Assessing the urban damage due to aerial bombing in Gaza City with the use of Combine Multispectral and SAR imagery

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Abstract*: This research investigates the level of urban damage of Gaza City in the Gaza strip, impacted by the aerial bombings campaign, that befallen from 7th October 2023 to 6th November 2023, using remotely sensed satellite imagery. The principal objective of the research investigation is to measure the effect of the aerial bombing campaign on mutually land use and land cover area (LULC) and building structure of the urban Gaza City. Sentinel-1 Synthetic Aperture Radar (SAR) data, that range from pre- and post- of the urban Gaza City was used for sensing the s of the building structures and Land Use Land Cover, while Sentinel-2 multispectral imagery was used to weigh the LULC alterations crossways the urban Gaza City. Combination of both datasets, the research investigation delivers a detailed examination of temporal s and computes the or damage shapes, particularly in urban infrastructure in urban Gaza City. The unique advance of using SAR data is its capability to capture structural s in all weather situations, whereas the multispectral imagery from Sentinel-2 counterparts the computation by providing comprehensive evidence on land cover s, such as vegetation loss or changes in urban environment, especially built-up areas, that ideal for this research investigation. The outcomes disclose noteworthy s in both LULC and infrastructure buildings, with nearly 47.1% of the cover out of the full extent of urban Gaza City has impacted some degree of or change. Moderate or change is the dominant observation according to the research investigation, signifying an extensive but not regularly severe or damage across the urban Gaza City. The research findings are important for apprising post-conflict recovery and rebuilding efforts, providing insights into which deviated or changed urban areas of the urban Gaza city, require priority in terms of rebuilding. Moreover, the study's outcomes have implications for urban warfare approach, stressing how damage assessments or assessments can help to derive tactical, operational and strategic decisions throughout the conflicts. By mixing SAR and optical data, the research study offers a wide-ranging method to considerate the scale and scope of urban or damage in war torn zones, aiding in more up-to-date forecasting for disaster management, recovery, and future military operations.*

Keywords: Urban Damage, Sentinel-1, Sentinel-2, Gaza City, Change Detection

Introduction

Investigate the urban deviation or damage in war-torn geography is vital equally for direct military manoeuvres and also lasting regaining efforts. Infrastructure damage assessment, a key component of battle damage assessment (BDA), plays a fundamental part not only in appraising the effect of airstrikes but also in supervisory post-war rebuilding and relief plans. In this background, remote sensing has developed as an essential instrument for weighing the change or damage of land use land cover in areas where ground surveys are problematic or intolerable. By leveraging cutting-edge satellite data, it can improvement a more complete thoughtful of the spatial and temporal degree of the change or damage.

In this regard, searching a significant case study to investigate from the contemporary world is the Gaza City, an ideal scenario, that presents and compels for investigation, given its compactly occupied urban setting and the exceptional encounters posed by tunnel warfare, a tactic that experimental during the time of Vietnam War. The complexity of Gaza's urban land, mutual with its widespread underground tunnel network, makes damage detection and assessment particularly challenging but vital for thoughtful the wider influences of war on building infrastructure and urban land use land cover systems (Dempsey et al., 2008).

This research investigation focuses on the aerial bombings that took place between October 7th and November 6th, 2023, measuring the changes and damage in the urban Gaza City, using Sentinel-1 Synthetic Aperture Radar (SAR) and Sentinel-2 multispectral imagery. Whereas SAR imagery supports to capture the structural damage and urban changes under all weather conditions, multispectral data delivers supplementary insights into land use and land cover (LULC) changes, principally in built-up areas.

The general objective of this research study is to measure the range of building infrastructure damage in Gaza City following the aerial bombing campaign. Accordingly specific objectives of the research study are, to weigh the change or damage in LULC and building infrastructure in the urban Gaza city for post-conflict rebuilding and aid valuation, and evaluate the proliferation of urban damage crossways different key dates throughout the aerial bombings.

By integrating SAR and optical imagery, this research work offers a vigorous method to understanding the spatial and temporal subtleties that represent the changes or damage in war-torn urban areas, contributing treasured insights for both military BDA and post-conflict recovery development.

Literature Survey

It is discuss that, in urban warfare, explosive weapons significantly effect building structures and adjacent buildings or infrastructure through a amalgamation of blast pressure, effect damage, and heat effects. The degree of damage produced by these weapons depends on several reasons, including the explosive vintage, closeness to the building infrastructure, and the characteristics of the urban environment (Shwaky et al., 2018). Blast waves can destroy or brutally compromise the physical integrity of buildings by twisting beams, destructive columns, and deeply pushing walls. Moreover, wreckages propelled by the explosion, such as cut-glass or blocks, can more contribute to physical damage. Temperature from explosions can alter building constituents, making them more brittle and even triggering fires, which enhances to the complete demolition. In compactly inhabited urban areas, the blast wave frequently reflects off adjacent constructions and narrow roads, directing the energy and spreading the harm over a wider extent than in open spaces. This phenomenon is predominantly important in "urban canyons" everywhere tall constructions concentrate the blast. The collaboration of the blast wave with the built environment confuses the calculation of the full degree of damage, specifically in extents like Gaza City, where civilian structure is consistent. Such difficulties emphasise the encounters in measuring urban damage, principally when both military objectives and civilian constructions are at close proximity. The use of satellite data in alteration detection helps deliver an objective view of these damage patterns, causal to additional effective post-conflict recovery plans.

