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# การประเมินความเสียหายของเมืองจากแผ่นดินไหวและการสู้รบด้วยการตรวจจับการเปลี่ยนแปลงค่าโคฮีเรนซ์ร่วมกับภาพถ่ายดาวเทียมเซนทิเนล-1

# Earthquake and Conflict-Related Urban Damage Assessment Using Coherence Change Detection with Sentinel-1 Imagery

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## บทคัดย่อ

**วัตถุประสงค์และที่มา** : ภัยพิบัติก่อให้เกิดความสูญเสียต่อชีวิตและทรัพย์สิน รวมทั้งความเสียหายทางเศรษฐกิจ การประเมินความเสียหายหลังเกิดภัยพิบัติจึงมีความจำเป็นเพื่อสนับสนุนการบริหารจัดการหลังการเกิดภัยพิบัติ การให้ความช่วยเหลือด้านมนุษยธรรม และการบรรเทาสาธารณภัย การวิจัยนี้เป็นการประยุกต์ใช้วิธีการตรวจจับการเปลี่ยนแปลงค่าโคฮีเรนซ์ร่วมกับภาพถ่ายดาวเทียมเซนทิเนล-1 ในการประเมินความเสียหายของเมืองซึ่งเกิดจากภัยพิบัติทางธรรมชาติและภัยพิบัติที่มีสาเหตุจากมนุษย์ ประกอบด้วย เมืองอันทักยาในจังหวัดฮาทัยทางตอนใต้ของประเทศตุรกีซึ่งได้รับผลกระทบจากเหตุการณ์แผ่นดินไหวเมื่อวันที่ 6 กุมภาพันธ์ 2023 และเมืองมารีอูปอลทางภาคตะวันออกเฉียงใต้ของประเทศยูเครนซึ่งได้รับผลกระทบจากความขัดแย้งระหว่างประเทศรัสเซียและประเทศยูเครน ตั้งแต่วันที่ 24 กุมภาพันธ์ 2022 จนกระทั่งเมืองถูกควบคุมโดยรัสเซียในช่วงปลายเดือนพฤษภาคม 2022

**วิธีดำเนินการวิจัย** : ภาพถ่ายดาวเทียมเซนทิเนล-1 ในช่วงเวลาสามเดือนก่อนเกิดเหตุการณ์ของพื้นที่ศึกษาแต่ละแห่งถูกนำมาสร้างเป็นภาพค่าโคฮีเรนซ์เฉลี่ยก่อนเกิดเหตุการณ์ ส่วนภาพถ่ายดาวเทียมภาพแรกหลังจากแผ่นดินไหวในเมืองอันทักยาและภาพถ่ายดาวเทียมจำนวน 9 ภาพหลักจากเหตุการณ์ในเมืองมารีอูปอลถูกนำมาสร้างเป็นภาพค่าโคฮีเรนซ์หลังเกิดเหตุการณ์ ภาพค่าโคฮีเรนซ์หลังเกิดเหตุการณ์แต่ละภาพจะถูกจับคู่กับภาพค่าโคฮีเรนซ์เฉลี่ยก่อนเกิดเหตุการณ์โดยใช้มาตราส่วนลอการิทึมในการคำนวณหาการเปลี่ยนแปลงของค่าโคฮีเรนซ์ของพื้นที่เมืองในพื้นที่ศึกษาแต่ละแห่ง

**ผลการวิจัย** : ค่าโคฮีเรนซ์ของเมืองอันทักยาลดลงอย่างมากหลังจากเกิดแผ่นดินไหว ส่วนเมืองมารีอูปอลนั้นมีค่าโคฮีเรนซ์ลดลงเล็กน้อยในช่วงแรกหลังจากวันที่เมืองเริ่มถูกโจมตี จากนั้นมีการเปลี่ยนแปลงมากขึ้นในช่วงกลางเดือนมีนาคมถึง

พฤษภาคม 2022 และส่วนที่มีความเปลี่ยนแปลงมากที่สุดเกิดขึ้นบริเวณกลางเมืองและบริเวณเขตอุตสาหกรรมอาซอฟสทัล ทั้งนี้ ยังปรากฏความเปลี่ยนแปลงกระจายอยู่ทั่วไปในพื้นที่เมือง จากผลการวิจัยพบว่า พื้นที่ที่ได้รับผลกระทบจากแผ่นดินไหวในเมืองอันทักยาคิดเป็นร้อยละ 44.58 ของพื้นที่เมืองทั้งหมด แบ่งเป็น เสียหายเล็กน้อยร้อยละ 26.50 เสียหายปานกลางร้อยละ 12.53 และเสียหายรุนแรงร้อยละ 5.55 และพื้นที่ที่ได้รับผลกระทบจากความขัดแย้งระหว่างประเทศรัสเซียและประเทศยูเครน ในเมืองมารีอูปอลคิดเป็นร้อยละ 43.15 ของพื้นที่เมืองทั้งหมด แบ่งเป็น เสียหายเล็กน้อยร้อยละ 26.01 เสียหายปานกลางร้อยละ 12.20 และเสียหายรุนแรงร้อยละ 4.94

**สรุปผลการวิจัย** : พื้นที่ศึกษาทั้งสองแห่งได้รับผลกระทบจากภัยพิบัติในรูปแบบที่ต่างกัน พื้นที่ที่ได้รับผลกระทบจากแผ่นดินไหวในเมืองอันทักยาคิดเป็นพื้นที่ 8.82 ตารางกิโลเมตร จากพื้นที่ทั้งหมด 19.79 ตารางกิโลเมตร และพื้นที่ที่ได้รับผลกระทบจากความขัดแย้งในเมืองมารีอูโปลคิดเป็นพื้นที่ 41.11 ตารางกิโลเมตร จากพื้นที่ทั้งหมด 95.28 ตารางกิโลเมตร ทั้งนี้ วิธีการตรวจจับการเปลี่ยนแปลงค่าโคฮีเรนซ์ร่วมกับภาพถ่ายดาวเทียมเซนทิเนล-1 สามารถประเมินความเสียหายของพื้นที่เมืองในได้อย่างรวดเร็ว โดยเป็นวิธีที่เหมาะสำหรับการตรวจจับการเปลี่ยนแปลงในพื้นที่เมืองแต่ไม่เหมาะกับการประยุกต์ใช้ในพื้นที่ที่มีพืชพรรณปกคลุม

**คำสำคัญ** : การตรวจจับการเปลี่ยนแปลงค่าโคฮีเรนซ์ ; การประเมินความเสียหายของเมือง ; แผ่นดินไหว ; ความขัดแย้งระหว่างรัสเซียและยูเครน

## Abstract

**Background and Objectives** : Disasters cause serious economic and human losses. Therefore, damage assessment is needed to support post-disaster management, humanitarian assistance, and disaster relief. This research focuses on applying the coherence change detection technique with Sentinel-1 data for damage assessment of urban areas affected by a natural disaster and a human-caused disaster including Antakya, the capital of Hatay Province, the southernmost province of Turkey affected form the earthquake on 6 February 2023 and Mariupol, a city in the south-eastern Ukraine affected by the conflict between Russian and Ukraine since 24 February 2022 until the city was fully controlled by Russia in late May 2022.

