة الأنماط المكانية والزمانية لتدمير البنية التحتية في قطاع غزة خلال الفترة الممتدة من أكتوبر 2023 وحتى عام 2026 وذلك بالاعتماد على صور الأقمار الصناعية وتقنيات نظم المعلومات الجغرافية. وقد جرى تقييم التغيرات في الغطاء الأرضي الحضري والمساحات الزراعية باستخدام صور الأقمار الصناعية من نوعي لاندسات وسنتينل-2، كما تم تقييم التغيرات في سطح الأرض والبنية التحتية باستخدام صور الرادار ذي الفتحة الاصطناعية من القمر الصناعي سنتينل-1 التي تغطي فترتي ما قبل الصراع وما بعده. وعلاوة على ذلك، دمجت تقييمات الأضرار الصادرة عن برنامج الأمم المتحدة للأقمار الصناعية التشغيلية مع بيانات البنية التحتية في نظم المعلومات الجغرافية لتحديد حجم الأضرار التي لحقت بالمباني والطرق والمرافق الصحية والمؤسسات التعليمية ومرافق المياه وشبكات الطاقة وقطاع النقل. واستخدم مؤشر الفرق المعياري للغطاء النباتي لتقييم التغيرات في الغطاء النباتي والأراضي الزراعية. وقد جمعت الدراسة بين مؤشرات الأضرار المختلفة لرصد عمليات تدمير البنية التحتية باستخدام مؤشر أضرار	النزاع تدمير البنية التحتية التغير الحضري الاستشعار عن بعد نظم المعلومات الجغرافية قطاع غزة فلسطين

*Corresponding author

https://doi.org/10.63318/waujpasv4i2_58

This work is licensed under a [Creative Commons Attribution-NonCommercial 4.0 International License](https://creativecommons.org/licenses/by-nc/4.0/) (CC BY-NC 4.0).



البنية التحتية. وأظهرت النتائج زيادة كبيرة في الأضرار التي لحقت بالمباني خلال فترة الدراسة، مع تركيز هذه الأضرار في المناطق ذات الكثافة العمرانية العالية. كما كشفت الدراسة أن الحرب أدت إلى أضرار واسعة النطاق في شبكات الطرق والبنية التحتية، مما أثر سلباً على الخدمات وإمكانية الوصول داخل المنطقة. وتشير التغيرات في الغطاء الأرضي الحضري والغطاء النباتي إلى حدوث اضطرابات بيئية وزراعية إضافية. وتخلص الدراسة إلى أن الجمع بين الصور الفضائية المتتابعة زمنياً وتقنيات نظم المعلومات الجغرافية يوفر منهجية فعالة لتقييم تدمير البنية التحتية في المناطق الجغرافية الواسعة التي يصعب الوصول إليها، كما يقدم رؤى قيمة تدعم عمليات التقييم الإنساني، والاستجابة للطوارئ، وتخطيط جهود إعادة الإعمار.

Introduction

War has adverse effects on the environment, including the destruction of natural habitats and the creation of obstacles to infrastructure reconstruction. Such man-made disasters as war and conflicts lead to the deterioration of the built environment and the disruption of essential services such as water supply, sewage system, healthcare, and electricity. Besides, war emissions, the destruction of urban infrastructure, and spillage of fuel and waste contribute to air, water, and soil pollution. Moreover, war impacts vegetation, water resources, and the amount of waste, which results in barriers to infrastructure reconstruction and threats to human health and the environment. In addition, war causes the damage to agricultural production, its natural environment, and waste management resulting in the deterioration of the ecosystem and significant challenges in infrastructure reconstruction [1-8].

Since 7 October 2023, the Gaza Strip has been subjected to extensive physical destruction. Satellite imagery can help document such changes because the area may not be accessible or the conditions of travel may be variable and potentially dangerous. Multi-temporal satellite observations allow the pre-conflict status to be compared with consecutive post-conflict observations and thus provide an objective spatial framework to measure physical change. Satellite-based assessments have already demonstrated the scale of structural destruction. UNOSAT's initial October 2023 assessment identified 10,584 affected structures, including 2,017 destroyed, 2,282 severely damaged, and 6,285 moderately damaged structures [9]. By early January 2024, the number had increased to 69,146 affected structures, representing approximately 30% of structures in Gaza [10]. The destruction continued to expand geographically. A UNOSAT assessment based on imagery acquired on 6 July 2024 identified 156,409 affected structures, equivalent to approximately 63% of the structures in the Gaza Strip. On October 11, 2025, UNOSAT reported 198,273 affected buildings, of which 123,464 were destroyed, 17,116 were severely damaged, 33,857 were moderately damaged, and 23,836 were potentially damaged. Approximately 81% of all structures were classified as damaged [11].

