DETECTING CHANGES IN WAR-DAMAGED URBAN AREAS USING THE IR-MAD METHOD AND SENTINEL-2 SATELLITE DATA

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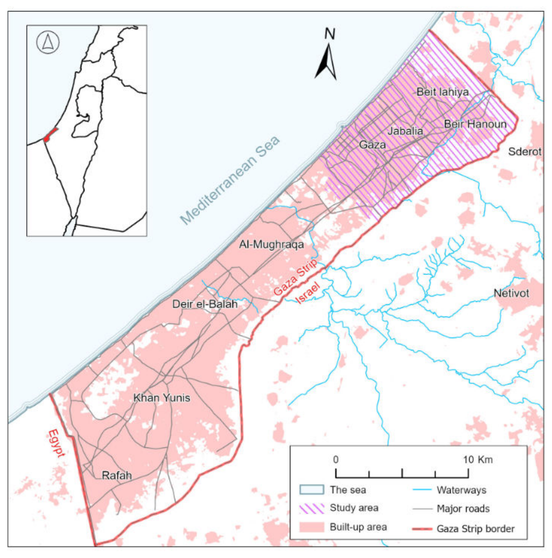
Introduction

Modern warfare devastates cities with a ferocity that makes traditional, on-the-ground damage assessment both dangerous and slow. Earth Observation (EO) offers a critical alternative, providing a safe and objective means for humanitarian support and accountability. This challenge is acutely evident in Gaza City, a densely populated 110 km² urban area that has suffered immense destruction since the start of the Gaza war in October 2023.

This study presents a workflow developed in Google Earth Engine to map this destruction, pairing a pre-conflict Sentinel-2 scene (27 September 2023) with a mid-conflict scene (26 November 2023). The approach applies the Iteratively Re-weighted Multivariate Alteration Detection (IR-MAD) algorithm; a robust method for identifying landscape alterations like rubble and craters, and focuses the analysis on the urban footprint using Dynamic World mask. Validation against 500 high-resolution control points confirmed an overall accuracy of 74%. The results indicate that approximately 52% of the city's built-up area was significantly altered during this initial two-month interval. The resulting openly available workflow provides a reproducible tool for monitoring the crisis in Gaza and serves as a potential model for assessment in other conflict zones.



Source: UNRWA: United Nations Relief and Works Agency for Palestine Refugees in the Near East

Methodology and Data

1) Data and Implementation

The analysis was performed in a Jupyter Notebook using the Google Earth Engine (GEE) API and a custom library based on Dr. Canty's (2019) scripts. Cloud-free Sentinel-2 L2A images (Bands B2, B3, B4, B8, B11, B12) acquired on 26 September 2023 and 27 November 2023 were selected and masked using the Dynamic World 'built' class (Figure 3) to isolate the urban environment. After running the IR-MAD algorithm, a final binary change map was generated by applying an optimized threshold. This threshold was identified using scikit-learn's Receiver operating characteristic (ROC) curve function as the point furthest from the diagonal.