It is discoursed that, structure extraction from high-resolution remote sensing imagery is vital for various applications such as urban development, population figures, and catastrophe assessment (Wang et al., 2022). However, precisely extracting structures in urban areas with high density and minor border variances poses noteworthy encounters. Current approaches encounter questions like border evidence loss, poor extraction in compact areas, and nosiness from construction shades. To address these encounters, this research study proposes a practical structure extraction technique founded on convolutional neural networks (CNNs). The projected technique integrates multi-scale repeated residual convolution to extract features, consideration gates skip connection to enhance information interaction, and an adversarial network with similar architecture to refine the extracted results. Furthermore, a conditional evidence restraint is presented to enhance the robustness and simplification capability of the technique.

It is discoursing that, the claim of Synthetic Aperture Radar (SAR) technology for detecting Earth's surface, mainly focusing on the use of SAR data for innumerable applications such as natural calamity calculation and monitoring of land cover changes (Uemoto, 2021). The study emphasis the importance of precisely retrieving height information of targets by means of SAR, mainly over cross-track interferometry (CTI). One of the encounters in SAR-based height estimation is refining the InSAR limits, which encompasses lessening faults in phase difference (PD) measurements and baseline parameters. The article analyses numerous approaches projected in the literature for refining InSAR parameters, counting the use of ground control points (GCPs) and global elevation models such as SRTM, ASTER GDEM, and ALOS World 3D 30 m mesh (AW3D30).

It is discuss that the expansion of the IFB-CEM algorithm for detection of urban fiery zones using optical images, and the Dual-Polarization Normalized Coherence Index (DPNCI) for measuring structure damage via multi-temporal SAR imagery. It proves the efficiency of medium-resolution satellite data and internet information in fast measuring damage instigated by armed battles. The study highlights the humanitarian encounters that contemporary battles pose, distressing survives, property, and the environment. With limited access to field surveys in conflict zones, remote sensing know-how suggests an alternate for change detection and damage assessment. Whereas high-resolution imagery delivers exhaustive insights, medium-resolution imagery like Landsat and Sentinel, along with SAR data, offers wider coverage and all-weather competences, making it more appropriate for large-scale battle monitoring. The article recommends a semi-automated outline by means of these resources to sense built-up fiery and measure the damage. The examination, focusing on Mariupol, discloses that 79.2% of structures were severely damaged or wrecked, correlating with fiery exposure. Although effective, challenges endure, such as the incapability to spot damage to small structures and timing differences between social media and satellite imagery. The investigate suggests appreciated insights for post-conflict rebuilding and calamity response, enhancing decision-making and resource distribution.

Study area and data

The geographic extent for the research interest area focuses on Gaza City, a tightly inhabited built-up area characterized by a high absorption of housing and commercial buildings structures. The city's urban stretch, shared with its complex building structures, presents unique encounters when measuring the change or damage triggered by aerial bombardment. As urban concentration stimuluses the effect of airstrikes, it is vital to investigate the changes in land cover and physical integrity widely (Ezugwu, 2023).

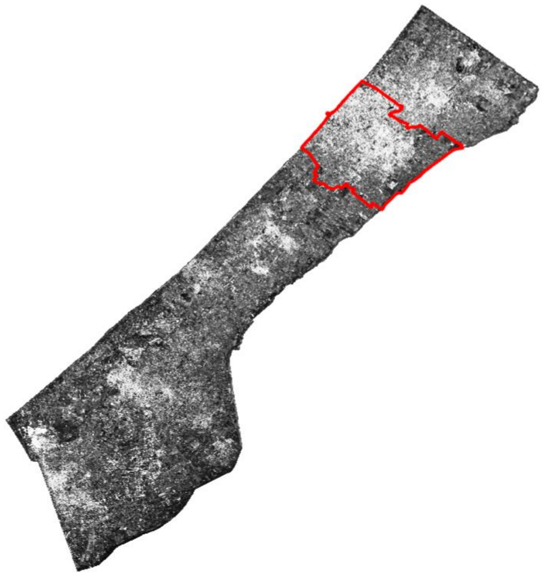

Figure 1: Study Area - Gaza City

This research study trusted on secondary data from the Sentinel-1 and Sentinel-2 satellite missions, covering the dates from 18th September 2023 to 5th November 2023. Sentinel-1 providing SAR imagery under all weather conditions, which was vital for given the persistent cloud cover and smoke over Gaza City during the aerial bombing campaign (Braun, 2018; Huang et al., 2023). SAR data was collected in Strip map Mode (SM), with VV polarization applied for urban change detection. Sentinel-2 multispectral imagery, acquired on important days, was used to counterpart the SAR data, providing insights into changes in land cover and vegetation. Data was sourced from the Copernicus Open Access Hub, and pre-processing was executed in the SNAP software atmosphere. This comprised orbit file application, thermal noise removal, radiometric calibration, speckle filtering, and terrain correction (Filipponi, 2019).