**Methodology** : Sentinel-1 images acquired in a three-month period before each event in each study area were used to generate an average pre-event coherence image. Then, the first image after the earthquake in Antakya and 9 images acquired after the beginning of the event in Mariupol were used to generate post event coherence images. Each post event coherence image was paired with the average pre-event coherence image using a log ratio to find the intensity of coherence changes of the urban area in each study area.

**Main Results** : The coherence of Antakya dramatically reduced all over the city after the event. In Mariupol, there were gradually changes in the beginning of the invasion, then a lot of changes occurred in middle March to middle

May 2022 and the most intense changes happened in the city centre and the Azovstal industrial site. However, there also were widespread changes all over the urban areas. The results showed that the urban area of Antakya affected by the earthquake is 44.58% including little change at 26.50%, moderate change at 12.53%, and severe change at 5.55%. In Mariupol, the urban area affected by the conflict between Russia and Ukraine is 43.15 % including little change at 26.01%, moderate change at 12.20%, and severe change at 4.94%.

**Conclusions** : Both study areas were affected by different kinds of disasters in different ways. The total area affected by the earthquake in Antakya is 8.82 square kilometres from a total area of 19.79 square kilometres and the total area of 41.11 square kilometres from a total area of 95.28 square kilometres is affected by the conflict in Mariupol. The coherence change detection technique with Sentinel-1 Imagery is a useful method in applying for damage assessment that can be used immediately during the early and critical state of disasters. It is suitable to identify changes in urban areas but not suitable to apply in areas that covered with vegetation.

**Keywords** : coherence change detection ; urban damage assessment ; earthquake ; Russia–Ukraine conflict

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## Introduction

Remote sensing plays an important role in supporting fast disaster response to both natural and anthropogenic disasters due to its abilities of rapid data acquisition during and after a disaster which is essential for disaster management, damage assessment, and recovery planning. There are two main types of remote sensing technologies including the optical sensor and the synthetic aperture radar (SAR) which can be applied to determine locations and severity of damage after a disaster. The optical sensor is a passive sensor which can deliver optical images that are easy to interpret visually. However, the optical sensor needs sun illumination for imaging, and cannot penetrate clouds, which severely limits its application as an emergency tool. Although, SAR data is relatively difficult to interpret, and can be easily influenced by speckle noises, it can operate both at day and night in any weather conditions, owing to the active characteristics of SAR and the long wavelength of the applied microwaves Therefore, SAR is considered to be more flexible and reliable for damage assessment at an early time following a disaster (Ge *et al*., 2020).

Many studies have compared the performance of SAR and optical sensors in urban change detection and damage assessment. Aimaiti *et al.* (2022) assessed the performance of Sentinel-1 and Sentinel-2 data for building damage assessment in Kyiv, the capital city of Ukraine, due to the ongoing war with Russia. They found that optical and SAR imagery have their own advantages with respect to damage recognition capabilities and outputs. Their comparison results showed that the SAR intensity-based analysis showed small to large scale damaged buildings, while optical texture-based analysis mainly showed the large-scale damaged buildings. Their comparison also showed that roof colour can influence the accuracy of the optical texture-based analysis, while both white and dark roof damaged buildings were identified by the SAR intensity analysis. While Putri *et al.* (2022) found that the best result of building damage assessment produced by the combination of Sentinel-1 and Sentinel-2 data, they also found that the performance of optical data from Sentinel-2 was better than SAR data from Sentinel-1 in classifying building damage of the earthquake in Lombok Island of Indonesia in 2018.

Coherence change detection (CCD) is a technique that detects differences between pairs of SAR images. In this process, the estimated coherence between a pair of complex SAR images is calculated. Commonly, if the estimated coherence is high there is no change whereas low estimated coherence provides an indication of change (Damini *et al*., 2013). The coherence image presents the confidence level of each pixel in the phase difference image. Coherence refers to a fixed relationship between waves in a beam of electromagnetic radiation. In SAR interferometry, coherence is used to describe systems that preserve the phase of the received signal. Coherence value can be estimated by means of the local coherence of an interferometric SAR image pair. The local coherence estimator is the complex cross-correlation coefficient of the couple estimated on a given window size, using Equation (1):

$$\gamma = \left| \frac{\frac{1}{N}\sum_{i=0}^{N} M_i S_i^*}{\sqrt{\frac{1}{N}\sum_{i=0}^{N} M_i M_i^* \frac{1}{N}\sum_{i=0}^{N} S_i S_i^*}} \right| \qquad (1)$$

where N is the number of neighbouring pixels to be estimated, M and S are the complex signal of the master and slave images, respectively and * denotes the complex conjugate. $\gamma$ is the resulting coherence (Washaya & Balz, 2018; Washaya *et al*., 2018). The coherence ranges from 0.0 (incoherent or total decorrelation, the interferometric phase is pure noise) to 1.0 (coherent, phase correlation is preserved). As a statistical value, it cannot provide quantitative measurements of the ground scatterers disturbances. However, a physical interpretation is that it represents the fraction of power scattered by unchanged parts of the scene (Bouaraba *et al*., 2012). The coherence image serves as a measure of the quality of an interferogram and gives information about the surface type or shows when change has occurred in the image. Coherence imagery is able to detect centimetre scale changes in the scatterers distribution (Closson & Milisavljevic, 2017).

The CCD technique has been used and studied by many researchers. Washaya and Balz (2018) studied on the urban areas affected by disasters including earthquake and a hurricane using the coherence characteristics of SAR images. They applied the CCD technique using Sentinel-1 imagery and concluded that the CCD technique is a useful method in measuring urban change in areas that have been affected by disasters. However, although the CCD technique can detect small changes, it is not a good indicator of the intensity of change. Furthermore, the technique is not very useful in vegetated areas, which are constantly unstable and can only be used in urban built-up areas. Moreover, Boloorani *et al.* (2021) studied to identify urban areas damaged or destroyed by war in the city of Mosul in Iraq. Their study showed that Sentinel-1 data with CCD can be generally used to detect war-induced damage and can be used as a robust tool to provide reliable information for decision-makers to plan post-war reconstruction programs or other disaster control procedures.

