

# INTEGRATING INSAR COHERENCE AND BACKSCATTERING FOR IDENTIFICATION OF TEMPORARY SURFACE WATER, CASE STUDY: SOUTH KALIMANTAN FLOODING, INDONESIA

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**KEY WORDS:** Temporary Surface Water, Flood, Sentinel-1, InSAR Coherence, SAR Backscattering

### ABSTRACT:

Accurate and reliable information about the spatiotemporal level of surface water can be provided by Temporary Surface Water (TSW) monitoring. TSW is defined as a waterbody experiencing frequent drying phases which also correspond to surfaces frequently affected by flooding. In Indonesia, flooding is a frequent disaster, which is about 30% of the total number of disasters that occurred. In mid-January 2021, South Kalimantan Province, Indonesia was hit by a flood. The loss impact of this disaster is estimated at Rp. 1.349 trillion. Synthetic Aperture Radar (SAR), one type of remote sensing, can be used to map the spatial distribution of flood inundation. SAR has the advantage of not being constrained by day or night, weather conditions, and cloud cover or fog. Nowadays, the availability of Sentinel-1 SAR images can increase the use of SAR imagery for flood mapping. Specular reflections that occur on the smooth water surface produce a darker color in the SAR backscattering data, which makes floodwater distinguishable on dry land surfaces. However, inundation between buildings can cause changes in the backscattering value. Several studies have shown that the Interferometric SAR coherence method is a good method for mapping floods in urban areas. The main goal of this study is thus to map Temporary Surface Water (flood) of the South Kalimantan flood event in Indonesia using Sentinel-1 SAR imagery. With backscattering data, flood in a non-urban area can be mapped, but it is difficult to map flood in an urban area. Therefore, we will try to integrate InSAR coherence and SAR backscattering data in order to map flood in the whole study area. The result shows that using backscattering data, bare soil or non-urban flood inundation in the whole study area can be mapped with an overall accuracy of about 76.4%. Yet, flood in an urban area cannot be mapped only with backscattering data. The result from coherence imagery can map flood inundation in an urban area. Thus, integration from both of them can map flood inundation in the whole study area, either urban or non-urban.

## 1. INTRODUCTION

Accurate and reliable information about the spatiotemporal level of surface water can be provided by Temporary Surface Water (TSW) monitoring. TSW is defined as a waterbody experiencing frequent drying phases, for example in the form of small ponds and wetlands. It can also correspond to surfaces frequently affected by flooding, thus causing hazards to humans, settlements, and infrastructures (Feyisa et al., 2014). Therefore, TSW information is very important for various environmental applications, such as flood monitoring.

In Indonesia, flooding is a frequent disaster, which is about 30% of the total number of disasters that occurred. This hazard has become a recurring disaster that takes place every year (Sulaeman and Suhartanto, 2017). Floods are widespread and dramatic natural disasters which affect the lives, infrastructure, economies, and local ecosystems of the world (Willner et al, 2018). A flood is an event or condition where an area or surface is submerged due to an increased volume of water.

In mid-January 2021, South Kalimantan Province, Indonesia was hit by a flood. Several areas in South Kalimantan were affected, including Tapin Regency, Banjar Regency, Banjar Baru City, Tanah Laut City, Banjarmasin City, Hulu Sungai Tengah Regency, Balangan Regency, Tabalong Regency, Hulu Sungai Selatan Regency, and Batola Regency. This flood is caused by the high intensity of rain. In addition, the Ministry of Environment and Forestry noted a change in land cover from dry

forest to plantations. Besides, there are also mining activities that took place from 1990 to 2019 which can be the factors for flooding. The floods in South Kalimantan in January 2021 are believed to be the worst in 50 years. The loss impact of this disaster is estimated at Rp. 1.349 trillion.

Remote sensing technology is very effective in determining Temporary Surface Water over large areas and can be used in mapping flood areas with an adequate temporal and spatial resolution (Moothedan et al, 2020). Synthetic Aperture Radar (SAR), one type of remote sensing, can be used to map the spatial distribution of flood inundation. SAR has the advantage of not being constrained by day or night, weather conditions, cloud cover, or fog which can eliminate important information from objects behind the closed area (Utomo et al, 2020). Nowadays, the availability of Sentinel-1 SAR images, with high spatial and temporal resolution and can be accessed freely, can increase the use of SAR imagery for flood mapping.