Asi [12] investigated damage to critical civilian infrastructure during the first phase of the conflict, from 7 October to 22 November 2023. The researchers used Copernicus Sentinel-1 SAR imagery and multi-temporal coherent change detection to identify likely damage to the built environment. Health, education, and water facilities were then mapped using datasets from OCHA, OpenStreetMap, and Humanitarian OpenStreetMap Team. The study demonstrated how to utilize radar-based satellite imaging and GIS infrastructure databases to identify the distribution of the damage to essential civilian infrastructure. UNOSAT [13] estimated approximately 1,511 km of destroyed roads, 484 km of severely affected roads, and 1,484 km of moderately affected main roads, corresponding to approximately 77% of the road

network when destroyed, affected, and obstacle-restricted roads were considered. Racek [14] developed an unsupervised method for detecting building destruction from publicly available Sentinel-1 radar imagery. The method statistically assesses changes in interferometric coherence and provides the likelihood of a probable destruction at both the pixel and the building level. The approach was tested using Gaza together with other conflict-affected cities and demonstrated the potential of freely available SAR data for repeated monitoring of building destruction when conventional field surveys are difficult. Yin [15] examined war-induced agricultural damage using PlanetScope and SkySat imagery. The researchers applied Random Forest classification in combination with the Segment Anything Model and harmonic time-series analysis to map tree crops and greenhouses and assess their damage after October 2023. Their analysis estimated that by September 2024, 64–70% of tree-crop fields and 58% of greenhouses had been damaged. The study illustrates the value of high resolution optical imagery in detecting agricultural changes at a finer spatial resolution than that of medium resolution satellite imagery. Dader [16] studied how the destruction and collapse of essential infrastructure in Gaza had disrupted everyday life and forced people to develop temporary ways to survive. The authors used the concept of “fitful infrastructure” to describe fragile and improvised solutions that people had developed under extreme conditions, including makeshift toilets, alternative methods of collecting and managing water, and improvised sources of electricity using bicycles, wind, and solar panels. The article argued that these practices should not simply have been described as resilience or innovation because they had resulted from severe deprivation and the destruction of normal living conditions. Instead, they had demonstrated how people had continued to maintain basic life and everyday activities despite the loss of essential infrastructure. Abdelnour [17] examined the enormous amount of debris produced by the destruction of buildings and infrastructure in Gaza and assessed the carbon emissions, time, and equipment required to remove and process it for future reconstruction. Using open-source spatial data, the authors estimated that more than 36.8 million tons of debris had been generated between October 2023 and December 2024. They estimated that transporting this material to disposal and processing sites would have required more than 2.1 million truckloads and produced about 65,642 tons of CO₂-equivalent emissions. The study also found that recycling the concrete could have supported reconstruction, road repair, and shoreline protection, but the time required would have depended greatly on the available crushing equipment. The authors concluded that debris removal would have represented a major logistical, environmental, and climate challenge and would have required substantial machinery, labour, time, and resources before large-scale rebuilding could have proceeded. Benguita [18] investigated the destruction of Gaza's urban environment during the

2023–2025 war and interpreted it through the concept of urbicide, meaning the systematic destruction of cities and the conditions that support urban life. The study used satellite images, an assessment of the damages, and the data from different organizations like UNOSAT, UNDP, OCHA, World Bank, FAO, and the Palestinian Central Bureau of Statistics to evaluate the damage to housing, infrastructure, healthcare, education, transport, water, and other essential services. It reported that more than 70% of Gaza's built environment had been destroyed or rendered non-functional, leaving large areas uninhabitable. In addition to buildings, social life, cultural memory, displacement, and the potential for future rebuilding and urban recovery were all impacted, according to the essay. It also showed how, despite the devastation, communities had been able to retain their social and political relevance. European Union [19] assessed the broader physical and socioeconomic consequences. The April 2026 final Rapid Damage and Needs Assessment estimated \$35.2 billion in physical infrastructure damage and \$71.4 billion in recovery and reconstruction needs over the following decade. Rinaldo [20] used Sentinel-1 imagery acquired on 62 dates between October 2023 and October 2024 and applied coherent change detection to map likely damage to urban and built-up areas. The researchers aggregated the results into 1-km² grid cells and reported that, by October 2024, 82% of the grid cells had experienced damage at least once, while approximately 67.9% of the pre-conflict built-up area had been affected. By collecting particular damage data using satellite imagery and nighttime light measurements, the relationship between physical devastation and economic growth was also investigated. Abuzerr [21] investigated how the war had disrupted solid waste collection, disposal, and management across the Gaza Strip. The authors used GIS-based spatial analysis, field observations, municipal records, humanitarian databases, and publicly available geospatial data to identify potential locations of waste accumulation and open-burning hotspots. The researchers identified 54 temporary dumpsites with an estimated volume of 4.11 million m³ of waste. They found that Gaza City, Khan Younis, and Rafah generated the most hotspots of waste accumulation and open burning, typically in highly populated places and centers of displaced persons. Accumulation of rubbish and its open burning could sometimes overlap resulting in additional environmental hazards and potential public health problems. The study concluded that GIS-based hotspot mapping could help identify priority areas for emergency waste collection, disposal, and environmental interventions during and after the conflict. Abulehia [22] examined how twelve mathematics students at Al-Aqsa University had continued their education through digital learning during the war. The study found that students had faced severe problems, including displacement, electricity shortages, unreliable internet, psychological stress, and limited interaction with teachers, which had made learning mathematics particularly difficult because the subject required continuous explanation, discussion, and immediate feedback. Although these obstacles were present, students have found collective learning methods such as peer-support networks, the use of various digital platforms and artificial intelligence tools to mitigate their limitations in accessing instructors. The study concluded that academic persistence had depended not only on individual resilience but also on collective cooperation, creativity, and cultural commitment, while emphasizing the need for education systems and