The CCD technique is not a new remote sensing technique and has been successfully applied in evaluating building damage. However, this approach has been used in a small number of studies, especially in the case of armed conflicts. Therefore, this study focuses on applying the CCD technique with Sentinel-1 imagery which is large-scale global data with very short revisit times and rapid product delivery. These advantages are crucial in disaster areas where timely availability of data is a requirement. We aim to detect destruction of urban areas caused by natural disasters and anthropogenic disasters which recently occurred in these few years. For a natural disaster, Antakya, the capital city of Hatay province, the southernmost province of Turkey was selected to be the study area which was one of the most affected provinces by the Turkey earthquake in February 2023 (Gunasekera *et al*., 2023). For a human-made disaster, the study area is the city of Mariupol in the south-eastern Ukraine. This city was affected by the conflict between Russian and Ukraine since Russia launched a military offensive in Ukraine on 24 February 2022.

## Methods

*1. Study Areas*

The first study area is Antakya, the capital city of Hatay province, the southernmost province of Turkey. It lies near the mouth of the Orontes River, about 19 kilometres northwest of the Syrian border. This city was built around 300 BC by a general of Alexander the Great, has survived several previous calamitous earthquakes. On 6 February 2023, the city was heavily damaged by two powerful earthquakes with their epicentre in Kahramanmaras. About 3,100 buildings collapsed, trapping residents, and killing more than 20,000 people in the city. The damage was so profound that officials estimated that 80% of the city's remaining buildings needed to be demolished. The area of interest is urban areas in Antakya which has a total area of 19.79 square kilometres as shown in Figure 1.

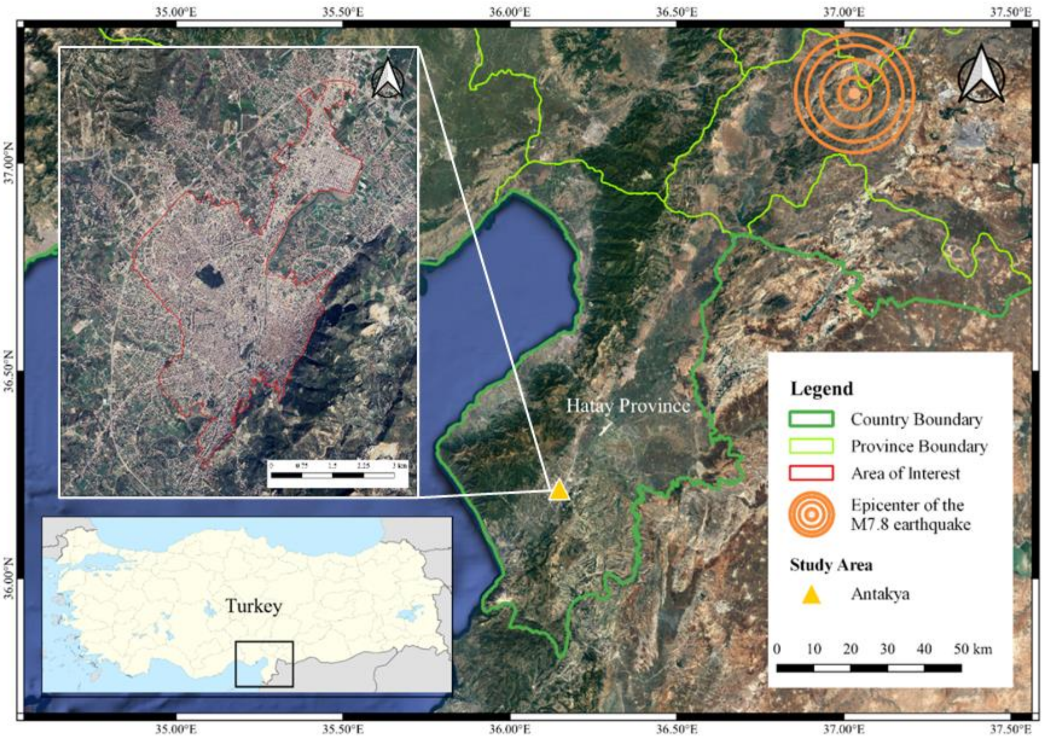


*Figure 1* Area of interest in Antakya, Hatay Province, Turkey

The second study area is Mariupol, a port city on the north coast of the Sea of Azov. It is located in Mariupol Raion (district) of Donetsk Oblast in the south-eastern Ukraine. Mariupol played a key role in the industrialization of Ukraine, and was a centre for the grain trade, metallurgy, and heavy engineering. Following the invasion started on 24 February 2022, Mariupol was bombarded, and many buildings and infrastructure were destroyed or damaged. On 21 May 2022, Russia's defence ministry announced that it had full control of Mariupol. United Nations Humans Rights assessed that up to 90 per cent of residential buildings were damaged or destroyed, as well as up to 60 percent of private houses. An estimated 350,000 people were forced to leave the city. The area of interest is urban areas in Mariupol which has a total area of 95.28 square kilometres as shown in Figure 2.