Specular reflections that occur on the smooth water surface produce a darker color in the SAR backscattering data, which makes floodwater distinguishable on dry land surfaces. However, the backscattering data does not have high accuracy in highlighting the presence of water. This is due to complex backscattering related to various types and heights of buildings, vegetation areas, and roads with different topography (Chini et al, 2019). Inundation between buildings can cause changes in the backscattering value. Several studies have shown that the InSAR

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coherence or Interferometric SAR coherence method is a good method for mapping floods in urban areas (Pulvirenti, 2016).

The main goal of this study is thus to map Temporary Surface Water (flood) of the South Kalimantan flood event in Indonesia using Sentinel-1 SAR imagery. The geography of the case study consists of urban and non-urban areas. With backscattering data, flood in a non-urban area can be mapped, but it is difficult to map flood in an urban area. Therefore, we will try to integrate InSAR coherence and SAR backscattering data in order to map flood in the whole study area. We will focus more on an urban area, since it is difficult to map flood there. The results from this research are hoped to be encouraging for rapid and accurate flood mapping and the first step for disaster management.

## 2. METHODOLOGY

### 2.1 Data and Study Area

In this paper, study area is focused on the South Kalimantan Province, Indonesia, especially in Banjarmasin City which is an urban area (Figure 1).

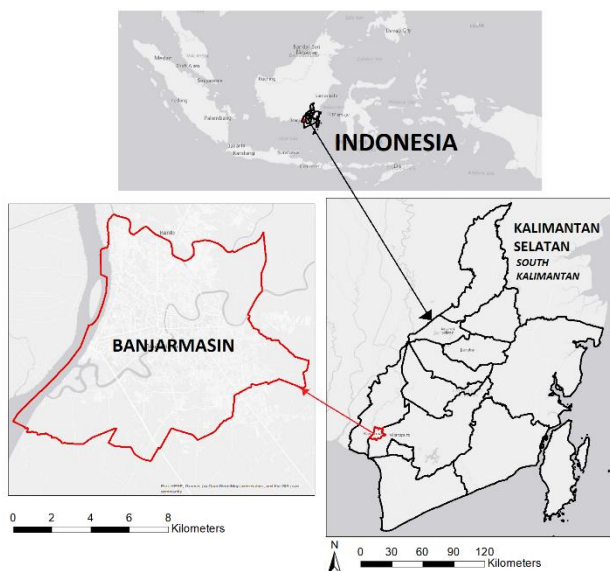


Figure 1. Study Area.

Sentinel-1 SAR IW GRD (Ground Range Detected) and Sentinel-1 IW SLC (Single Look Complex) are collected from the European Space Agency (ESA) Sentinels Scientific Data Hub. Sentinel-1 GRD is used as backscattering information. Meanwhile, Sentinel-1 SLC is used to produce InSAR coherence information. Even though backscattering information can also be extracted using Sentinel-1 SLC data, we directly use Sentinel-1 GRD in order to reduce the processing stage.

For the InSAR coherence process, three image dates of Sentinel-1 SLC data are used. Two image dates before the flood (15/12/2020 and 27/12/2020) and one image date during the flood event (20/01/2021). Images taken before the event are used to build the pre-event coherence image, while the co-event coherence image is built with one before and one during the flood event. As for backscattering information, only one image before the flood (17/08/2020) and one image during the flood event (20/01/2021) are used. In this study, images with different dates for the pre-event are used. This is because, for the coherence process, near dates are needed to avoid a high systematic phase

variation contributed by topographic, atmospheric, or deformation effects and to reduce sources of decorrelation e.g., baseline or geometric decorrelation, doppler centroid decorrelation, volume decorrelation, and thermal or system noise (Hanssen, R., 2001). Meanwhile, in the backscattering process, the date during the dry season is used for the pre-event, thus the TSW area can be completely extracted.

Several additional datasets, e.g., The JRC Global Surface Water dataset and a digital elevation model (WWF HydroSHEDS), are used to eliminate false positives within the flood extent layer produced from Sentinel-1 GRD. To assess our results, a reference map is available through Development Planning Agency at the Sub-National Level, South Kalimantan Province in the form of South Kalimantan Flood Distribution Vector Data.

### 2.2 Method

In this study, VH polarization of Sentinel-1 IW GRD is used. Pre-processing is carried out in order to reduce speckle noise, and geometric distortion. The process consists of some stages such as thermal noise removal, radiometric calibration, speckle filtering and terrain correction (United Nations, 2022). Thermal Noise Removal is performed to reduce the noise effect in the texture between sub-plots. Thus, to normalize the backscattering signal in all Sentinel-1 scenes. To transform raw amplitude images to calibrated products for the quantitative use of SAR images, radiometric calibration is carried out. Among available calibrated products sigma-nought is selected since it provides a better separation between water and land surfaces. In order to reduce speckle noise, speckle filtering with a Lee filter and window size of  $7 \times 7$  is used. Subsequently, Range Doppler Terrain Correction is applied to geocode the images (Bioresita et. al., 2018).