Methodology

The methodology combined change detection techniques using SAR and multispectral data to identify the extent and severity of urban damage. SAR imagery was processed using an order of pre-processing steps, counting the removal of thermal noise and speckle filtering. The treated images were then examined using a change detection algorithm to classify areas of substantial structural change among the pre-damage (18th September 2023) and post-damage (5th November 2023) images.

Conceptual Diagram

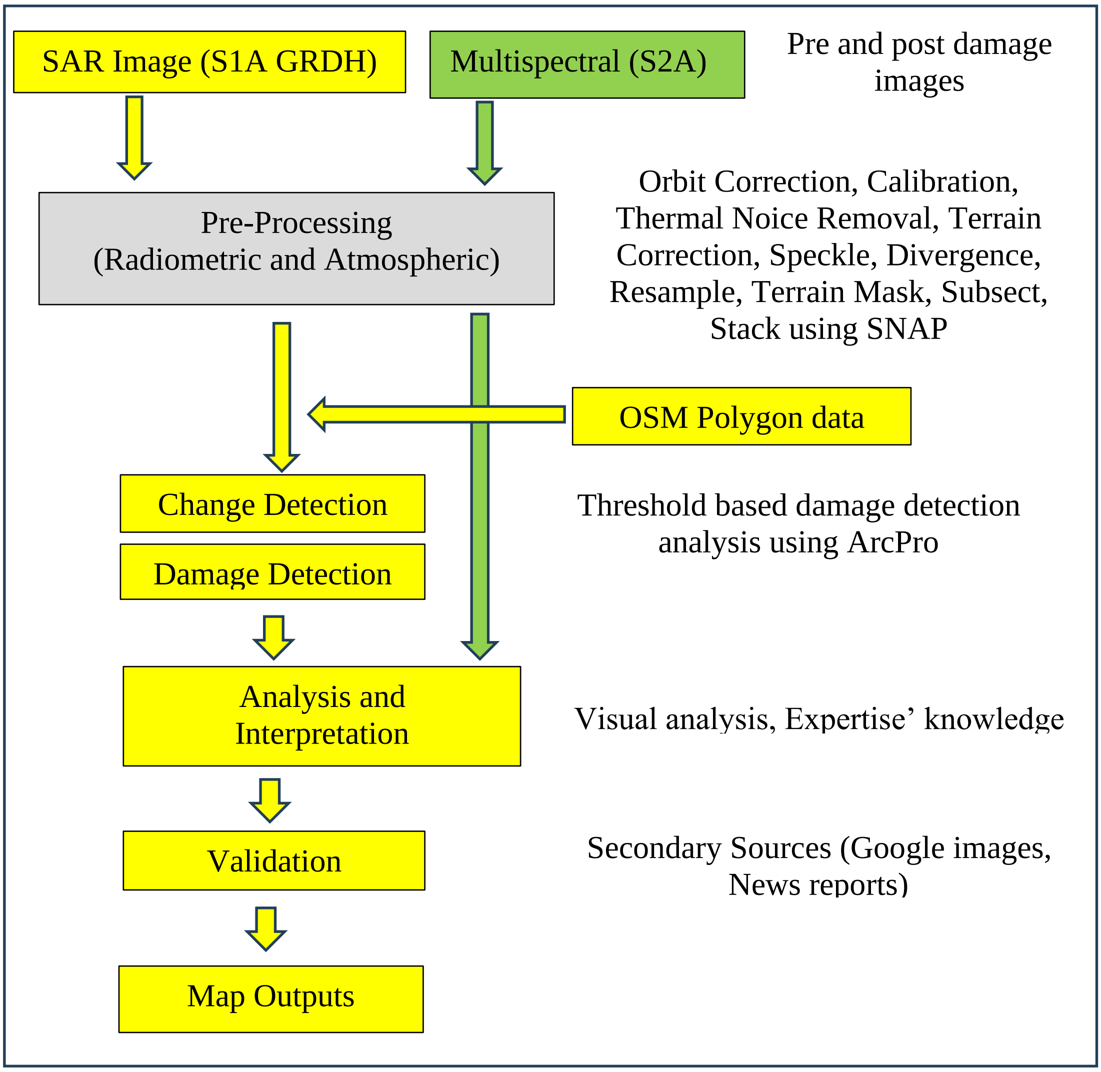

Figure 2 : Conceptual diagram

A threshold-based damage detection using density slicing classification method was applied to classify the deviations or changes detected in the SAR imagery. Change detection between the SAR images of key dates as 30th September, 12th October, 24th October, and 5th

November was conducted to assess the proliferation of change over time. The resulting change maps were categorized into three classes as No Significant Change, Moderate Change, and Severe Change. Multispectral data from Sentinel-2 was used to confirm and validate these changes, focusing on differences in urban land cover and vegetation in addition to the news reports.

The research study also employed auxiliary data from the Copernicus Hub, such as orbit determination and calibration files, to certify the precision of SAR image geolocation and radiometric steadiness. The shared use of SAR and multispectral imagery provided a added all-inclusive understanding of urban damage, accounting for both physical changes and alterations in land cover (Li et al., 2019).