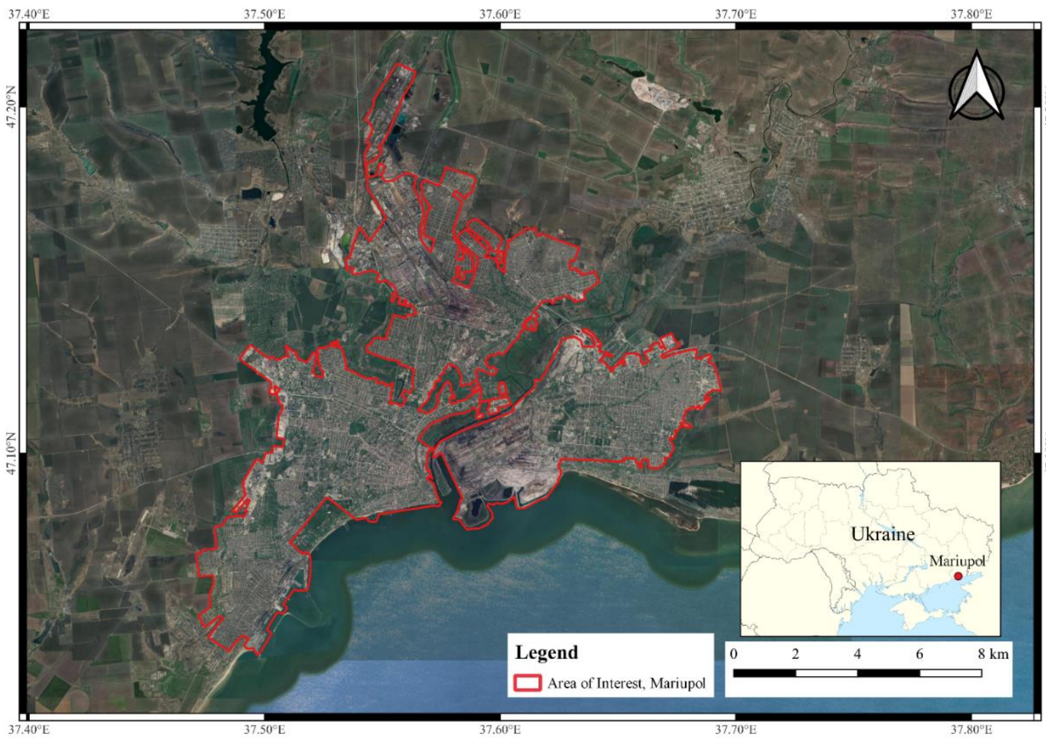


***Figure 2*** Area of interest in Mariupol, Donetsk Oblast, Ukraine

## <u>2. Datasets</u>

Interferometric Wide swath (IW) SAR images acquired by Sentinel-1A satellite were used to analyse changes and damage in urban areas of each study areas. These images are Level-1 Single Look Complex (SLC) with 250 kilometres swath and 5 metres x 20 metres spatial resolution. Images acquired in a three-month period before the event were used to generate an average pre-event coherence image for each study area. For the earthquake in Turkey, the first image after the earthquake were used as a post event image. For Ukraine, the conflict in Mariupol occurred over a three-month period, therefore, we used 9 images acquired after the beginning of the event to be post event images. Each post event image was paired with the average pre-event coherence image to detect changes of the urban area throughout that period. The list of images used in this study is shown in Table 1.

*Table 1* List of SAR images used in each study area

| Study area | Category | Date of acquisition | Details |
|---|---|---|---|
| Antakya, Turkey | Pre-event | 5, 17, 29 November 2022<br>11, 23 December 2022<br>4, 16, 28 January 2023 | Satellite: Sentinel-1A (C-band)<br>Polarisation: VV, Mode: IW<br>Pass direction: ascending<br>Relative orbit number: 14 |
| | Post event | 9 February 2023 | |
| Mariupol, Ukraine | Pre-event | 4, 16, 28 November 2021<br>10, 22 December 2021<br>3, 15, 27 January 2022<br>8, 20 February 2022 | Satellite: Sentinel-1A (C-band)<br>Polarisation: VV, Mode: IW<br>Pass direction: descending<br>Relative orbit number: 94 |
| | Post event | 4, 16, 28 March 2022<br>9, 21 April 2022<br>3, 15, 27 May 2022<br>8 June 2022 | |

*3. Workflow*

The basic idea is to identify the natural statistical behaviour of each pixel before the hazardous event and minimize the impact of atmospheric phase disturbances by using a stack of pre-event coherence images and generating a master coherence image before the event, a series of images can be analysed to get more reliable pre-event master coherence image. Then, compare the post-event behaviour of a pixel with its estimated natural behaviour from the pre-event master coherence image to determine whether there is a change.

A software named SNAP (Sentinel Application Platform) was used to process SAR images acquired by Sentinel-1A. We generated a coherence image using each consecutive image pair. The time interval of 2 images of each pair is 12 days due to a repeat cycle of Sentinel-1A. The coherence estimation was calculated based on a window of 10x3 pixels in range and azimuth direction. We used Range Doppler Terrain Correction to correct the geometry of the images. Then, pre-event coherence images of each study area were stacked in chronological order to generate an average pre-event coherence image to be the master coherence image and the representative coherence image for all pre-event coherence images.

To detect changes after an event, we used the log ratio which is the logarithm with base 10 or common logarithm. The log ratio of coherence value is calculated as Equation (2).

$$I_{ratio} = \log\left(\frac{I_{post}}{I_{pre}}\right) \quad (2)$$

Where $I_{post}$ is the post event coherence image and $I_{pre}$ is the average pre-event coherence image. The log ratio is an effect-size statistics, not a significance statistic. Therefore, the log ratio can represent how large the difference of coherence value between before and after the event. By taking the log-ratio, the distribution is more likely to behave like a normal distribution or Gaussian distribution and the value of log ratio are positive and negative. In this study, negative log ratio value indicates decreasing in coherence value and positive log ratio value indicates increasing in coherence value, while log ratio value of zero means no change. The workflow overview of this study is shown in Figure 3. From our experiments, a 50% reduction in coherence value results in around -0.30 of log ration value which is considered to be a change. Coherence reducing at 70% and 80% results in around -0.52 and -0.70, respectively. Therefore, we classified the log ratio value as severe change (<-0.7), moderate change (-0.7 to -0.5), little change (-0.5 to -0.3), and no change (>-0.3).

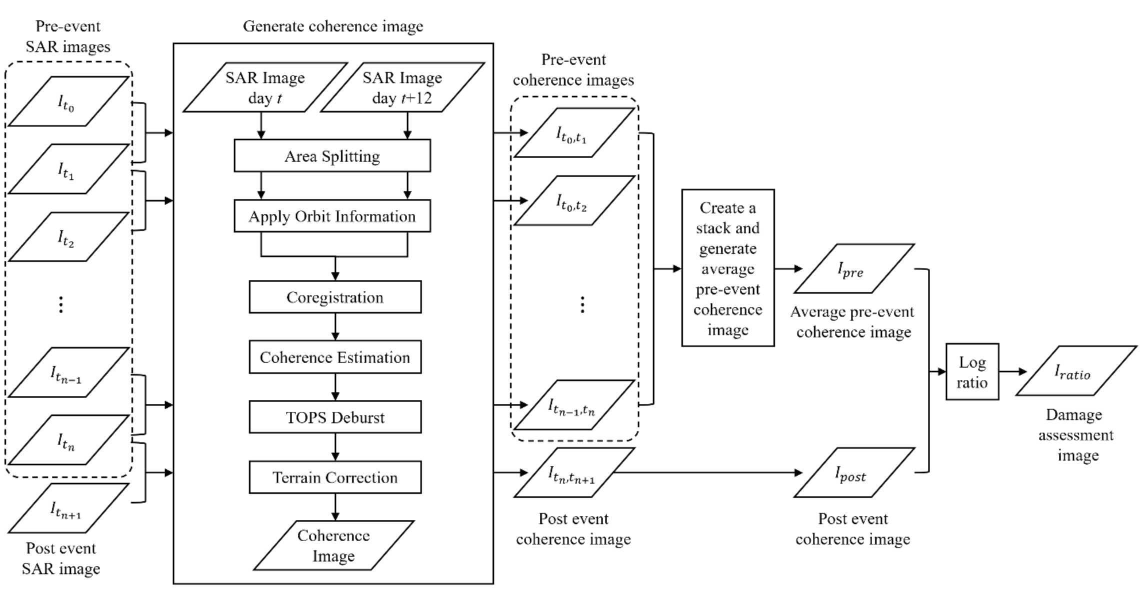


*Figure 3* The workflow overview of the study.