In the interest of detect flood inundation, change detection approach is carried out after pre-processing. In this step, the sigma-nought image during flood is divided by the before-flood sigma-nought image, resulting in a raster layer showing the degree of change per pixel. High values (bright pixels) indicate high change, low values (dark pixels) point toward little change (United Nations, 2022). The predefined threshold of 1.1 is applied assigning 1 to all values greater than 1.1 and 0 to all values less than 1.1 (Bioresita et. al., 2021). The binary raster layer created by this process shows the potential flood extent.

In order to eliminate false positives within the flood extent layer, several additional steps were taken, e.g., exclude Permanent Water, exclude area with 5% slope, and exclude pixel with  $< 8$  neighbors. The JRC Global Surface Water dataset is used to mask out all areas covered by Permanent Surface Water. A digital elevation model (WWF HydroSHEDS) has been chosen to remove areas with over 5% slope. Then, the connectivity of the flood pixels is assessed to eliminate those connected to eight or fewer neighbors. The noise of the flood extent product can be reduced through this operation (United Nations, 2022).

Sentinel-1 IW GRD only consists of amplitude or backscatter information. In order to create coherence image, amplitude and phase information are needed. Thus, Sentinel-1 SLC is used. The InSAR coherence process in here is carried out only for Banjarmasin City as urban area in order to focused in detecting urban flood area. Coherence imagery is the result from InSAR coherence process. In order to create one coherence image, a pair of two Sentinel-1 SLC images must be used. The first step which must be done is coregistration. This step has the aim of aligning both products at sub-pixel accuracy by using image statistics. Coregistration consists of apply orbit file and back-geocoding.

Apply orbit file can considerably improve the geolocation accuracy. Back Geocoding coregisters the two products based on the orbit information and information from a digital elevation model (DEM) (Braun and Veci, 2021).

Using SNAP platform, coherence estimation is included in the Interferogram Formation process. The coherence from reference and the secondary image is estimated as an indicator for the quality of the phase information. Basically, it shows if the images have strong similarities and are therefore usable for interferometric processing. Loss of coherence can produce poor interferometric results and is caused by temporal (over vegetation and water bodies), geometric (errors or inaccuracies in the orbit metadata) and volumetric decorrelation (potential scattering mechanisms of voluminous structures, such as complex vegetation or dry surfaces) (Braun and Veci, 2021). Based on those concepts, it can be said that low coherence value in some areas means there are many changes in the areas.

TOPSAR Deburst is applied to the coherence product in order to remove the seamlines between the single bursts. Then, TOPSAR Merge is carried out to merge the debursted split product of different sub-swaths into on complete product. To reduce the inherent speckled appearance, multibook is applied. Lastly, terrain correction will geocode the image by correcting SAR geometric distortions using a digital elevation model (DEM) and producing a map projected product (Braun and Veci, 2021).

Using three images of Sentinel-1 SLC, two pair data are used in InSAR coherence processing and resulted two coherence images, e.g., pre-event and co-event coherence image. The concept for this process is based on methods proposed by Chini et al., 2019 and Li et al., 2019. A preliminary analysis provides that coherence values less than equal to 0.3 indicates a change in the study area. Therefore, coherence values less than equal to 0.3 are extracted. We assumed those values in the pre-event coherence image mean there are no change due to the flood. Whereas, those values in the co-event coherence image will include a change due to the flood. Therefore, in order to get only the change due to the

flood, we subtract the pre-event from the co-event. Those areas are then labelled as flood inundation areas.