Results and discussion – Area specific damage assessment

The experimental results reveal a detailed progression of changes in urban infrastructure over the study period. Gaza City covers an area of approximately 45 km^2, and the analysis focused on quantifying the percentage of land that experienced varying degrees of change.

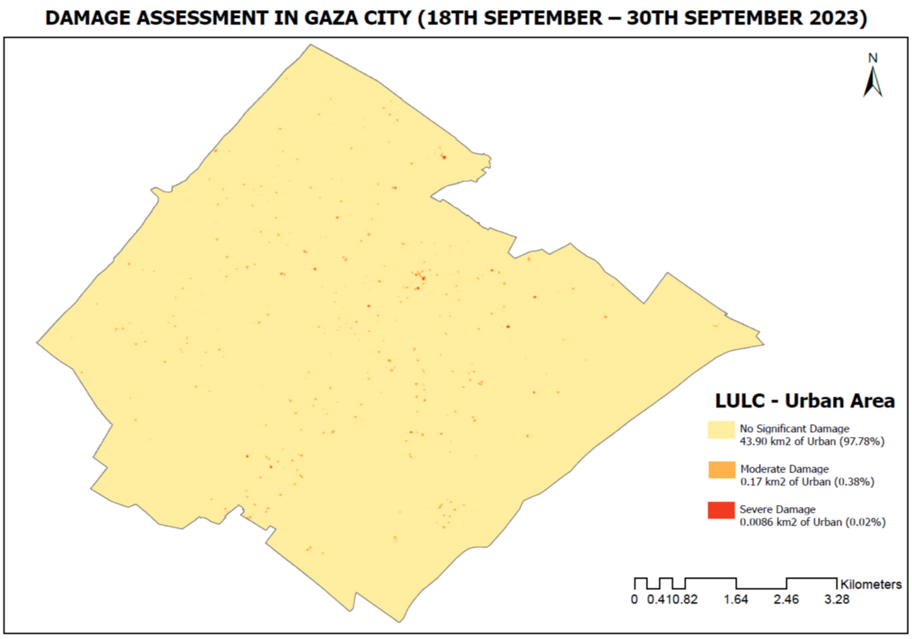

Figure 3 : Damage Assessment as 30th September 2023

On 30th September 2023, the SAR imagery showed that 43.90 km^2 (97.78%) of the city's land exhibited no significant change, while 0.17 km^2 (0.38%) experienced moderate change, and 0.0086 km^2 (0.02%) showed severe change. This period reflects the pre-bombing baseline, with limited observable changes.

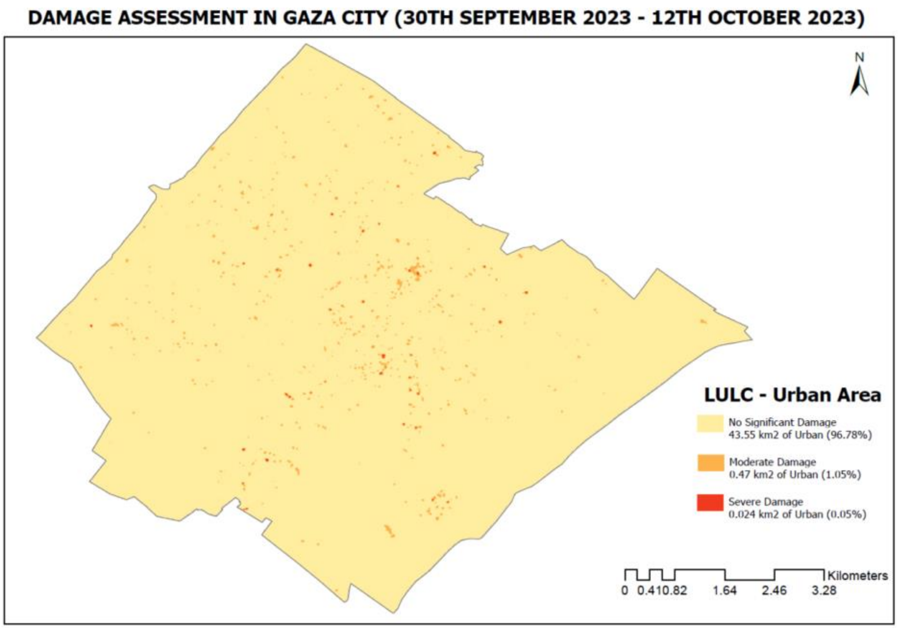

Figure 4 : Damage Assessment as 12th October 2023

By 12th October 2023, five days into the aerial bombing campaign, the percentage of land showing no significant change dropped to 43.55 km^2 (96.78%). Moderate change increased to 0.47 km^2 (1.05%), and severe change rose to 0.024 km^2 (0.05%). These early results indicate the onset of structural damage in targeted areas, with an observable increase in moderate and severe damage categories.