2) Algorithm

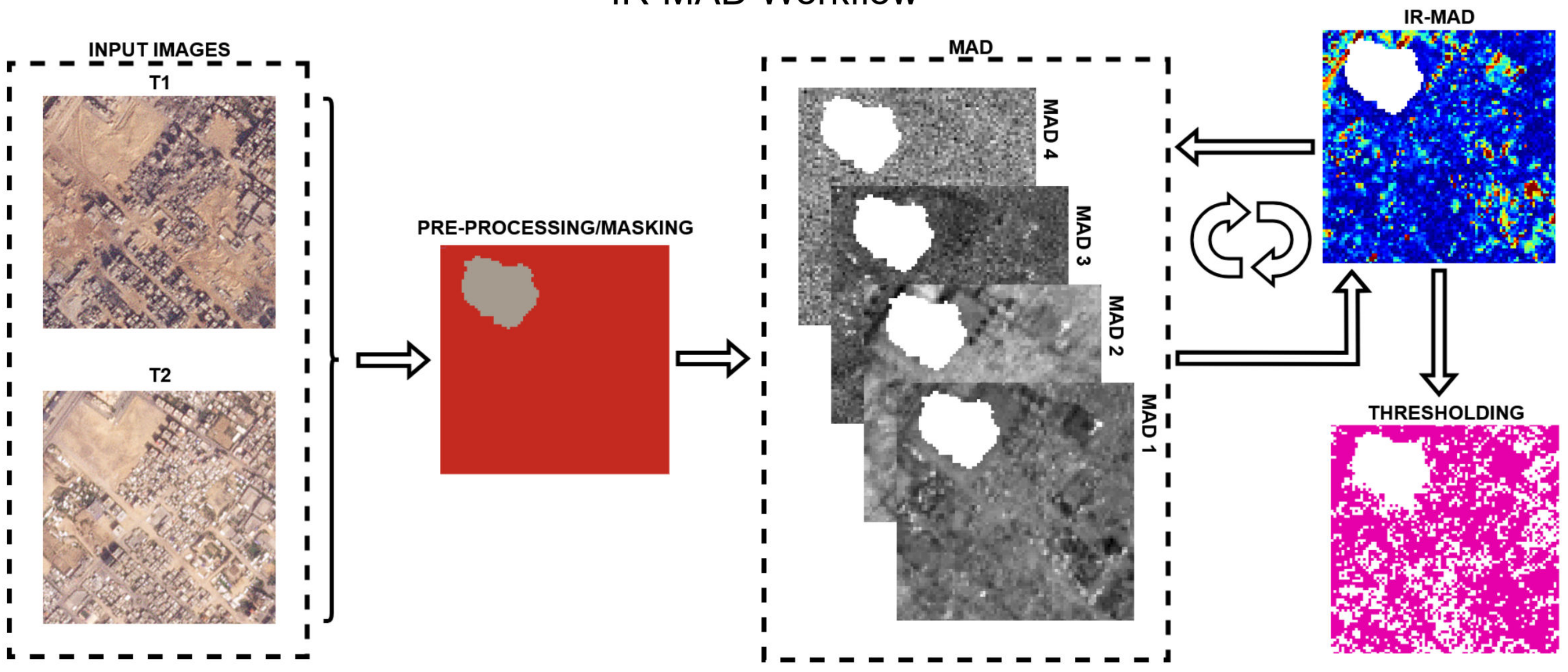
This study employed the Iteratively Reweighted Multivariate Alteration Detection (IR-MAD) algorithm. This statistical method identifies changes between two multi-band satellite images acquired at different times. The method was developed by Nielsen (2005), and the analysis was performed using a Google Earth Engine implementation adapted by Canty (2019). The algorithm functions in two main stages:

a) Multivariate Alteration Detection (MAD)
The input are two satellite images (a 'before' and 'after' scene (T1,T2). The MAD algorithm transforms the spectral band data to find the linear combinations that exhibit the maximum difference between the two dates. This creates a set of "change components," (MAD components) where the initial components highlight significant alterations.

b) Iterative Reweighting (IR)
The MAD result is refined through an iterative reweighting. The algorithm identifies invariant pixels with a low probability of change. These pixels are assigned a greater statistical weight. This process reduces the influence of noise and minor atmospheric differences and increase the statistical separability between pixels representing change (destroyed buildings, debris fields) and those representing no-change.

Final output is a single-band raster where each pixel's value represents a transformed spectral difference. (Figure 1,2)