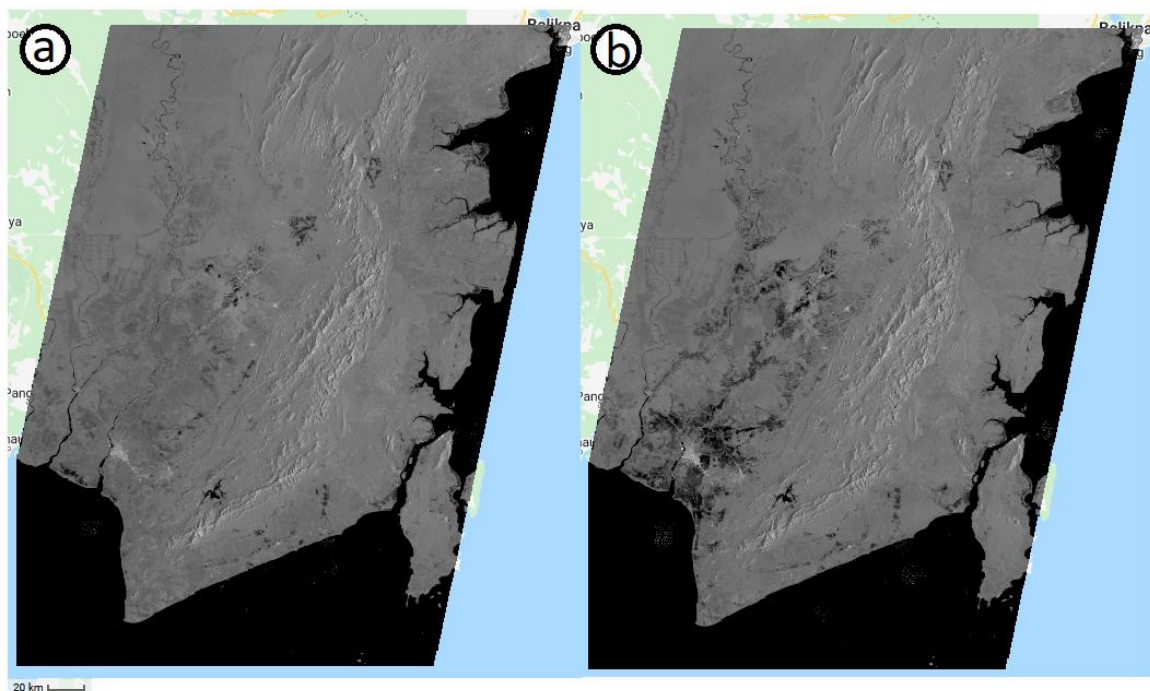
Image fusion are then applied to integrate the result from InSAR coherence process and backscattering data in order to get Temporary Surface Water map in South Kalimantan Province, Indonesia. For this research, we used image fusion at decision level. This fusion is the process of merging information from several individual data sources after each data source has undergone a preliminary classification (Bioresita, 2019).

The accuracy of results is assessed by calculating overall accuracy obtained by a comparison with South Kalimantan Flood Distribution Vector Data from Development Planning Agency at Sub-National Level, South Kalimantan Province.

### 3. RESULTS AND DISCUSSIONS

Backscattering data can be seen in Figure 2. From the figure, it can be seen the difference between before and during flood event. Dark pixels appear in during flood event image which may be interpreted as flood inundation areas. Using change detection and thresholding method, the Temporary Surface Water (TSW) result from backscattering data can be seen in Figure 3. Distribution of flood inundation is spread from north to south in South Kalimantan Province with a total area of  $\pm 226,905$  ha.

Flood inundation spread in almost all districts and cities in South Kalimantan Province. These include Tanah Bumbu Regency, Tanah Laut Regency, Tabalong Regency, Balangan Regency, Hulu Sungai Utara Regency, Hulu Sungai Selatan Regency, Hulu Sungai Tengah Regency, Tapin Regency, Banjar Regency, Barito Kuala Regency, Banjarmasin City, and Banjar Baru City. However, in Banjarmasin city as an urban area, only the flood on the suburbs can be detected. Therefore, InSAR coherence process is performed in order to detect urban flood area in Banjarmasin City.



**Figure 2.** Backscattering Data (Sigma-nought imagery) from Sentinel-1 GRD, VH Polarization: (a) Sigma-nought image of before flood event (17/08/2020); (b) Sigma-nought image of during flood event (20/01/2021).