**Results**

*1. Damage Assessment of Antakya, Turkey*

In the coherence images, high coherence value is displayed in blue while low coherence is displayed in white. The results of Antakya show that the coherence value reduced dramatically all over the area of interest after the earthquake. The average pre-event coherence image has coherence value more than 0.5 in most of the area of interest. There are obvious changes in the post event coherence image which the coherence value dramatically decreases to be less than 0.5 in most of the area of interest. The vegetation area in the centre of the city has low coherence in both pre- and post-disaster images same as the Orontes River that runs through the city. The log ratio images also show widespread damage all over the area of interest. In the log ratio image, the log ratio value classified as little change is displayed in yellow, moderate change displayed in orange, and severe change display in red as showed in Figure 4. We calculated the number of pixels by ranges of log ratio value and got the results that 44.58% of the area of interest is affected by the earthquake which are little change at 26.50%, moderate change at 12.53%, and severe change at 5.55%.

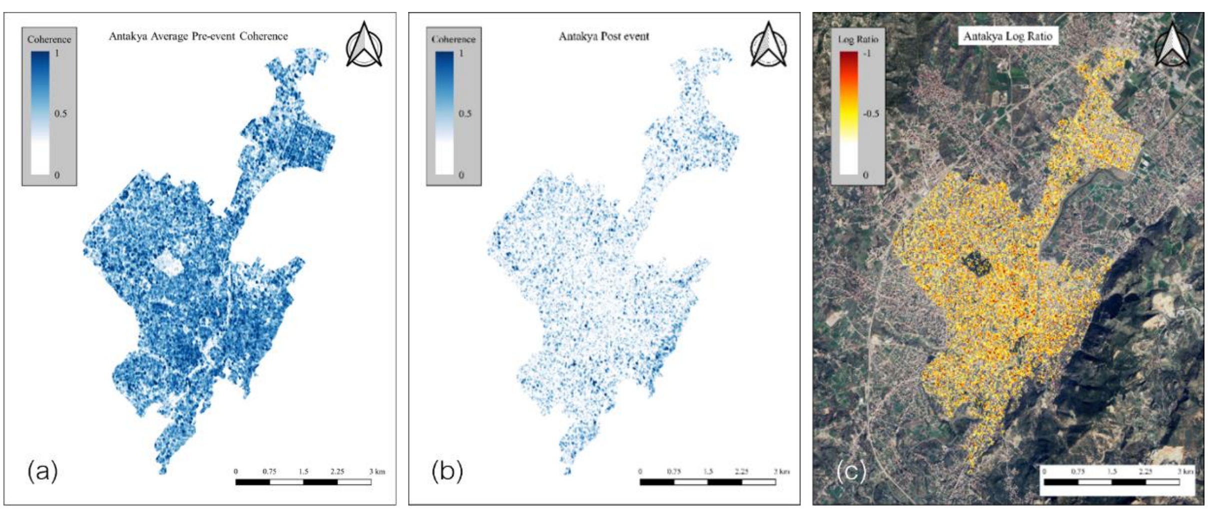


***Figure 4*** The area of interest of Antakya (a) average pre-event coherence (b) post event coherence (c) log ratio

*2. Damage Assessment of Mariupol, Ukraine*

The results of Mariupol show that there was no change in the first two weeks of the invasion as the coherence value of this period shows higher than the average pre-event coherence image shown in Figure 5. The results of 4 and 16 March show changes as clusters, mostly in the western part of the city, some on the eastern edge of the area of interest, and near the area of Azovstal industrial site located on the coastal area in middle part of the city. From middle March to early April, the changes appeared mostly in the middle of the city. Then, from early April to middle May, the log ratio images also show that there were significant changes in the area of Azovstal industrial site. After late May, there was no large cluster of change in the city. It appeared to be small points of changes widespread across the city, yet there was high coherence value in the area of Azovstal industrial site more than other parts of the city. The post event coherence images and the log ratio images are visualised in Figure 6 and Figure 7, respectively.