digital-learning policies that were better adapted to conditions of war and infrastructure collapse. Zawawi [23] investigated how repeated conflicts, particularly the 2023–2024 war, had changed land use and land cover (LULC) and land surface temperature (LST) in the Gaza Strip. The researchers used Landsat satellite imagery from 2005–2024 and GIS techniques to map changes in urban, agricultural, bare, and other land-cover types and to evaluate their relationship with surface temperature. The results showed widespread destruction of urban and agricultural areas, with substantial increases in LST. While temperature increases during earlier periods were typically about 5–10 °C, the increase following the 2023 war reached close to 5–18 °C in some parts. The study concluded that the destruction and loss of agricultural land had not only reduced food-production capacity but had also contributed to higher surface temperatures and greater environmental stress, demonstrating the usefulness of remote sensing for monitoring the long-term environmental effects of war in Gaza. Ziadah [24] explored how infrastructure had played a central role in the war on Gaza, arguing that the destruction of homes, hospitals, schools, roads, water, electricity, and communication systems had affected not only physical structures but also the basic conditions necessary for Palestinian life. The authors related this destruction to broader regional and global connections of military supply chains, finance, energy, logistics, and political support, illustrating the role of infrastructure as a mechanism of domination as well as a means of displacement and reliance. The article also drew attention to Palestinian infrastructures of resistance, such as survival networks, underground spaces, worker actions, and other forms of resistance. It concluded that infrastructure had been both a tool of domination and a potential site of resistance, and that international solidarity could challenge the global systems that had enabled and sustained the destruction.

Fig. 1 shows the geographical location of the Gaza Strip and its five main governorates: North Gaza, Gaza, Deir al-Balah, Khan Yunis, and Rafah. The spatial framework for the study and the distribution of major urban centers are presented in the map. The Gaza Strip is a relatively narrow and densely populated coastal area, with urban settlements distributed along much of its length. The administrative division shown in the figure provides a useful basis for comparing infrastructure damage and environmental changes between different parts of the study area.

Objective

The main objective of the study is to analyze the spatiotemporal pattern of destroyed infrastructure in the Gaza Strip between 2023 and 2026 using multi-temporal remote sensing data, including GIS analysis procedures. The objectives are to:

- (1) Create baseline satellite images of infrastructure using the 2023 data.
- (2) Estimate changes in the distribution of infrastructure since October 2023.
- (3) Quantify the number and percentage of damaged or destroyed buildings.
- (4) Map destruction of major and secondary road networks.
- (5) Assess changes in urban land cover.
- (6) Identify spatial concentrations of infrastructure destruction.
- (7) Evaluate changes in damage between different governorates.

- (8) Examine the temporal progression of destruction.
- (9) Evaluate changes in agricultural and open space polygons related to various conflict-specific effects.
- (10) Assess the impact on different categories of infrastructure.
- (11) Develop a GIS-based infrastructure damage index (IDI).
- (12) Produce maps suitable for humanitarian and reconstruction planning.

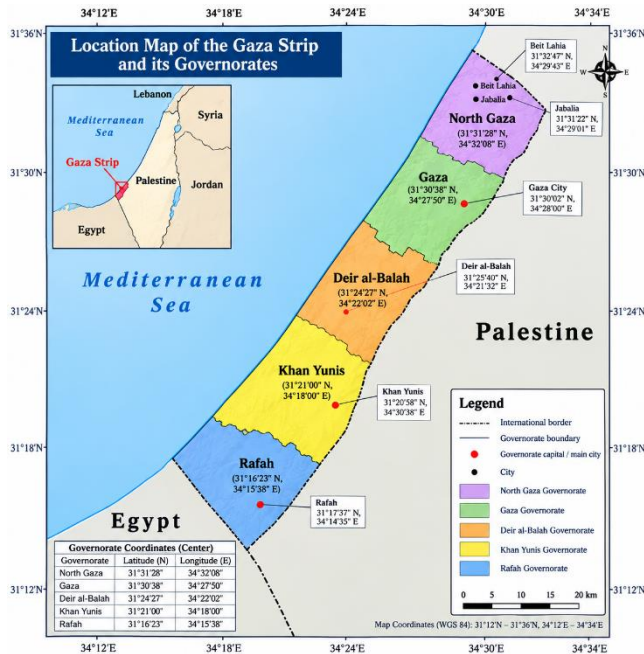


Figure 1: Location map of the Gaza Strip and its governorates.

The previous studies have provided valuable information on building destruction, critical infrastructure, roads and urban areas, agricultural land, debris, and economic impacts, they generally examine individual components or limited periods. In addition, many existing assessments end during 2024 or 2025, rather than providing an integrated framework extending to 2026. Therefore, the proposed study, “Destruction of Infrastructure in the Gaza Strip from October 2023 to 2026 Using Satellite Imagery and GIS,” can build on these previous investigations by integrating building damage, road damage, critical infrastructure, urban land-cover change, agricultural disturbance using NDVI, Sentinel-1 SAR change detection, and a GIS-based Infrastructure Damage Index within a common spatial and temporal framework. This method would enable the study to look at the extent of infrastructure destruction as well as its chronological evolution and spatial distribution throughout the Gaza Strip.