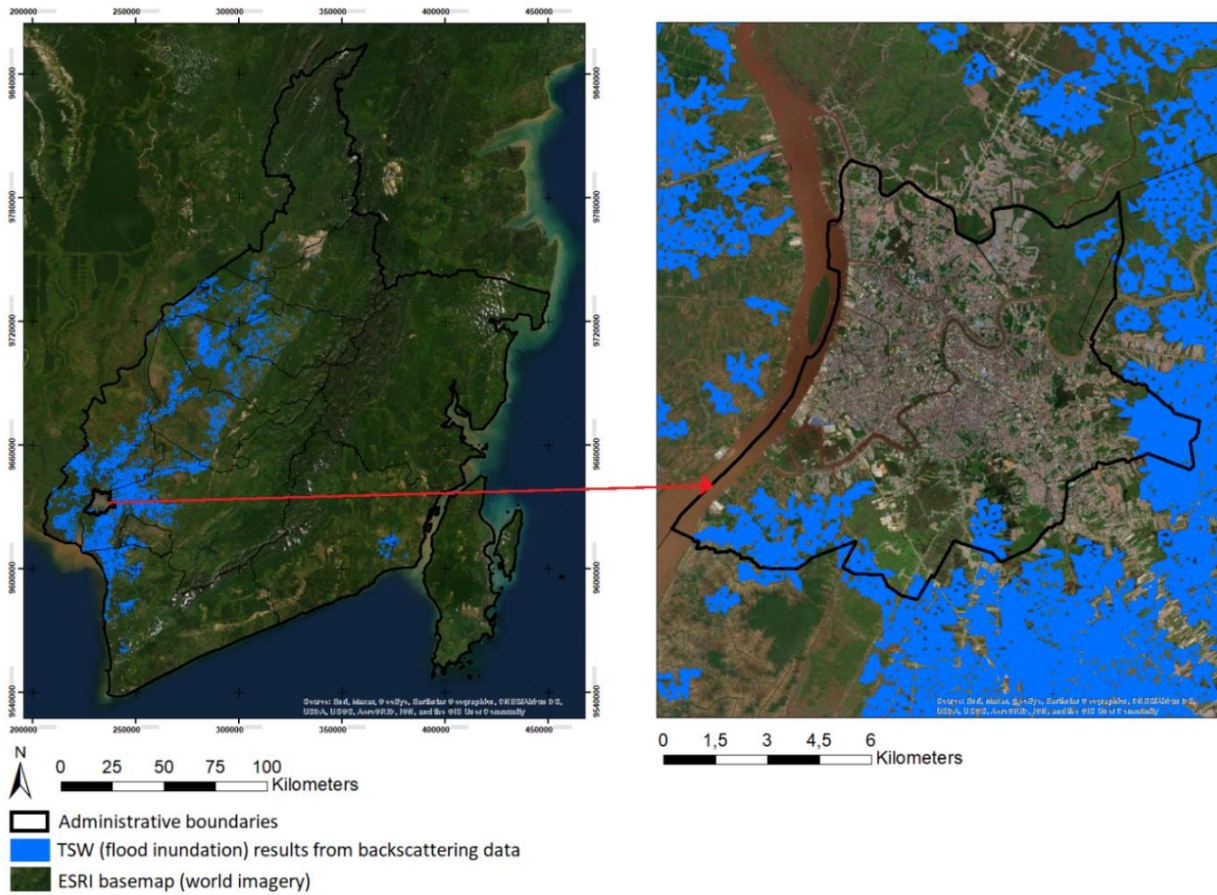


Figure 3. Temporary Surface Water (TSW) Result from Backscattering Data.