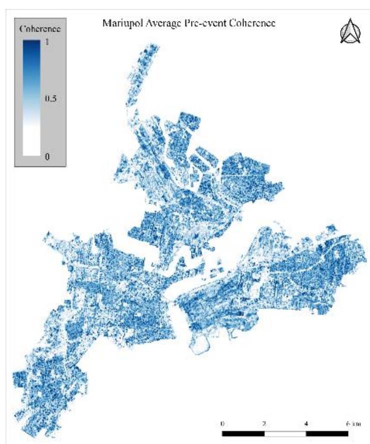


***Figure 5*** Average pre-event coherence image of the area of interest of Mariupol

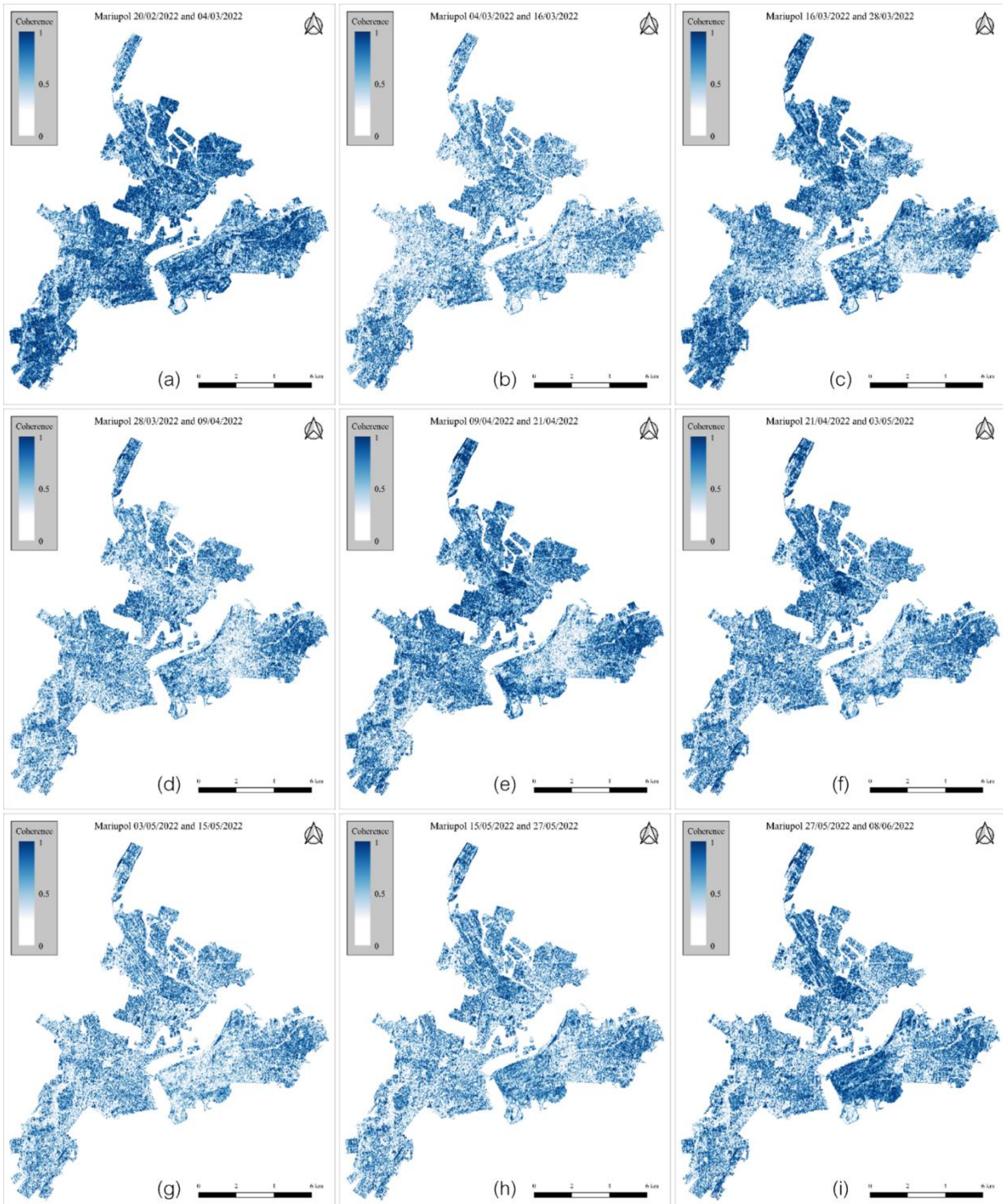


***Figure 6*** Post event coherence images (a) 20/02/22 and 04/03/22 (b) 04/03/22 and 16/03/22 (c) 16/03/22 and 28/03/22 (d) 28/03/22 and 09/04/22 (e) 09/04/22 and 21/04/22 (f) 21/04/22 and 03/05/22 (g) 03/05/22 and 15/05/22 (h) 15/05/22 and 27/05/22 (i) 27/05/22 and 08/06/22