Methodology

In order to evaluate infrastructure and environmental changes in the Gaza Strip between 2023 and 2026, the technique used an integrated remote sensing and GIS technique. First, the geographic boundaries, governorates, cities, roads, and major infrastructure were compiled in a GIS environment and projected to WGS 84 (EPSG:4326). Pre-conflict infrastructure was mapped as a baseline using available geographic and OpenStreetMap-type datasets. Building damage was assessed using published UNOSAT satellite-based damage assessments, and the reported damage categories were used to visualize temporal changes and

spatial damage density. Road and critical-infrastructure impacts were mapped by integrating available satellite-derived damage information with GIS infrastructure layers. Landsat and Sentinel-2 imagery were used for multi-temporal land-cover and agricultural analysis, including normalized difference vegetation index (NDVI) to evaluate vegetation and agricultural disturbance. Sentinel-1 SAR imagery was used for radar-based change detection by comparing pre- and post-conflict observations to identify areas of significant surface and infrastructure change. Finally, the different infrastructure-damage indicators were integrated in GIS to develop an infrastructure damage index (IDI) and classify areas according to relative damage intensity. Generally, the methodology combines satellite imagery, published damage assessments, GIS spatial analysis, change detection, vegetation indices, and multi-source geospatial data to characterize the spatial and temporal impacts on Gaza's infrastructure and environment.

Results and Discussion

Fig. 2 represents the infrastructure situation before the conflict and provides a baseline for subsequent damage assessment. The map shows the placement of significant roads, various buildings, medical facilities, educational institutions such as schools and universities, water-related establishments, and other infrastructures. It can be seen that most of these objects are located in large conurbations or separate cities like Gaza City, Khan Yunis, and Rafah. Establishing this pre-conflict baseline is important because it allows subsequent satellite observations to be interpreted in terms of changes to the original infrastructure distribution.

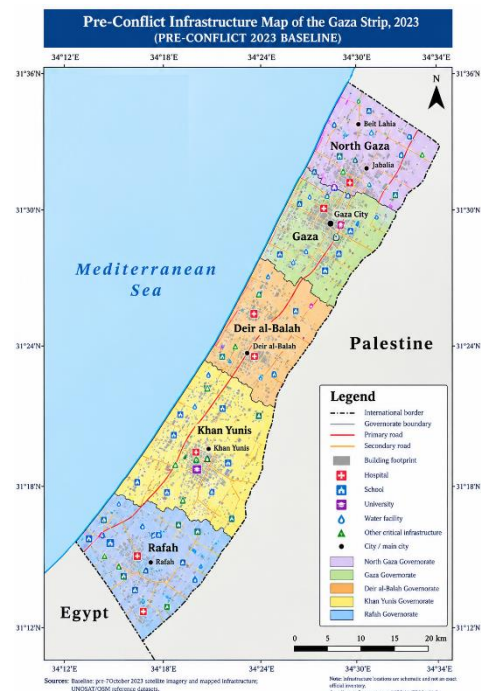


Figure 2: Pre-conflict infrastructure map of the Gaza Strip, 2023.

Fig. 3 illustrates the progressive improvement in building damage during the study period using multiple satellite-based assessment dates. There was a significant increase in the number of damaged buildings during the studied period – from October 2023 to October 2025. The first assessment shows a relatively low number of affected buildings,

compared to the next ones. Thus, the number of partially destroyed, severely damaged, moderately damaged, and possibly damaged buildings grew substantially during these two years.

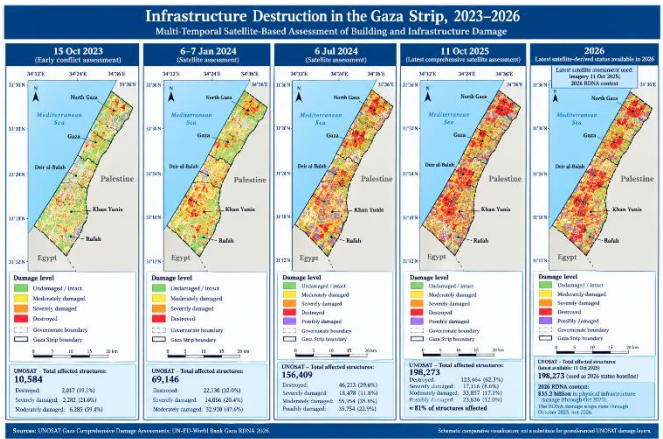


Figure 3: Infrastructure destruction in the Gaza Strip, 2023–2026.

The spatial distribution of building-damage density across the Gaza Strip is shown in Fig. 4. Higher damage-density zones are concentrated around heavily urbanized areas, where large numbers of buildings occur within relatively small areas. Lower-density areas generally correspond to less densely developed locations. The map demonstrates that damage is not spatially uniform and that GIS-based density analysis can help identify areas where the concentration of affected buildings is particularly high. For quantitative research, the density surface should be calculated from actual georeferenced building-damage data.