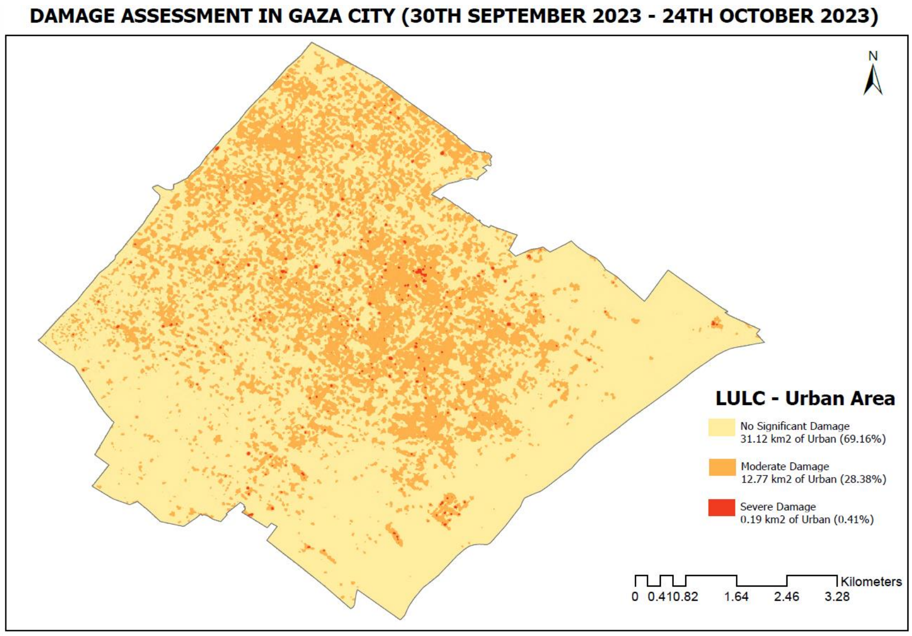

Figure 5 : Damage Assessment as 24th October 2023

The peak of change was observed on 24th October 2023, 17 days after the bombing began. At this point, only 31.12 km^2 (69.16%) of the city's land remained unchanged, while 12.77 km^2 (28.38%) experienced moderate change, and 0.19 km^2 (0.41%) suffered severe damage. The significant rise in both moderate and severe damage suggests widespread destruction across the city’s urban infrastructure during this period.

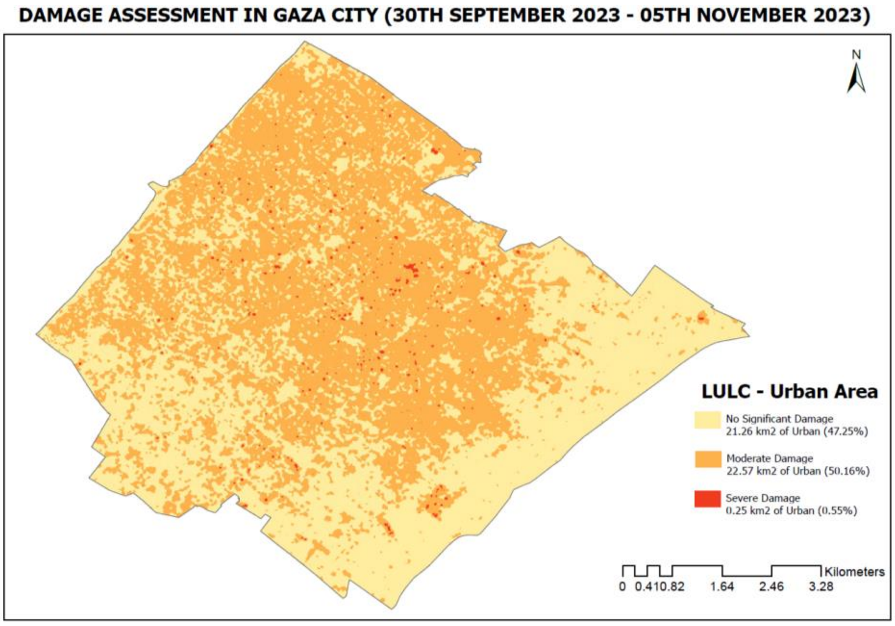

Figure 6 : Damage Assessment as 05th November 2023

By 5th November 2023, the area of no significant change further decreased to 21.26 km^2 (47.25%), while moderate change expanded to 22.57 km^2 (50.16%), and severe damage grew to 0.25 km^2 (0.55%). These results indicate that, over the study period, more than half of Gaza City's urban area experienced some form of structural damage.

Results and discussion – Structure (Building) specific damage assessment

In terms of building specific damage, similar patterns were observed. On 30th September 2023, the SAR imagery indicated that 12.43 km^2 (27.63%) of the buildings in Gaza City showed no significant change, while moderate change was observed in 0.10 km^2 (0.22%) of buildings, and severe change affected 0.0045 km^2 (0.01%). This period represents the pre-bombing baseline, with minimal changes observed, serving as a reference point for damage comparison in the later stages of the conflict.