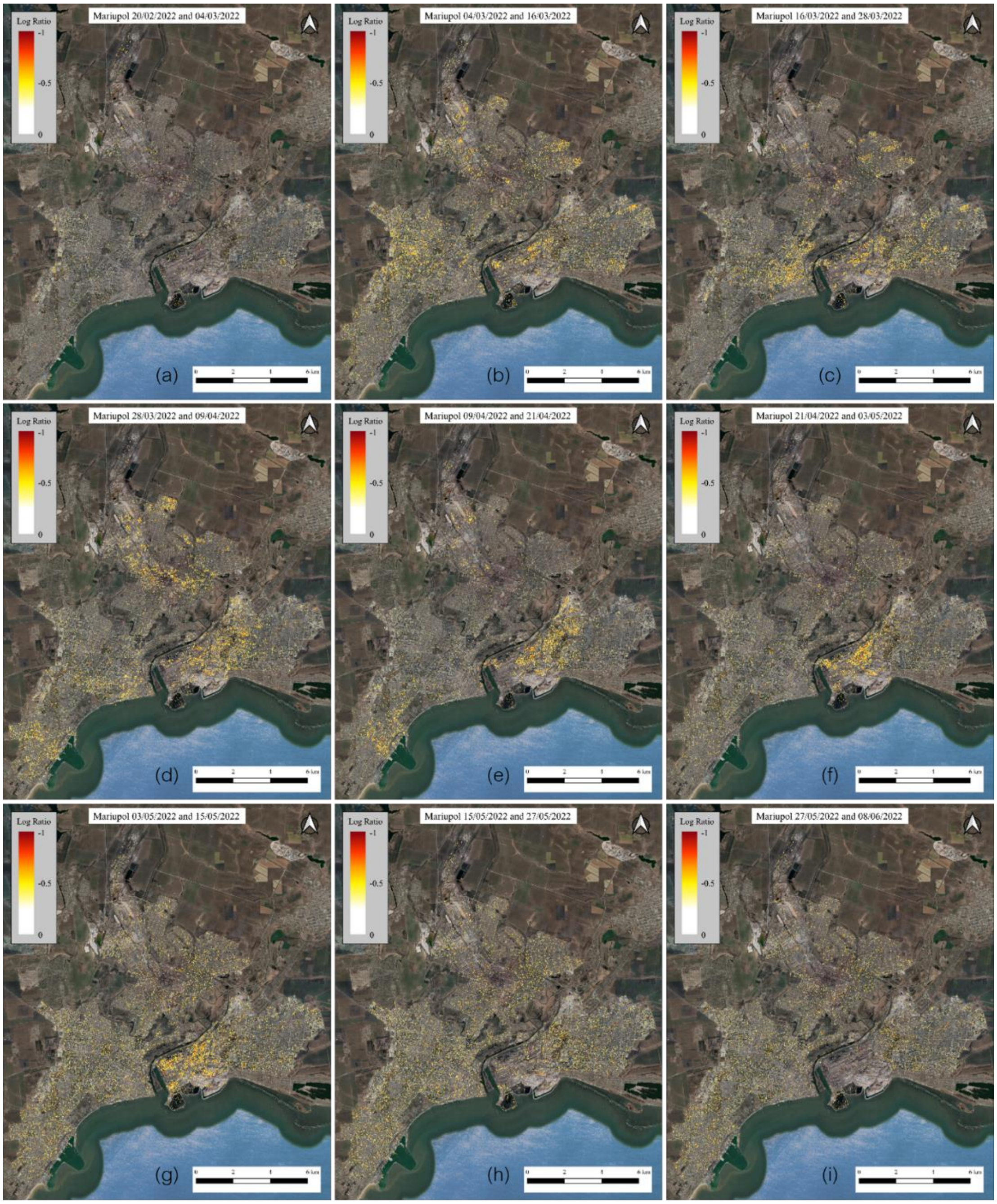


*Figure 7* Log ratio images (a) 20/02/22 and 04/03/22 (b) 04/03/22 and 16/03/22 (c) 16/03/22 and 28/03/22 (d) 28/03/22 and 09/04/22 (e) 09/04/22 and 21/04/22 (f) 21/04/22 and 03/05/22 (g) 03/05/22 and 15/05/22 (h) 15/05/22 and 27/05/22 (i) 27/05/22 and 08/06/22

We calculated and classified the log ratio value of each log ratio image as shown in Table 2. Then, we combined the log ratio data from 9 log ratio images to estimate changes from the beginning of the invasion until 8 June 2022, we found that 43.15% of the area of interest were affected which includes little change at 26.01%, moderate change at 12.20%, and severe change at 4.94%.

*Table 2* Percentage of log ratio value of Mariupol by levels of changes

| Post event period | Severe change | Moderate change | Little change | No change |
|---|---|---|---|---|
| 20 Feb and 4 Mar 2022 | 0.14% | 0.46% | 1.61% | 97.79% |
| 4 and 16 Mar 2022 | 0.76% | 2.28% | 7.01% | 89.95% |
| 16 and 28 Mar 2022 | 0.61% | 1.61% | 4.67% | 93.11% |
| 28 Mar and 9 Apr 2022 | 0.82% | 2.27% | 6.57% | 90.34% |
| 9 and 21 Apr 2022 | 0.49% | 1.33% | 3.97% | 94.21% |
| 21 Apr and 3 May 2022 | 0.46% | 1.34% | 4.24% | 93.96% |
| 3 and 15 May 2022 | 0.88% | 2.51% | 7.73% | 88.88% |
| 15 and 27 May 2022 | 0.66% | 2.04% | 6.74% | 90.56% |
| 27 May and 8 Jun 2022 | 0.43% | 1.46% | 4.99% | 93.12% |

At the beginning of invasion, there was almost no change appeared in the results as the media reported that on the first few days, the fighting was limited to the outskirts of the city. Then, changes appeared to be more intense in middle March as the Russian forces entered the city centre with heavy fighting. From early April to middle May, the heavy fighting focused on the Azovstal industrial site as thousands of Ukrainian fighters uses the plant and its sprawling network of underground tunnels as the final shelter which corresponds to the log ratio results. The fighting continued until the Ukrainian fighters surrendered and Russia claimed to take full control of the Azovstal steel plant on 20 May. Then, there was no large cluster of change in the city and the area of Azovstal industrial site appeared high coherence value more than other parts of the city.

*3. Result Comparison*

To compare our results, we used pre-event images and post event images from Google Earth in selected locations for each study area to compare with the log ratio images. In Antakya, we can obviously see in the Google Earth image that many buildings were totally collapsed, and log ratio images show severe changes in the areas of those buildings as shown in Figure 8(a). In Figure 8(b), severe changes occurred in the large area near the centre of the image which large collapsed buildings can be seen in the Google Earth image.

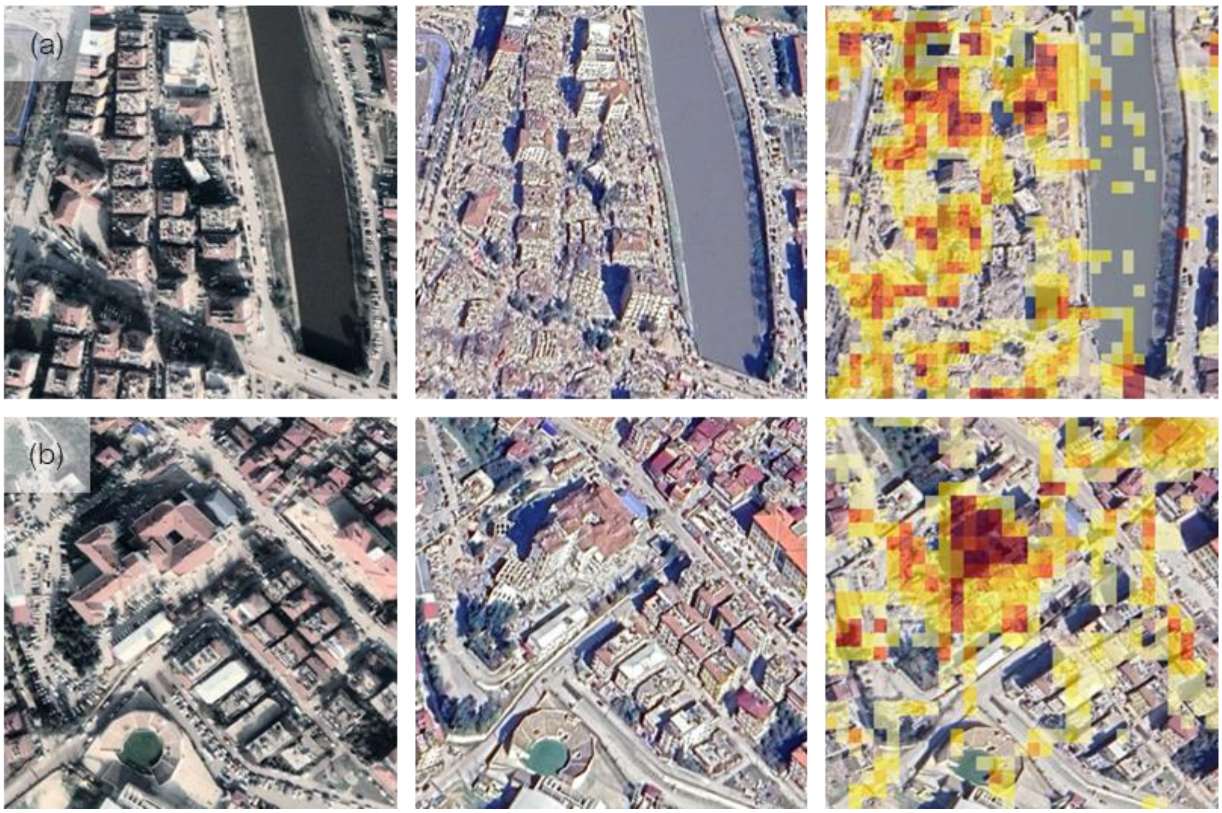


*Figure 8* Comparison of the results of Antakya. The locations (a–b) were selected as representative areas for comparison. The columns from left to right indicate the Google Earth images of 22 December 2022, 9 February 2023, and 15 February 2023 with log ratio image overlay.