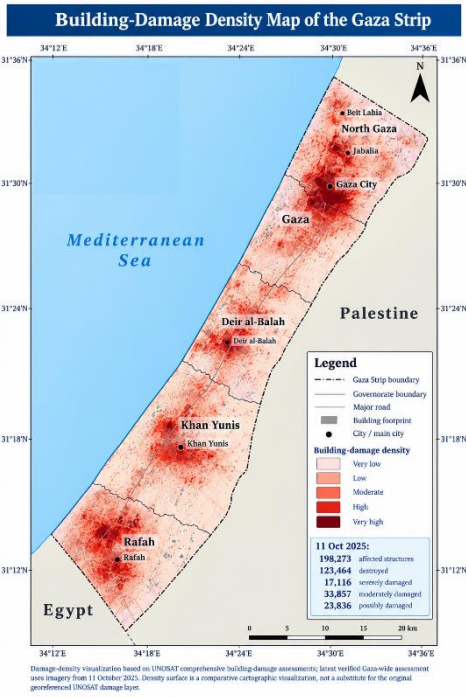


Figure 4: Building-damage density map of the Gaza Strip.

The distribution of the damaged and obstructed roads in the Gaza Strip is displayed in Fig. 5. The figure demonstrates the classification of roads with various degrees of damage, from minimally disturbed to completely destroyed or blocked. The

most significant impact of the damaged roads is a disruption of the connection between separate cities and the provision of services. Consequently, the damage to the roads may lead to limitations in the delivery of goods and emergency services and disrupt the transportation system. The application of changes in satellite imagery and GIS can provide an opportunity to detect variations in transport infrastructure development.

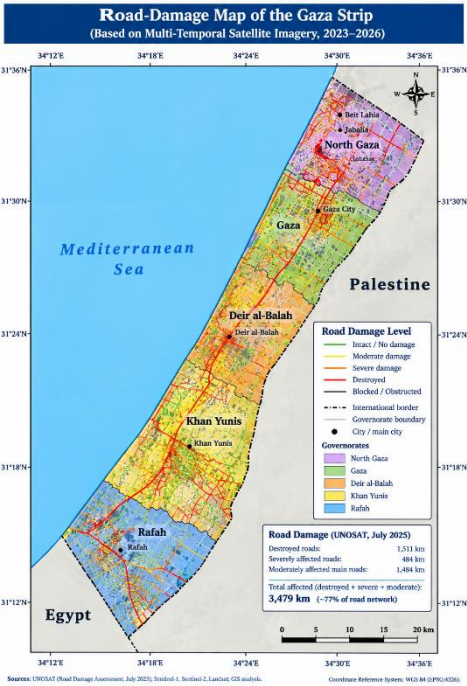


Figure 5: Road damage map of the Gaza Strip.

Fig. 6 presents the spatial distribution of damage to critical infrastructures, including the health facilities, educational institutions, water facilities, energy, transport, and other essential assets. It can be seen that apart from impacts on housing, critical infrastructures were also affected by fighting. The display of this information enables the identification of those regions with multiple damaged infrastructure facilities, which can then be prioritized for detailed assessment to support the post-conflict rebuilding of infrastructure and services.

Fig. 7 illustrates the change of the areal extent and distribution of urban land cover as assessed by multi-temporal satellite-image analysis. The comparison of different years shows the development of built-up areas. The changes seen after 2023 can be the result of destruction, rebuilding, disturbances, and shifts in the surface of the land. Satellite-based land-cover classification is particularly useful for examining large areas where field-based surveys may be difficult or impossible.

Fig. 8 uses the NDVI to assess changes in vegetation and agricultural areas. Higher values of this index usually indicate a more significant amount of vegetation, while lower values indicate a lack of it or its absence. By comparing the index values for the areas before and after conflict, it is possible to identify vegetative areas with a high degree of accuracy. The reason for the decline in vegetation can be both human and non-human. It can be either anthropogenic: farming, cutting down trees, or removing vegetation to use the land for a specific purpose or natural: seasonal fluctuations in

vegetation levels due to climate change during the year. Therefore, NDVI values should not be considered independently but be compared with other spatial data on the territory to draw a conclusion about the cause of the decrease and not confuse the causes.

suggest that their surface characteristics have changed considerably in these regions relative to the SAR's reference image. On the other hand, regions with relatively little change appeared to have similar radar response characteristics. As a consequence, the change detection analysis should take into account all the factors that could influence the measurement of the SAR, such as surface vegetation, surface wetness, and others.



Figure 6: Critical infrastructure damage in the Gaza Strip.

