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Flood Inundation Mapping Using Synthetic Aperture Radar Data Single Polarization: A Case Study of Flood in Lake Tempe, South Sulawesi – Indonesia

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Abstract. Remote sensing data can be used to help disaster management and environmental management because this data has advantages in terms of speed, is more efficient, can reach large and remote areas. Aside from that, it has consistency in measurement, can make repeated measurements, and has measurable accuracy. Floods in Lake Tempe occur almost every year due to overflowing of Lake Tempe. This research will detect flood inundation from Sentinel-1 data with single-polarization flooding in Lake Tempe, South Sulawesi. The data used were Sentinel-1 data before flooding (2 May 2018) and after flooding (26 May 2018). The Single polarization of the Sentinel-1 can be used very well to identify floods event. The difference of input band uses the threshold of -6, and enables smoothing of 10. Utilization of tidal junction between Lake Tempe and Lake Sidenreng for agriculture and settlement has caused flooding due to lake water overflowing in the rainy season. This single polarization method can already be used in flooded areas, although in some locations it is still overestimates.

1. Introduction
Flooding is a natural disaster that can cause a high level of economic loss [1] and a high frequency of events [2]. Therefore, flood mapping needs to be done as part of an emergency response effort. This flood mapping can be made in two ways, namely direct and indirect approaches. The direct approach is carried out by field measurements, while the indirect approach is conducted by using tools without field measurements. The direct approach usually has limitations in flood mapping, such as limited time, cost, and the number of personnel in the field. This problem can be solved by indirect approach an indirect approach that utilizes remote sensing data [3, 4, 5].

Smith [6] and Khan et al. [1] state that one of the uses of remote sensing data is that it can be used to provide objective information, monitoring, detection and mapping of spatial-temporal floods. The use of remote sensing for flood mapping is reliable particularly in detection approach of an object changes that appear on multi-temporal imagery (pre and post-flood) [7, 8, 9].

Islam and Sado [10] state that flood-mapping can be divided into two categories, namely: flood mapping by passive remote sensing system and active remote sensing system. Research related to
flood mapping using passive remote sensing system has been carried out, such that SPOT data [11], NOAA / AVHRR [12], MODIS [13, 14], Landsat Mapper (TM) [15], ASTER [16], and others. Meanwhile, several flood mapping using active remote sensing system have been carried out, such as ERS-1 data [17, 18], ASAR [19, 20], RADARSAT-1 [21, 22], TerraSAR-X [23], ALOS PALSAR [9, 24], and others.

Optical sensor satellites’ use in Indonesia is not easy, because the data of solar illumination on the equatorial orbit and the problem of cloud coverage on optical sensors are high. An effort to overcome this problem is by using radar data. The use of Synthetic Aperture Radar (SAR) data for flood mapping in Indonesia is very important, because Indonesia has quite high cloud coverage. Radar data can penetrate cloud coverage so that it can provide information on the ground. However, the method of interpretation of SAR satellite imagery is still not much developed. Interpretation of SAR satellite imagery is not yet popular. This is because the texture effect of objects is relatively more difficult to interpret than optical satellite images. SAR satellite sensors initially only used a single polarization (HH or VV) such as JERS-1 SAR L-Band or ERS-1 SAR C-Band.

In this study, the data from Sentinel-1 is utilized to monitor flood inundation in the event of flooding on Lake Tempe on May 19, 2018. Flood disasters almost every year have inundated the districts around Lake Tempe. There are 8 districts affected by this flood, namely Belawa, Gilireng, Majauleng, Pitfeedua, Sabangparu, Sajoanging, Tanasitolo, and Tempe Districts. Rain with moderate intensity (20 - 50 mm) to heavy (50 - 100 mm) which occurred for several days resulted in flooding in several areas in Wajo Regency, and was worsened by the increase of water shipments from Soppeng Regency, and Sidrap Regency. As a result, the water from river and Lake Tempe was overflowed to the residential areas with water level increases from 30 cm to 2 m.

As an effort to increase speed and accuracy in flood mapping in emergency response conditions, therefore in this paper flood detection is carried out by using Sentinel-1 data for Lake Tempe flood events in Wajo Regency, South Sulawesi. It is expected that Sentinel-1 data can detect flood inundation well.

2. Remote Sensing

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance from the targeted area. Special cameras collect remotely sensed images of the Earth, which help researchers "sense" things about the Earth. Remote sensing instruments are of two primary types: active and passive. Active sensors, provide their own source of energy to illuminate the objects they observe. An active sensor emits radiation in the direction of the target to be investigated. The sensor then detects and measures the radiation that is reflected or backscattered from the target. On the other hand, passive sensors detect natural energy (radiation) that is emitted or reflected by the object or scene being observed. Reflected sunlight is the most common source of radiation measured by passive sensor.