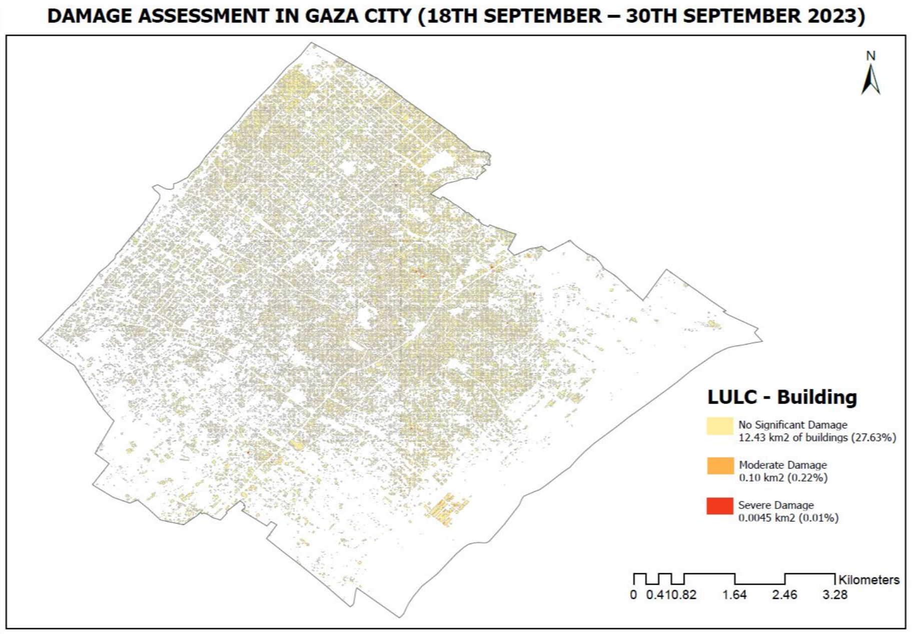

Figure 7: Building Damage Assessment as 30th September 2023

By 12th October 2023, five days after the onset of aerial bombing, SAR imagery showed a noticeable shift in building conditions. No significant change was observed in 9.89 km² (22.00%) of the buildings, indicating a decrease in unaffected areas. Moderate change had increased to 0.23 km² (0.51%), and severe change impacted 0.011 km² (0.03%) of the buildings. This stage reflects the initial effects of the bombing campaign, with damage starting to spread across the city's built-up areas.

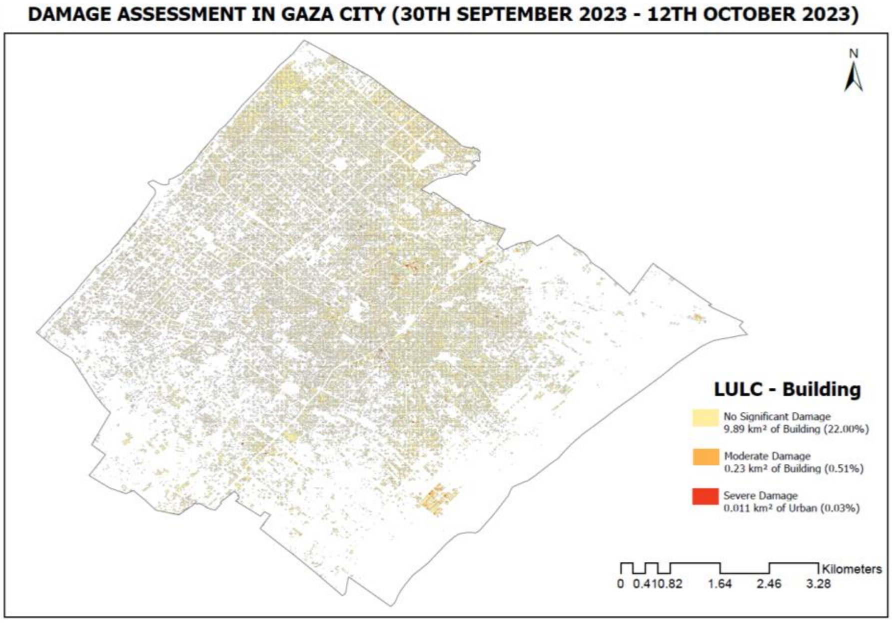

Figure 8 : Building Damage Assessment as 12th October 2023

By 24th October 2023, the damage to buildings had intensified. No significant change was observed in 7.74 km² (17.20%) of the buildings, while moderate change had escalated to 2.30 km² (5.11%). The severe change category also rose to 0.109 km² (0.24%), reflecting a sharp increase in damage. This period marks a critical phase of the conflict, as more of Gaza City's building infrastructure began to exhibit the effects of sustained bombardment.