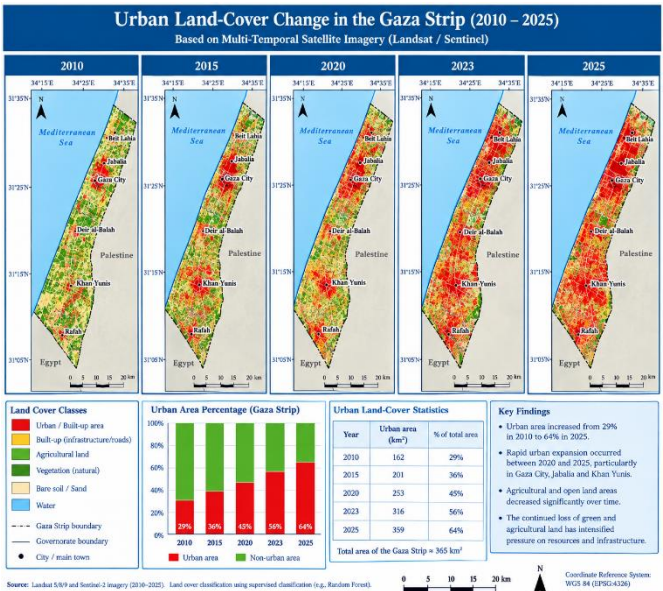


Figure 7: Urban land-cover change in the Gaza Strip.

Fig. 9 shows a radar-based change detection analysis using Sentinel-1 SAR imagery. SAR is a valuable tool, as it can capture images regardless of the time of the day and is less dependent on weather conditions such as clouds compared to optical forms of light. The difference between the pre- and post-conflict SAR can be used to highlight significant changes to buildings, roads, and other objects on the Earth's surface. The areas of intense change in the SAR imagery

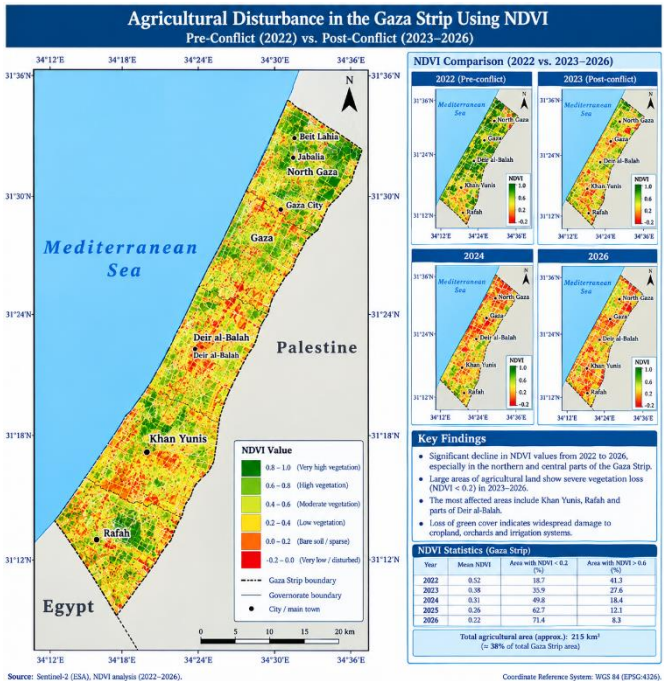


Figure 8: Agricultural disturbance in the Gaza Strip using NDVI.

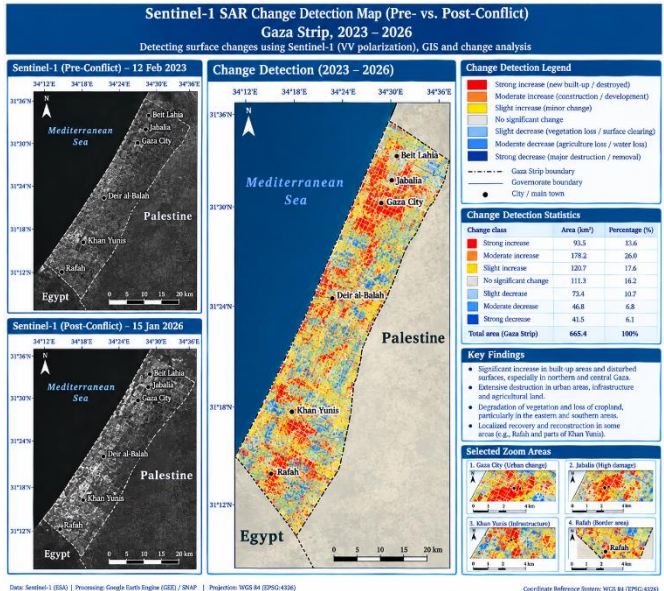


Figure 9: Sentinel-1 SAR change-detection map of the Gaza Strip.

Fig. 10 integrates several infrastructure-related measurements into an infrastructure damage index (IDI) that represents the relative intensity of infrastructure disturbance spatially. Values in the index are higher in places where there are more signs of damage and lower in places where there were few signs of damage. However, the numerical values of the index should only be reported as actual results after determining its

values for a documented geospatial data set using a specific weighting scheme and normalization procedure.