The majority of active sensors operate in the microwave portion of the electromagnetic spectrum, which makes them able to penetrate the atmosphere under most conditions. An active technique views the target from either end of a baseline of known length. The change in apparent view direction (parallax) is related to the absolute distance between the instrument and target. Passive sensors include different types of radiometers and spectrometers. Most passive system used in remote sensing applications operate in the visible, infrared, thermal infrared, and microwave portions of the electromagnetic spectrum. Difference of system of two primary types is shown on Figure 1. The passive sensor system needs energy source to get information of the surface conditions, because radiation from sun will be reflected by object (vegetation/land/water/building etc.).
Figure 1. The difference between active and passive sensor of remote sensing (Source: https://energyeducation.ca/encyclopedia/Remote_sensing).

Data from passive sensor is also called optic data, while active sensor data is called radar data. Active sensors have several advantages including having their own energy source that makes it operate well during the day and night. The main advantage that is different from optical images is that radar images are not affected by atmospheric conditions such as cloud cover and rain (Table 1).

Table 1. Advantages of active sensor remote sensing system.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather resistance: able to penetrate clouds, rain, snow, dust, and fog</td>
<td>Data intervened by other radiation sources</td>
</tr>
<tr>
<td>Operate day and night</td>
<td>Complicated analysis</td>
</tr>
<tr>
<td>Application in several fields</td>
<td>More expensive cost</td>
</tr>
</tbody>
</table>

2.1. Synthetic Aperture Radar (SAR)

Synthetic Aperture Radar is when satellite illuminates microwave and receives backscattered wave, then process it to be an image. Because of that sometimes it is called microwave sensor or active sensor or image radar or side looking radar. Advantages of SAR among other are having a high coherency/phase information and polarization (polarimetric, circularly polarized Synthetic Aperture Radar (CP-SAR)). The disadvantages point of SAR is that interpretation of backscattered image is very complicated and has distortion effect of terrain.

Sentinel-1 SAR is the most widely used data today. Sentinel-1A, which was active on 3 April 2014, is a satellite of the European Space Agency (ESA). It carries a C-band synthetic-aperture radar instrument which provides a collection of data in day or night, in all-weather. The applications for the data collected via the Sentinel-1 mission are sea and land monitoring, emergency response due to environmental disasters, and economic applications. Sentinel-1 has worked in conjunction with SMAP (Soil Moisture Active and Passive) to help achieve a more accurate measure of soil moisture estimates [25].
3. Data and Methods
This study is located around Lake Tempe are Wajo, Sidenreng Rappang, and Soppeng Regencies. Lake Tempe was having a very high level of sedimentation. Therefore, the vicinity area of Lake Tempe is widely used for agriculture, ponds, and even settlements. The area was supposed to be a water body, is converted inappropriately, so when rainfall is high, locations that have experienced land conversion have been flooded up to 4 meters high. The appearance of Lake Tempe as a research location can be seen in Figure 2.

![Figure 2. Study of Interest Area Lake Tempe, South Sulawesi – Indonesia.](image)

3.1. Data
The availability of spatial and non-spatial data was needed in this study to answer research questions and achieve research objectives. The spatial data used in this study consisted of: remote sensing satellite image data and other supporting spatial data, such as: topographic maps or Rupa Bumi Indonesia (RBI) scale of 1: 25,000. Meanwhile, non-spatial data also used, such as: historical flood data, locations of flood events and others.

The Sentinel 1-A data used in this study is a product of C-band Synthetic Aperture Radar (SAR) from the European Space Agency (ESA) - EO Missions (https://earth.esa.int/web/guest/data-access/browse-data-products). This study applies a single polarization data set in the vertical transmit-vertical receive (VV) reception mode. This data set is a Level Range Ground Detected (GRD) Product, which has been detected, multi-visible and projected onto various soils using the Earth ellipsoid model. The data before and after the flood event 15 - 19 May 2018 are used, namely 02 May 2018 for data before the event and 26 May 2018 for after the event. In detail, the availability of data used in this study are shown in Table 2.
Table 2. The data of Sentinel 1A and topographic map for Lake Tempe flood.

<table>
<thead>
<tr>
<th>Data</th>
<th>Acquisition data</th>
<th>Spatial resolution / scala</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sentinel 1A</td>
<td>Year 2018</td>
<td>5 m</td>
<td>ESA</td>
</tr>
<tr>
<td>Topographic map</td>
<td>Year 1998</td>
<td>1:25.000</td>
<td>BIG</td>
</tr>
</tbody>
</table>

3.2. Methods

Flood mapping using remote sensing was done with the detection approach of object changes that appear on multi-temporal imagery (pre and post flood) [7][8][9].