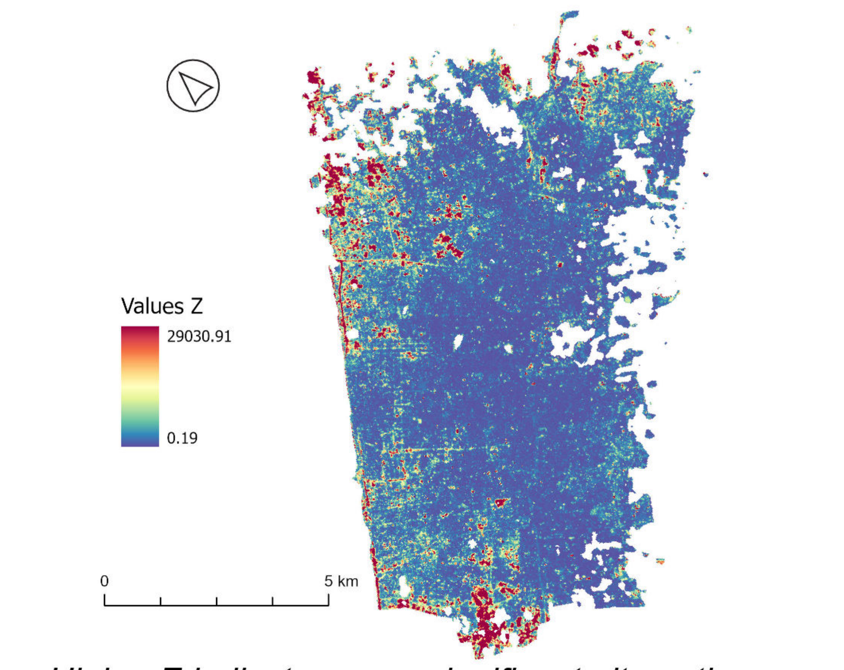
IR-MAD Workflow



3) Thresholding and Validation

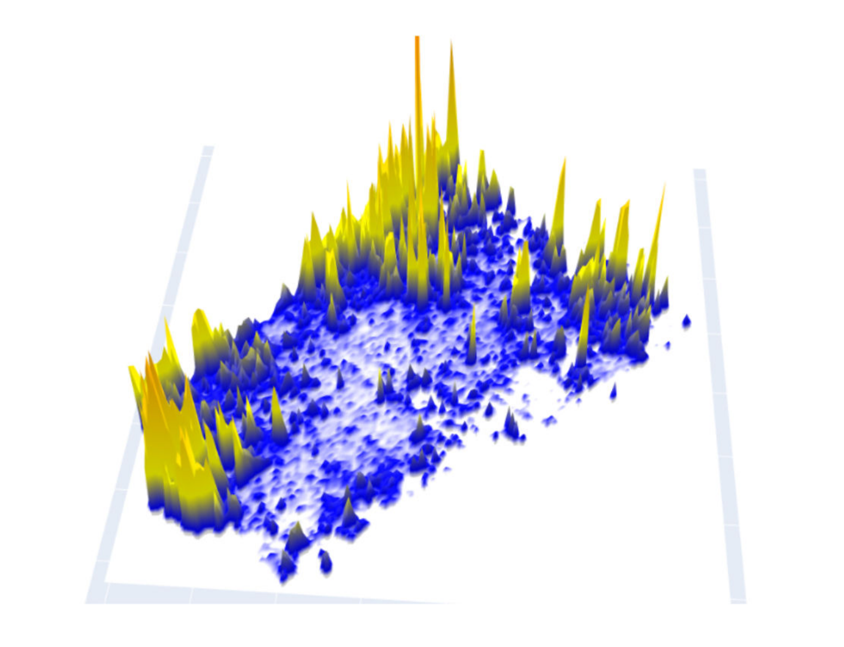
A reference set of 500 random points was created by visually interpreting 3 m PlanetScope imagery together with the UNOSAT damage report (Figure 4). Each point was labelled "change" or "no change" and used to compute performance metrics and to select the optimal threshold for the Standardised Sum of MAD components. The threshold was chosen by the point that maximises Youden's J statistic (TPR − FPR) on ROC.(farthest point from the diagonal)

Figure 1. Standardized sum of MAD components



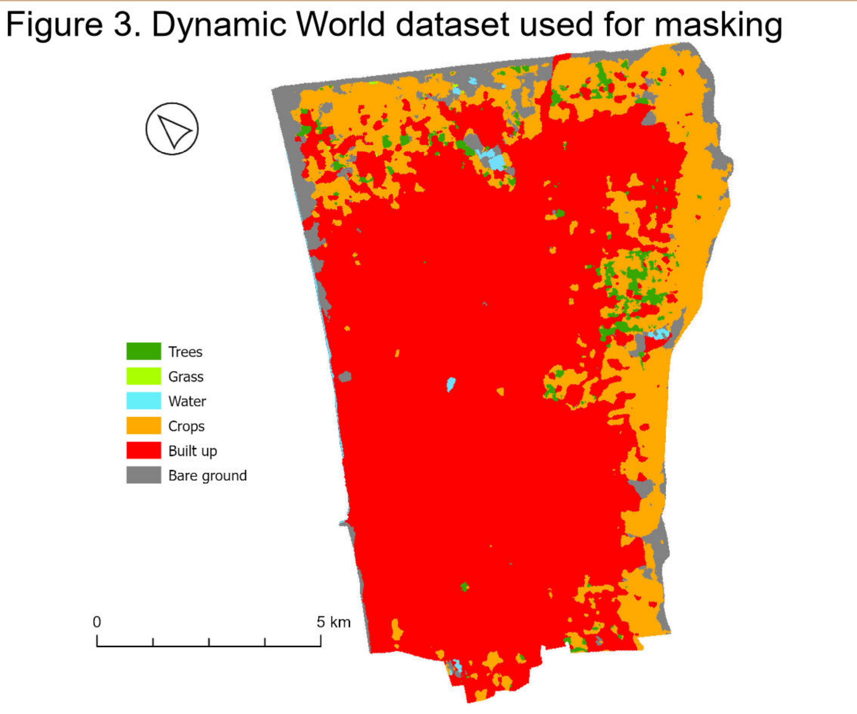
Higher Z indicates more significant altercations