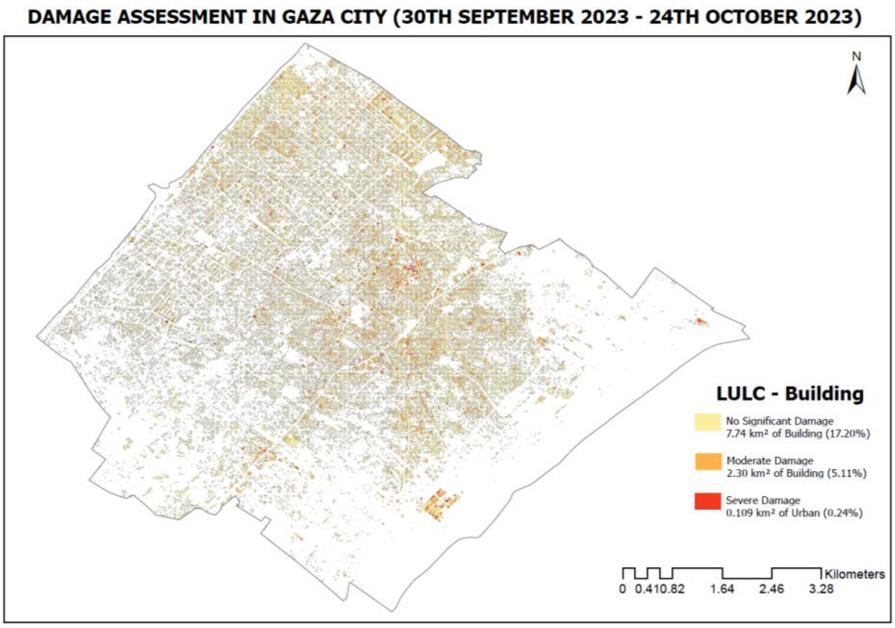

Figure 9 : Building Damage Assessment as 24th October 2023

By 5th November 2023, near the end of the bombing campaign, the SAR imagery revealed that only 1.56 km² (3.47%) of the buildings remained unchanged. Moderate change had spread to 8.46 km² (18.81%) of the built-up area, and severe change affected 0.13 km² (0.29%). This represents the culmination of the aerial bombardment's impact on Gaza City's buildings, with the majority of the urban infrastructure suffering some level of damage, and only a small portion remaining unaffected.

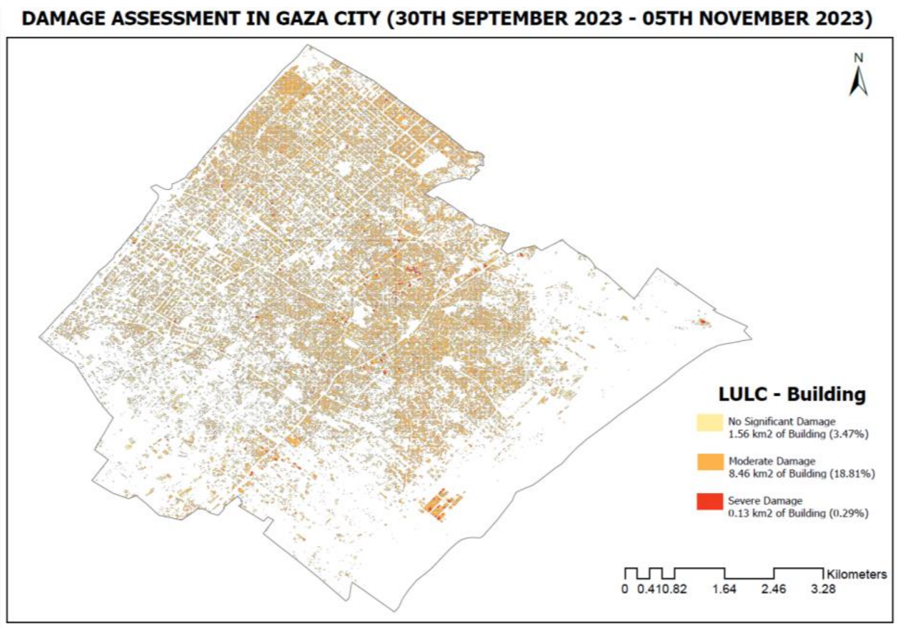

Figure 10 : Building Damage Assessment as 05th November 2023

These results highlight the rapid escalation of damage over time, with the most significant changes occurring between 12th October to 05th November 2023. The analysis of urban land cover and building-specific damage provides a comprehensive view of the destruction inflicted on Gaza City during the bombing campaign.

Findings and Recommendation

By the 5th of November 2023, changes in Land Use and Land Cover (LULC) and building categories in urban Gaza City were assessed, revealing the following transformations. The 45 km² of Gaza City's urban area was categorized as 'No Significant Damage' areas covered 21.259 km², 'Moderate Damage' spanned 22.572 km², and 'Severe Damage' affected 0.249 km². In terms of buildings, the areas with 'No Significant Damage' measured 1.562 km², 'Moderate Damage' covered 8.461 km², 'Severe Damage' accounted for 0.130 km². With ground operations commencing on the 7th of November, these results show that approximately 47.1% of the total urban area experienced some level of alteration due to the aerial campaign. This significant extent of change reflects the operational threshold that prompted the movement of ground forces. It underscores that once a critical level of damage is inflicted upon the urban environment, the conditions become conducive for land forces to advance, demonstrating how aerial bombardment directly shapes tactical decisions in urban warfare.

Another key finding from the analysis relates to identifying structural changes, particularly in buildings is that, while many buildings remain standing and appear to retain their original shape, aligning with the building polygons, the analysis reveals a limitation. The changes caused to the internal structure of these buildings, such as interior damage or structural weakening cannot be detected using the current satellite data. The study primarily focuses on surface-level changes observable in the imagery those represent by scatter signature, but significant internal damage may still exist despite the exterior appearing intact. This limitation highlights the need for complementary ground assessments or higher-resolution data to fully capture the extent of building damage in conflict zones.