3.2.1. Pre-processing. The Sentinel-1 mission provides data from a dual-polarization C-band Synthetic Aperture Radar (SAR) instrument. This collection includes the S1 Ground Range Detected (GRD) scenes, processed using the Sentinel-1 Toolbox to generate a calibrated, ortho-corrected product. The Collection of data from Sentinel-1 is updated weekly.

The Sentinel-1 data contains all of the GRD scenes. Each scene has one of 3 resolutions (10, 25 or 40 meters), 4 band combinations (corresponding to scene polarization) and 3 instrument modes. Use of the collection in a mosaic context will likely require filtering down to a homogenous set of bands and parameters. Each scene contains either 1 or 2 out of 4 possible polarization bands, depending on the instrument's polarization settings. The possible combinations are single band VV or HH, and dual band VV+VH and HH+HV:

1. VV: single co-polarization, vertical transmit/vertical receive
2. HH: single co-polarization, horizontal transmit/horizontal receive
3. VV + VH: dual-band cross-polarization, vertical transmit/horizontal receive
4. HH + HV: dual-band cross-polarization, horizontal transmit/vertical receive

Each scene also includes an additional ‘angle’ band that contains the approximate viewing incidence angle in degrees at every point. This band is generated by interpolating the ‘incidence angle’ property of the ‘geolocation Grid Point’ gridded field provided with each asset.

Each scene was pre-processed with Sentinel-1 Toolbox using the following steps:
1. Thermal noise removal; removes additive noise in sub-swaths to help reduce discontinuities between sub-swaths for scenes in multi-swath acquisition modes.
2. Radiometric calibration; computes backscatter intensity using sensor calibration parameters in the GRD metadata.
3. Terrain correction (ortho rectification); converts data from ground range geometry, which does not take terrain into account, to \( \sigma^0 \) using SRTM 30 or ASTER DEM for areas greater than 60 degrees latitude, where SRTM is not available. \( \sigma^0 \) is a linear expression of radar backscatter per unit area on the ground. The final terrain-corrected values are converted to logarithmic decibels (dB) via log scaling \((10\log_{10}(x))\) to get better contrasts the range of pixel value.
Identify flood area. Create Stack is a component of co-registration. The Create Stack Operator allows collocating two spatially overlapping products. Collocating two products implies that the pixel values of one product (the before flood image) are resampled into the geographical raster of the other (the after flood image). Difference of input band use threshold is -6 and enable smoothing is 10.

4. Result
Sentinel-1 data has dual-polarization, VV, and VH, but only VV was used in this study. Water features are characterized by dark colors because the water that appeared on the radar image is not received again by the radar sensor. While the bright appearance indicates the area is residential. In addition to bright appearance, settlements can also be characterized by the presence of reflections on the hill. The process carried out in the processing of radar data includes 3 things namely radiometric calibration to eliminate noise and improve the value that is on the radar data. Speckle filtering was useful for removing noise in the form of small spots on the Sentinel 1 and the smoothing process. The final method was to use geometric terrain correction to improve position by using SRTM data online.

![Figure 3.](image)

**Figure 3.** Single co-polarization, vertical transmit/vertical receive (VV) pre flooding (a) and post flooding (b).

Based on the analysis of events when overlaid with land use data analysed using Landsat data in 2018, it was found that the area affected by floods that inundated Lake Tempe mostly occurred in residential land use and agricultural land. The distribution of flooded areas in the map that visibly near the lake implies that flooding is dominated by the overflow of Lake Tempe. Land use is obtained using cloud-free Landsat 2019 mosaics. The survey evidence that the floods occur and inundated on the settlements and agricultural land.

Flood was occurred in May 2018 with the cause with the cause of high rainfall in the covered area. The high rainfall caused the Lake Tempe to flood in Wajo. The result of Sentinel 1 is good enough to identify floods because penetration can be carried out in areas covered by clouds. However, the limitation of Sentinel 1 data is appear when the result of that flood mapping in residential areas were not very good.
5. Conclusions
Land uses around Lake Tempe generally consist of vegetation (paddy fields and gardens) and settlement. Utilization of tidal junction between Lake Tempe and Lake Sidenreng for agriculture and settlement has caused flooding due to the overflow of the lake water during the rainy season. The use single-polarization method of Sentinel-1 in this study resulting in an overestimate prediction of potential flood in several locations. Therefore, further research use of the dual-polarization method of Sentinel-1 is required.

Acknowledgments
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6. References