*Figure 9* Comparison of the results of Mariupol. The locations (a–b) were selected as representative areas for comparison. The columns from left to right indicate the Google Earth images of 21 June 2021, 29 March 2022, and 29 March 2022 with log ratio image overlay

Figure 9(a) shows a residential area that was affected by armed fighting. Most of the buildings in the severe change area in the log ratio image were totally destroyed and can be seen in the Google Earth image. Figure 9(b) shows an industrial area which many large buildings were located. Most of the buildings in this area had damaged roofs, especially the largest building in the centre of the image. The result of log ratio shows in the same way that there were a cluster of changes in the centre of the image.

## Discussion

This study presented the potential use of Sentinel-1 images with the coherence change detection technique for damage assessment in two situations of disasters including the earthquake in Turkey which occurred in 2023 and the invasion of Russia in Ukraine in 2022. we focused on the decreasing of coherence to monitor changes and destruction of the urban areas. The results in the experiments showed significant loss of coherence after the earthquake all over the area of Antakya. According to Bogazici University researchers, Antakya experienced more severe ground motion than other cities (Şeşetyan *et al.*, 2023). In Mariupol, there was decreasing of coherence in different parts of the city and different periods of time. However, the percentage of damage calculated from log ratio images seems to be lower than the reports from media since we calculated all pixels in each area of interest. These areas of interest include not only buildings but also parks, gardens, vegetation, water bodies, and bare lands. There were studies that integrated the coherence images to street blocks and land use classification which can be used to analyse affected coherence in the different land use. In this way, it is more appropriate in an urban set-up as street blocks are relate to objects in the real world (Washaya *et al.*, 2018).

As seen from the results, there are damages detected by the CCD technique in some areas that could not be seen by looking at Google Earth images. Those could be small changes since the CCD technique is able to detect even small changes. On the other hand, those changes could be affected by a variety of factors which caused coherence loss. Moreover, coherence is also suffering from speckling, which requires the combination of several pixels to get reliable results (Balz *et al.*, 2018). It should be noted that the approach of this study provides only a rough qualitative assessment of the damage status of urban areas. It is essential to find methods to improve detection and assessment of the intensity of damage.

Due to the lack of ground-truth data, it is difficult validate the accuracy of the results. Expanding the research to include more case studies from various urban and rural environments can significantly enhance the applicability and reliability of the method. Furthermore, Sentinel-1 data processing is time-consuming and user-intensive, which limits the CCD technique's application.

Urban areas naturally have high coherence over a long period, instant changes of coherence can indicate changes on that area. On the other hand, coherence is uncertain in non-urban areas which often show rapid coherence dropping in a short period as shown in the results that in the coherence image, vegetation appeared to be poor coherence while buildings have very high coherence. Many researchers used changes in SAR backscattering intensity and coherence for building damage assessment. The CCD technique makes use of the similarity or difference of the phase properties of SAR images in order to detect changes after a disaster (Washaya *et al.*, 2018). It is suitable to identify changes in urban areas. The coherence information is also more sensitive to minor ground changes than intensity information, so the CCD technique is useful to identify even small changes (Ge *et al.*, 2020). However, it is generally acknowledged that speckle effects, and single-pixel damage classification from the medium resolution SAR image can lead to ineffective results while the damage assessment at a block level can achieve effective results (Dell'Acqua & Gamba, 2012; Aimaiti *et al.*, 2022). Moreover, using high-resolution SAR images such as TerraSAR-X and COSMO-SkyMed accurate single-building scale damage mapping can achieve detailed single-building scale damage mapping while medium resolution SAR images like Sentinel-1 can detect damage of large buildings.

## Conclusions

In this study, we introduced the concept of using the coherence change detection technique (CCD) with Sentinel-1 images and we focused on the urban areas of Antakya which damaged from the earthquake. We also focused on damage of the urban of Mariupol occurred by war. For each study area, we used SAR images of three months before an event to generate an average pre-event coherence image as a master image to compare with one image after the event. In case of Mariupol, we used several post event images to compare with an average pre-event coherence image. Since the event lasted for three months, we used 9 post event coherence images to find changes of coherence in the period of each post coherence image. We applied a log ratio to find the intensity of coherence changes after an event occurred in each study area.

Both study areas were affected by different kinds of disasters which caused damage in different ways. A natural disaster like major earthquake occurs in a short period of time but it can cause widespread damage and destruction of buildings, roads, bridges, and other infrastructure unlike an anthropogenic disaster like war which may take a long period of time. This can result in a significant loss of life, infrastructure, and economy much more than a natural disaster.

The study showed that the pre-event coherence value of the area of interest of Antakya was high then turned to low after the earthquake in all over the city. The area of interest of Antakya can be classified as little change (log ratio -0.5 to -0.3) at 26.50% (5.24 square kilometres), moderate change (log ratio -0.7 to -0.5) at 12.53% (2.49 square kilometres), and severe change (log ratio <-0.7) at 5.55% (1.09 square kilometres). All changes in the area of interest are 44.58% which is a total area of 8.82 square kilometres.

In the city of Mariupol, the study showed loss of coherence in areas that were affected by war in each period. There were gradually changes in the beginning of the invasion, then a lot of changes occurred in middle March to middle May 2022 and the most intense changes happened in the city centre and the Azovstal industrial site. However, there also were widespread changes all over the urban areas. The total area that affected by the conflict is 43.15% which is a total area of 41.11 square kilometres including little change (log ratio -0.5 to -0.3) at

26.01% (24.78 square kilometres), moderate change (log ratio -0.7 to -0.5) at 12.20% (11.62 square kilometres), and severe change (log ratio <-0.7) at 4.94% (4.71 square kilometres).

The CCD technique is a useful method in applying to measure changes in urban areas affected by disasters like earthquakes and wars. However, the CCD technique is not suitable to apply in areas that covered with vegetation. Moreover, the global accessibility of Sentinel-1 data is useful to monitor any kind of disasters.

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