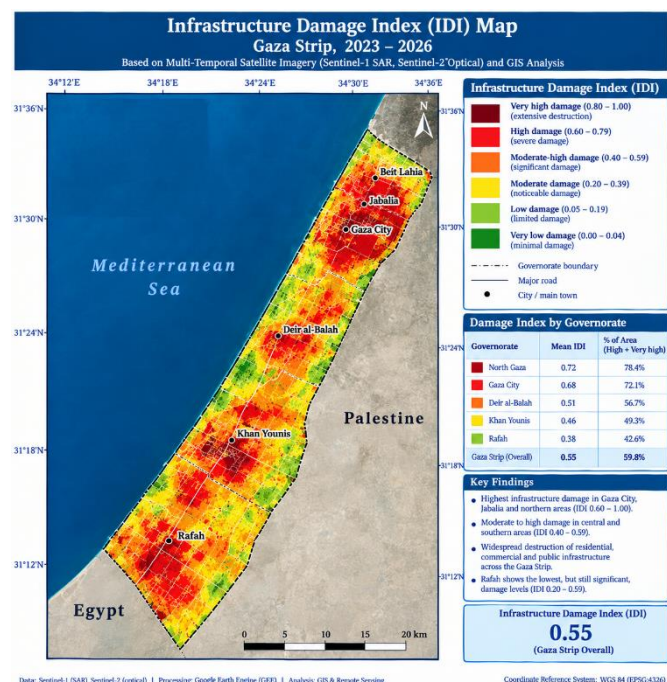


Figure 10: Infrastructure damage index (IDI) map of the Gaza Strip.

Conclusions and Recommendation

This study demonstrates that multi-temporal satellite imagery and GIS are effective tools for assessing the destruction of infrastructure in the Gaza Strip from October 2023 to 2026. The analysis shows a major increase in building damage during the conflict, with the highest concentrations of destruction occurring in densely populated urban areas. Roads and other key infrastructure, such as health, education, water, energy, and transport facilities were also significantly impacted causing major disruptions to movement and vital services. The satellite land cover analysis indicates that there are significant changes in built-up areas, while the NDVI analysis shows that vegetation and farmlands have been disturbed. Additional information on ground and infrastructure surface changes was obtained using Sentinel-1 SAR change detection capabilities, especially where there is a limitation of using optical imagery. The integration of these different indicators through GIS and the Infrastructure Damage Index provides a useful spatial framework for identifying areas of high, moderate, and low infrastructure disturbance. Generally, the study confirms the value of remote sensing and GIS for documenting the progression and spatial distribution of infrastructure destruction and for supporting humanitarian assessment and future reconstruction.

It is recommended that multi-temporal satellite imagery and GIS continue to be used to monitor infrastructure damage and recovery throughout the Gaza Strip. Regular updates using Sentinel-1, Sentinel-2, Landsat, and other high-resolution satellite data can help identify newly damaged areas and areas where reconstruction has started. The Infrastructure Damage Index should be further developed using clearly documented datasets, normalization procedures, and weighting schemes so that damage levels can be quantitatively compared between locations and through time.

Damage maps should be combined with information on the distribution of the population and essential services to prioritize areas requiring humanitarian assistance and reconstruction. Particular attention should be given to roads, hospitals, schools, water facilities, energy systems, and other critical infrastructure because their damage directly affects access to essential services. Agricultural and environmental monitoring should also continue using NDVI and other satellite-based indicators to evaluate the recovery of vegetation and agricultural land. Finally, the resulting GIS databases and satellite-derived maps should be regularly updated and used by humanitarian organizations, local authorities, and reconstruction planners to support damage assessment, prioritize resources, and guide long-term recovery of the Gaza Strip.

Author Contributions: Shaltami, El-Khozondar and Nassar: Conceptualization, methodology. Shaltami, Ben Hkoma, Almahdi, Mohammed and Salm: writing of the original draft, software, and analysis. El-Khozondar and Nassar: Data collection, and Review and editing. All authors read and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

Funding: This research received no external funding.

Data Availability Statement: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

References

- [1] A. Durakovic, L. Dietz, and I. Zimmerman, "1048 Estimate of the pulmonary neoplastic hazard of inhaled depleted uranium in Gulf War veterans," *European Journal of Cancer Supplements*, vol. 1, no. 5, p. S312, 2003.
- [2] I. W. Oliver, A. B. Mackenzie, R. M. Ellam, M. C. Graham, and J. G. Farmer, "Determining the extent of depleted uranium contamination in soils at a weapons test site: An isotopic investigation," *Geochimica et Cosmochimica Acta*, vol. 70, no. 18, p. A457, 2006.
- [3] F. P. Carvalho and J. M. Oliveira, "Uranium isotopes in the Balkan's environment and foods following the use of depleted uranium in the war," *Environment International*, vol. 36, no. 4, pp. 352–360, 2010.
- [4] M. V. Bakhmutsky, K. Squibb, M. McDiarmid, M. Oliver, and J. D. Tucker, "Long-term exposure to depleted uranium in Gulf-War veterans does not induce chromosome aberrations in peripheral blood lymphocytes," *Mutation Research/Genetic Toxicology and Environmental Mutagenesis*, vol. 757, no. 2, pp. 132–139, 2013.
- [5] F. Albarède, J. Blichert-Toft, M. Rivoal, and P. Telouk, "A glimpse into the Roman finances of the Second Punic War through silver isotopes," *Geochemical Perspectives Letters*, vol. 2, pp. 127–137, 2016.
- [6] E. Salama, S. U. El-Kameesy, and R. Elrawi, "Depleted uranium assessment and natural radioactivity monitoring in North West of Iraq over a decade since the last Gulf War," *Journal of Environmental Radioactivity*, vol. 201, pp. 25–31, 2019.
- [7] C. Ji, Y. Zhu, S. Zhao, H. Zhang, S. Wang, J. Zhou, X. Liu, Y. Zhang, and X. Liu, "Arsenic and heavy metals at Japanese abandoned chemical weapons site in China: Distribution characterization, source identification and