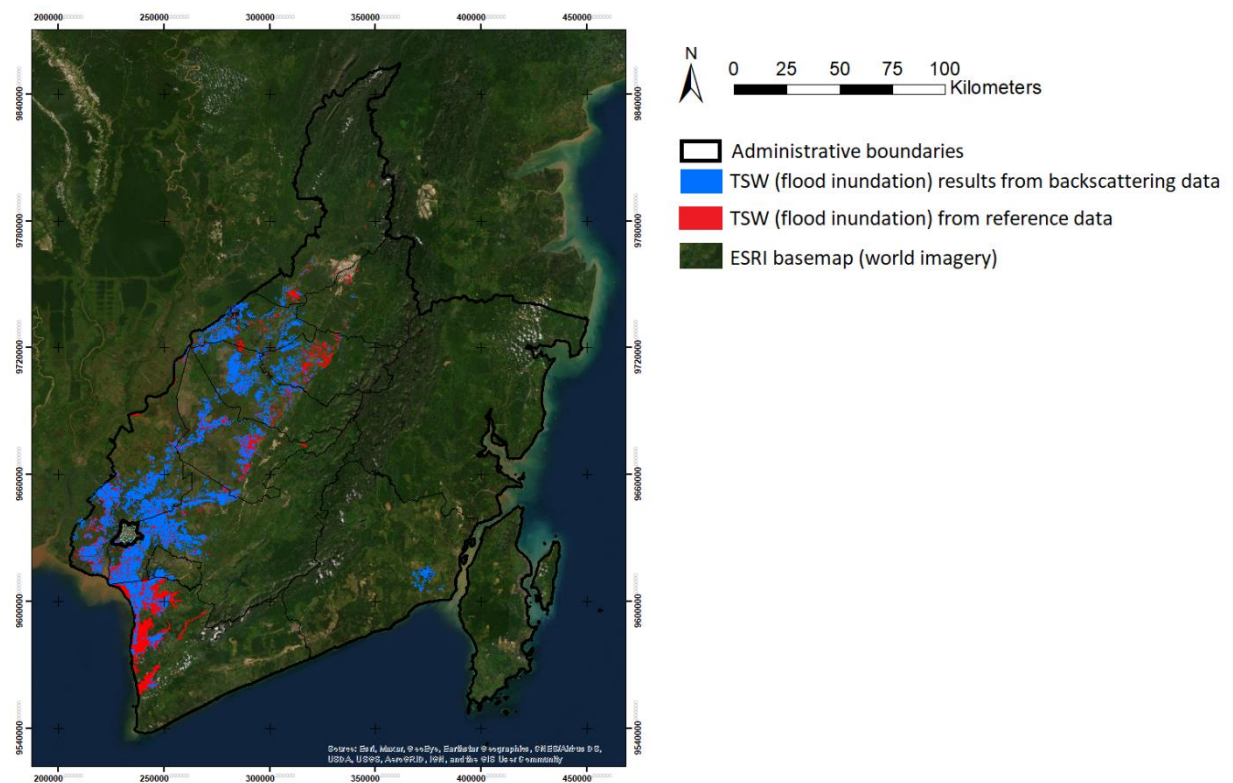
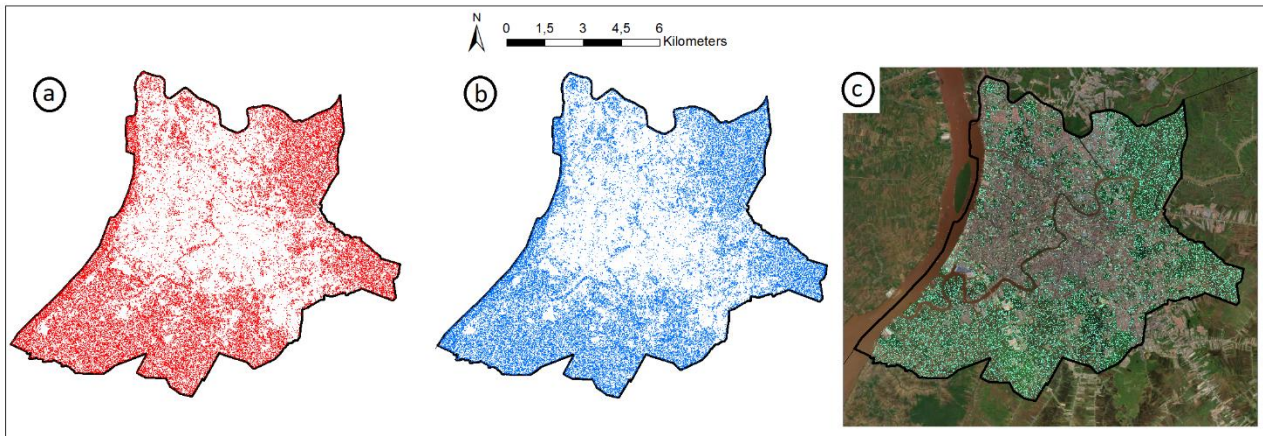


Figure 4. Comparison of Temporary Surface Water (TSW) Result from Backscattering Data with Reference Data.