Figure 2. *Standardized sum of MAD components (3D)*



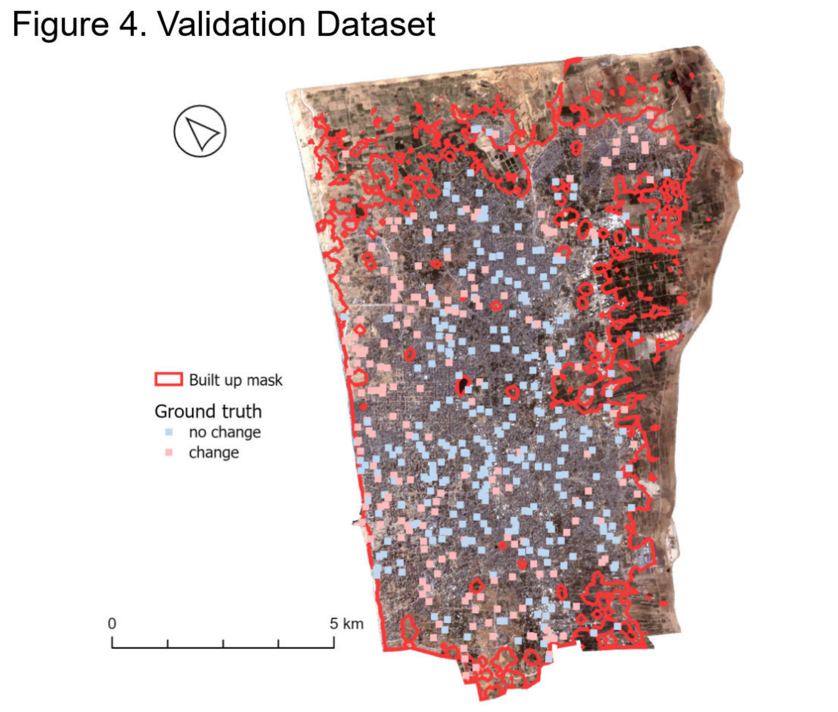
Higher Z indicates more significant altercations

Figure 3. Dynamic World dataset used for masking



The classification corresponds to 26.9.2023

Figure 4. Validation Dataset



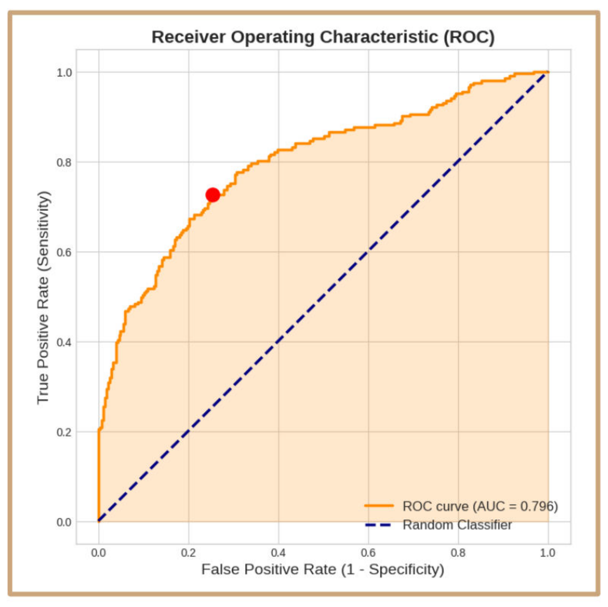
16 points were removed in Sample Cleaning

Results

Change detection was run with and without an urban mask on imagery from 27 September 2023 and 26 November 2023. The final results use the masked run, reflecting the focus on urban areas. Based on the ROC analysis, pixels with Z ≈ 32 or higher were classified as change

Using the validation reference dataset (Figure 4), the method achieved an overall accuracy of 73.76 % and a weighted F-score of 0.739.

Large, devastated tracts of vegetation were detected most readily, followed by changes to infrastructure and roads. At the selected threshold, approximately 52 % of Gaza's land cover was altered during the study period, corresponding to about 57.2 km² out of a total area of 110 km².