The study reveals that minor structural changes, such as the collapse of walls, roof damage, or broken windows, cannot be effectively detected through visual analysis or thresholding techniques used in SAR data. These subtle changes fall below the detectable threshold in the imagery, highlighting a limitation in capturing small-scale damage. As a result, while major damage to buildings is easily identified, finer structural impacts may remain undetected, necessitating supplementary ground assessments or higher-resolution data for a more comprehensive understanding of urban damage.

Another significant finding is that the majority of changes observed in land use and land cover (LULC) and buildings fall into the moderate category. Specifically, the data indicates that moderate changes were predominant in both LULC and building conditions, reflecting a considerable but not extreme level of impact. This moderate level of change suggests that while there has been substantial alteration in the urban environment, the damage is not uniformly severe across all areas.

However, the study also identified limitations in the resolution of the SAR imagery, particularly regarding smaller buildings that fall below the 10-meter resolution threshold. Future studies may benefit from higher-resolution data or alternative techniques to improve the accuracy of damage assessments. Additionally, the inability to determine the exact timing of damage between SAR acquisitions presents a challenge for pinpointing specific events. More frequent data acquisition, coupled with ground-based validation, could address this limitation (insert appropriate author reference).

The study grounded on the research findings, suggests following recommendations.

In order to address limits in noticing tiny physical deviations, such as roof damage or wall collapses, it is suggested to integrate higher-resolution satellite data. This would improve the competence to capture subtle but critical damage that existing medium-resolution imagery failures.

Increasing the frequency of satellite data gaining could progress the precision of measuring damage over time and help in pinpointing exact events that cause the urban damage. This would be predominantly appreciated in fast-evolving battle zones where swift apprises are necessary for decision-making.

Use of Cutting-edge Procedures for Small Buildings in order to overcome the limits of current SAR imagery, mostly regarding smaller constructions, it is advisable to explore alternate remote sensing procedures, such as drone imagery or high-resolution optical data. This would improve the capacity to detect deviations or changes in smaller buildings that fall below the 10-meter threshold.

Integrate Ground Forces Data for given the findings associated to ground operations, upcoming studies should deliberate integrating data from military ground forces, specially to compare the degree of urban damage with tactical movements and operational conclusions.

In order to urban warfare adaptation, it is recommend that the indicated results which significant aerial bombardment stimuluses ground force operations. Military leadership should continue utilizing damage assessments to refine tactics for urban warfare, recognizing the point at which damage thresholds trigger ground advancement.

In addition, in terms of Long-Term Urban Monitoring for post-conflict rebuilding and humanitarian planning, long-term monitoring of urban areas is recommended to assess repossession and infrastructure rebuilding. This would contribution in resource distribution and reintegration efforts, particularly in moderately scratched areas.

Conclusion

In conclusion, this study proves the efficiency of remote sensing for urban deviation or damage assessment, providing valuable insights for future air force operations, particularly pre-emptive air campaigns. By participating SAR and multispectral data, it can attain a added nuanced understanding of the effects of aerial bombardment on urban infrastructure, aiding in the development of more precise and informed strategies for future conflicts.

References

Braun, A. (2018). Assessment of building damage in raqqa during the syrian civil war using time-series of radar satellite imagery. In *GI_Forum* (Vol. 6, Issue 1, pp. 228–242). Austrian Acedemy of Sciences Press. https://doi.org/10.1553/GISCIENCE2018_01_S228

Dempsey, N., Brown, C., Raman, S., Porta, S., Jenks, M., Jones, C., & Bramley, G. (2008). *Elements of Urban Form* (pp. 21–51). https://doi.org/10.1007/978-1-4020-8647-2_2

Ezugwu, O. (2023). The 21st Century Israel-Palestine Conflict Over Jerusalem and its Peace Processes. *Malaysian Journal of International Relations*, *11*(1), 107–127. https://doi.org/10.22452/mjir.vol11no1.6

Huang, Q., Jin, G., Xiong, X., Ye, H., & Xie, Y. (2023). Monitoring Urban Change in Conflict from the Perspective of Optical and SAR Satellites: The Case of Mariupol, a City in the Conflict between RUS and UKR. *Remote Sensing*, *15*(12). https://doi.org/10.3390/rs15123096

Shwaky, M., Amer, F., Mosa, O., & Hamza, E. (2018). A Comparative Study of Supervised Classification Techniques for Multi-Spectral Images. *The International Conference on Electrical Engineering*, *11*(11), 1–13. https://doi.org/10.21608/iceeng.2018.30172

Uemoto, J. (2021). Refinement of interferometric SAR parameters using digital terrain model as an external reference. *ISPRS Journal of Photogrammetry and Remote Sensing*, *175*, 34–43. https://doi.org/10.1016/j.isprsjprs.2021.02.017

Wang, Z., Xu, N., Wang, B., Liu, Y., & Zhang, S. (2022). Urban building extraction from high-resolution remote sensing imagery based on multi-scale recurrent conditional generative adversarial network. *GIScience and Remote Sensing*, *59*(1), 861–884. https://doi.org/10.1080/15481603.2022.2076382