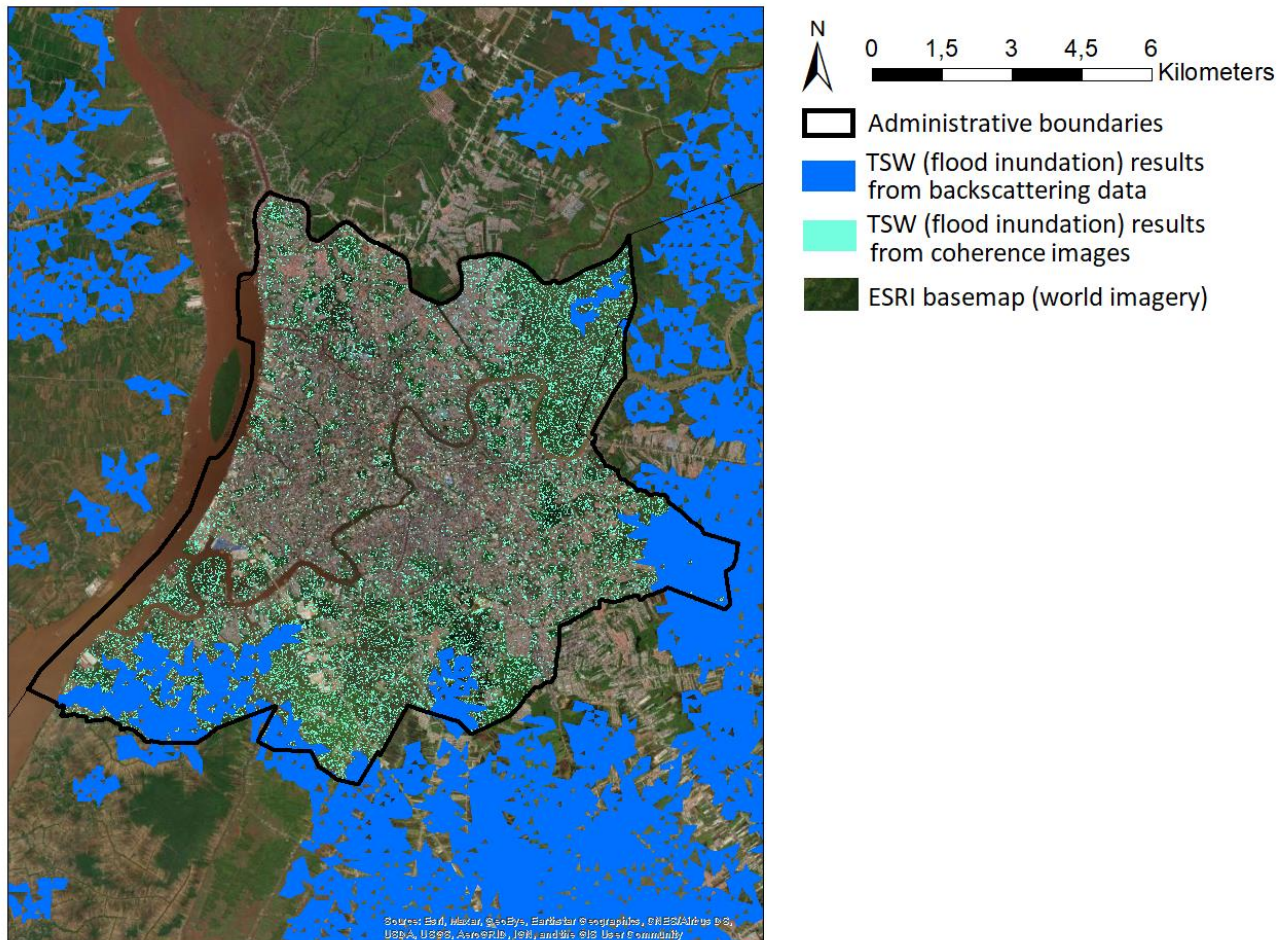


Compared with reference data, bare soil or non-urban flood inundation from backscattering data in whole study area can be mapped with overall accuracy about 76.4%. Figure 4 point that comparison visually. It can be seen that some areas are fall to false negatives and false positives in the classification process. There is flooded narrow river which cannot be detected and lead to false negatives. It is probably due to vegetation along the river banks which leads to increased backscattering in those areas.

Figure 5 represents pre-event and co-event coherence images of Banjarmasin City with values less than equal to 0.3. The pre-event coherence is subtracted from the co-event coherence, then labelled as TSW or flood inundation areas. From Figure 6, it can be seen that coherence images are successfully mapped flood inundation in urban area (Banjarmasin City) and complete flood inundation mapping from backscatter data.