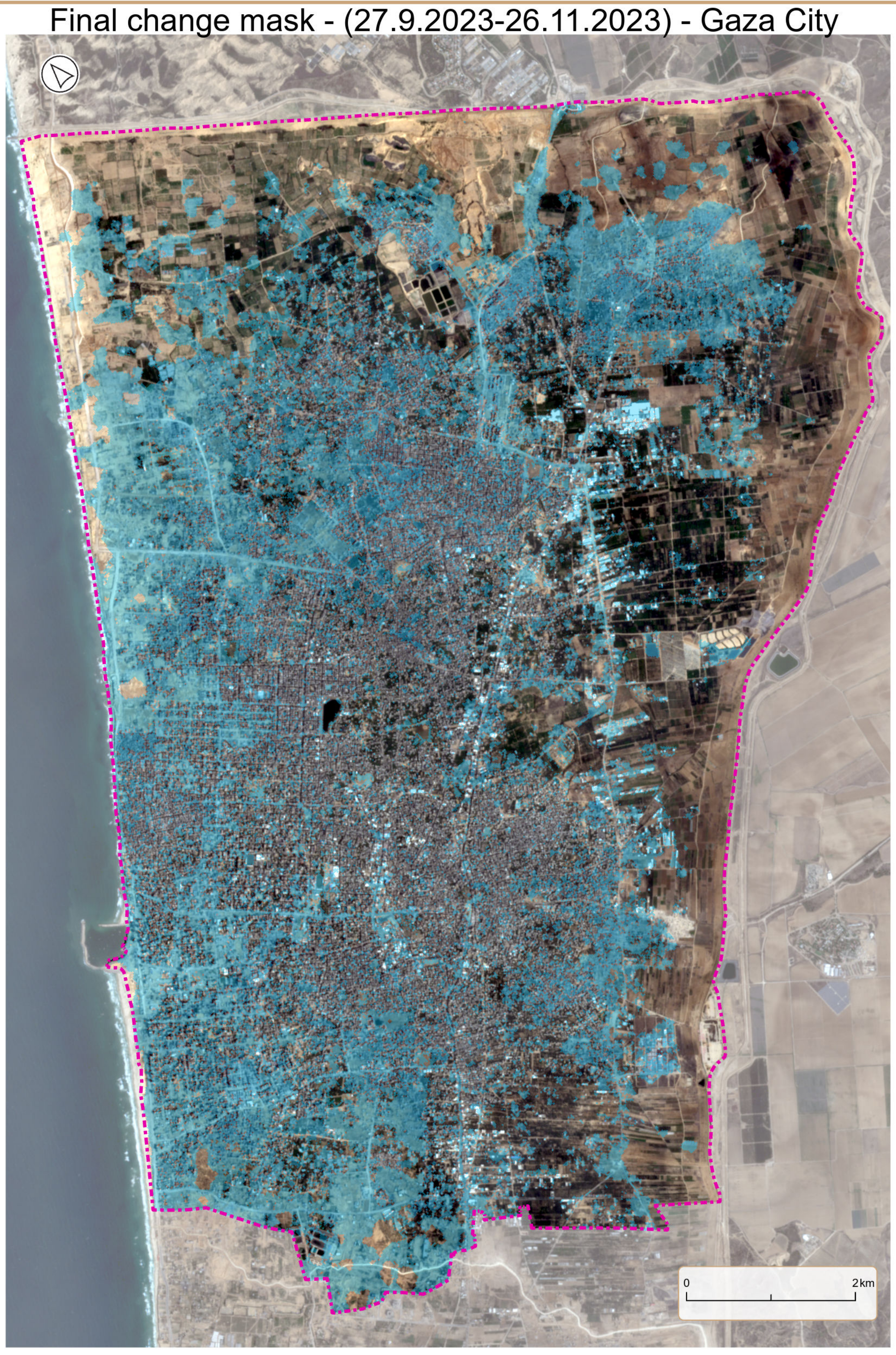


	No Change	Change	UA
No Change	211	72	0.7456
Change	55	146	0.7264
PA	0.7932	0.6697	

	Precision	Recall	F1-Score
No Change	0.7932	0.7456	0.7687
Change	0.6697	0.7264	0.6969

Examples of detected changes

Final change mask - (27.9.2023-26.11.2023) - Gaza City



Conclusion

This study demonstrated the potential of the IR-MAD algorithm as a viable tool for addressing the urgent need to use Earth Observation for monitoring damage in war-torn countries. The case study of Gaza City showed that IR-MAD successfully detected significant alterations associated with conflict, such as the destruction of buildings and vegetation, while correctly avoiding false detections in unchanged areas.

However, the study has several limitations. First, selecting an optimal threshold is a challenging and subjective task that could be improved with machine learning approaches. Second, the method's reliance on optical imagery makes it vulnerable to cloud cover. Therefore, fusing the workflow with Synthetic Aperture Radar (SAR) data, which can penetrate clouds, would enhance its reliability and applicability in all weather conditions.

*All produced scripts and materials will be uploaded to GitHub

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