- contamination risk assessment,” *Environmental Geochemistry and Health*, vol. 45, pp. 3069–3087, 2023.
- [8] O. R. Shaltami, M. Ben Hkoma, A. E. Algomati, K. A. Almahdi, and F. K. Muhammed, “War and weapon geochemistry: Key areas, applications and impact on the sustainable development goals,” *Al-Farooq Journal of Sciences*, vol. 2, no. 2, pp. 168–181, 2026.
- [9] UNOSAT (United Nations Satellite Centre), “UNOSAT Gaza Strip comprehensive damage assessment,” 2023. [Online]. Available: UNOSAT Gaza Strip comprehensive damage assessment (2023)
- [10] UNOSAT (United Nations Satellite Centre), “UNOSAT Gaza Strip comprehensive damage assessment,” 2024. [Online]. Available: UNOSAT Gaza Strip comprehensive damage assessment (2024)
- [11] UNOSAT (United Nations Satellite Centre), “UNOSAT Gaza Strip comprehensive damage assessment,” 2025. [Online]. Available: UNOSAT Gaza Strip damage assessment, 31 October 2025
- [12] Y. Asi, D. Mills, P. G. Greenough, D. Kunichoff, S. Khan, J. Van Den Hoek, C. Scher, S. Halabi, S. Abdulrahim, N. Bahour, A. K. Ahmed, B. Wispelwey, and W. Hammoudeh, “Nowhere and no one is safe: Spatial analysis of damage to critical civilian infrastructure in the Gaza Strip during the first phase of the Israeli military campaign, 7 October to 22 November 2023,” *Conflict and Health*, vol. 18, Art. no. 24, 2024.
- [13] UNOSAT (United Nations Satellite Centre), “UNOSAT Gaza Strip comprehensive damage assessment,” 2025. [Online]. Available: UNOSAT Gaza Strip comprehensive damage assessment (2025)
- [14] D. Racek, Q. Zhang, P. W. Thurner, X. X. Zhu, and G. Kauermann, “Unsupervised detection of building destruction during war from publicly available radar satellite imagery,” *PNAS Nexus*, vol. 4, no. 12, Art. no. pgaf367, 2025.
- [15] H. Yin, L. Eklund, D. Habash, M. B. Qumsiyeh, and J. Van Den Hoek, “Evaluating war-induced damage to agricultural land in the Gaza Strip since October 2023 using PlanetScope and SkySat imagery,” *Science of Remote Sensing*, vol. 11, Art. no. 100199, 2025.
- [16] K. Dader and M. Joronen, “Fitful infrastructures: Dwelling with infrastructural elimination in Gaza,” *Antipode*, vol. 57, no. 3, pp. 886–906, 2025.
- [17] S. Abdelnour and N. Roy, “Processing debris from destroyed and damaged buildings in Gaza: Carbon emissions, time frames, and implications for rebuilding,” *Environmental Research: Infrastructure and Sustainability*, vol. 5, Art. no. 035002, 2025.
- [18] M. Benguita, “Urbicide in Israel’s War on Gaza: Architecture of erasure and the unmaking of urban life (2023–2025),” *Kış/Winter*, vol. 18, pp. 397–417, 2025.
- [19] European Union, United Nations, and World Bank, “Final Gaza Rapid Damage and Needs Assessment estimates \$71.4 billion for recovery and reconstruction,” 2026. [Online]. Available: Gaza Rapid Damage and Needs Assessment
- [20] D. Rinaldo, R. Alazzeah, J. Arcand, C. Scher, and J. Van Den Hoek, “The destruction of Gaza: Satellite measurements of the economic cost of war,” *PNAS Nexus*, vol. 5, no. 5, Art. no. pgag124, 2026.
- [21] S. Abuzerr and I. A. Al-Khatib, “Environmental and spatial patterns of disrupted solid waste management during ongoing war on Gaza,” *Waste Management Bulletin*, vol. 4, no. 3, Art. no. 100369, 2026.
- [22] R. S. A. Abulehia, “When infrastructure collapses: Collective resilience and digital learning among Palestinian university mathematics students during the war on Gaza,” *International Journal of Educational Development*, vol. 125, Art. no. 103651, 2026.
- [23] Z. Zawawi, I. Khudiesh, and A. Helal, “Remote sensing role in assessing the changes of LULC and LST during war on Gaza,” *Advances in Space Research*, vol. 77, no. 6, pp. 6832–6854, 2026.
- [24] R. Ziadah, C. Henderson, O. J. Salamanca, S. Plonski, C. Chua, R. Al Sanah, and E. El Khazen, “Disruptive geographies and the war on Gaza: Infrastructure and global solidarity,” *Geopolitics*, vol. 31, no. 1, pp. 453–491, 2026.