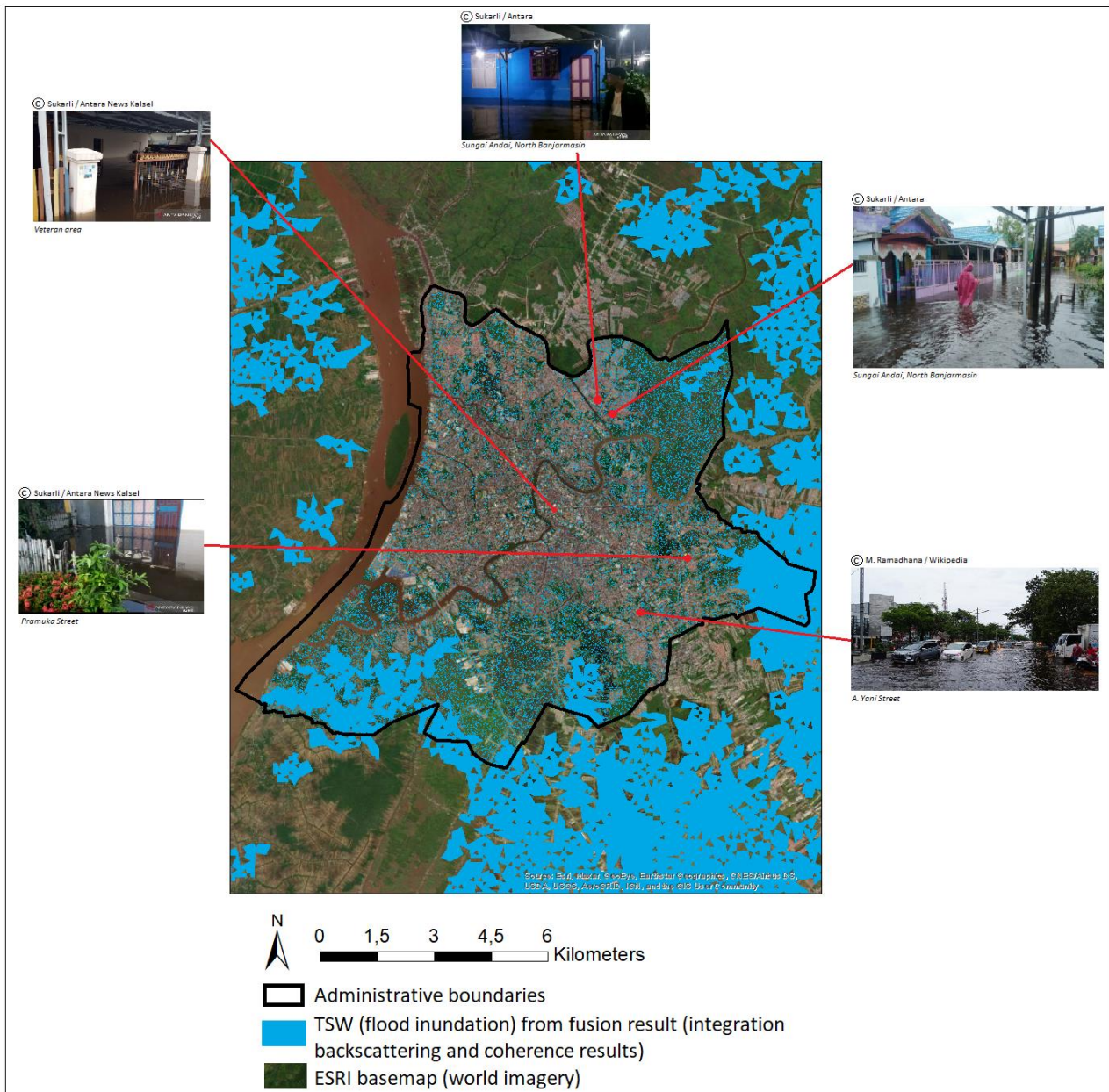


**Figure 5.** Coherence results from pre-event and co-event: (a) Pre-event coherence image in Banjarmasin City with values less than equal to 0.3; (b) Co-event coherence image in Banjarmasin City with values less than equal to 0.3; (c) Temporary Surface Water (TSW) Result from Coherence Images.



**Figure 6.** Temporary Surface Water (TSW) Result from Backscattering Data and Coherence Images.





**Figure 7.** Temporary Surface Water (TSW) Result from Fusion/Integration of Backscattering Data and Coherence Images, with some flood inundation photos.

Compared with reference data, TSW result from the fusion process can be mapped with an overall accuracy of 76.5%. The accuracy is increased by 0.1% compared to the backscatter result alone. Although the increase is not significant, the advantage of using coherence imagery is that it can map urban flood areas. Figure 7 denotes TSW or the flood inundation result from the fusion/integration process. The figure signifies flood inundation in an urban area with some photos from some flood inundation points. Those photos also become proof that there is a match between the flood inundation area resulting from this study and the flood inundation in the field. From Figure 7, it can be seen that flood inundations are detected in Pramuka Street, A. Yani Street, the Veteran area, and the Sungai Andai area.

#### 4. CONCLUSION

In this research, two approaches are performed in order to identify South Kalimantan flooding area in Indonesia, especially for urban flood detection in Banjarmasin City. First, using backscatter data, sigma-nought imagery is resulted to extract bare soil or non-urban flood inundation in the whole study areas. Second, InSAR coherence process is conducted to extract urban flood inundation areas in Banjarmasin City. The results from both of those approaches are integrated using decision fusion method in order to produce urban and non-urban flood mapping. The study shows quite satisfactory results which prove the initial hypothesis that InSAR coherence can map urban flood inundation and complement the results from backscatter data. The results from this research are encouraging for rapid urban flood inundation mapping using SAR data and the first step for disaster management.

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