Rapid mapping of temporary surface water using Sentinel-1 imagery, case study: Zorn River flooding, Grand-Est, France

F Bioresita¹, A Puissant²

¹Department of Geomatics Engineering, Institut Teknologi Sepuluh Nopember, Sukolilo-60111, Surabaya, Indonesia
²Laboratoire Image, Ville, Environnement—LIVE/CNRS UMR 7362, Department of Geography, University of Strasbourg, 3 rue de l’Argonne, 67000 Strasbourg, France

*correspondence email : filsa_b@geodesy.its.ac.id

Abstract. Temporary Surface Water (TSW) is defined as waterbody experiencing frequent drying phases (small ponds, puddles, and wetlands) or correspond to surfaces frequently affected by flooding, thus causing hazards to human, settlements, and infrastructures. The Zorn is one of main river in Grand-Est, France which overwhelmed by strong precipitations from the Storm Eleanor (Cyclone Burglind). It caused inundation in Zorn surrounding areas. On 23 January 2018, data reported that floods occurred in Zorn watershed near to the municipalities of Brumath, Hoerdt and Hochfelden. Zorn River lies in the Moselle and Bas-Rhin departments with 580 km of linear streams. Historically, floods are frequently occurred in the Zorn watershed area. The municipalities of Eschbourg, Brumath and Dossenheim-sur-Zinsel are the most affected floods areas. Synthetic Aperture Radar (SAR) is an effective way to detect surface water over large areas. Sentinel-1 is a new available SAR, and its spatial resolution and short temporal baselines have the potential for surface water rapid mapping. Thus, the objective is to perform rapid mapping to produce flood map around the catchment of the Zorn River (next to Brumath).

1. Introduction

Surface waters are important in human’s everyday life. They can be used for irrigation, drinking water, production of energy, and many more [3, 7, 12, 13]. In the global system, surface waters are essential as the resources for the biosphere and the anthroposphere. They can control nutrient cycles and global carbon; thus, they play a role to provide ecosystem service. Surface waters can also preserve diverse habitat and support biodiversity. Temporary Surface Water (TSW), such as small ponds or wetlands, is defined as waterbody experiencing frequent drying phases. It also corresponds to surfaces frequently affected by flooding which can cause hazards to human, settlements, and infrastructures [9].

Floods become a representation of the most common type in natural disaster which have led to losses of lives and property [15]. Floods can affect buildings, residential or farm areas, also contaminate waters and lead to diseases. From 1980 to 2015, Duggar et al. [6] highlights that 25.3% of global damage caused by natural hazards are due to flooding. For example, flood events which are occurred the winter 2018 in the Grand-Est Region. The passage of the Storm Eleanor (Cyclone Burglind) had already brought significant amounts of rain in 2-3 January 2018 and affected Ireland, the United Kingdom, France, the Benelux, Germany, Austria, and Switzerland. After the storm, heavy rainfall occurred and caused several overflowing floods in France including the Grand-Est region [4]. One of the main rivers in Grand-Est, the Zorn, was overwhelmed by those strong precipitations and caused inundation in its surrounding areas.

Since it is difficult to avoid flood risks or prevent their occurrence, flood disaster management is important to reduce their effects. Flood mapping to identify sites in high hazard zones is one of the powerful tools for this purpose [18]. Mapping floods will be beneficial to urban and infrastructure planners, also for risk managers and disaster response.
For temporary surface water, Earth Observation (EO) data from optical or Synthetic Aperture Radar (SAR) sensors offers a relevant alternative for mapping and monitoring surface water resources. Synthetic Aperture Radar (SAR) as one of active remote sensing is an effective way to detect surface water over large areas. SAR sensors offer clear advantages by providing their own sources of illumination, thus being able to operate in nearly all-weather/day-night conditions. For almost 20 years, spaceborne SAR sensors have increasingly been used for large-scale surface water mapping. In 2014, the European Space Agency (ESA) launched the Sentinel constellation including freely available SAR data (Sentinel-1) with high revisiting time (about 12 days) and high spatial resolution (about 20 m). This constellation offers the possibility to increase the capture of genuine time series, for example to monitor floods event.

The main goal of this study is thus to map temporary surface water (flood) of the Zorn River flooding, Grand-Est, France using Sentinel-1 SAR imagery through rapid mapping method.

2. Study area and datasets
On 23 January 2018, data reported that floods occurred in Zorn watershed near to the municipalities of Brumath, Hoerdt and Hochfelden [16]. Zorn River lies in the Moselle and Bas-Rhin departments with 580 km of linear streams. Historically, floods are frequently occurred in the Zorn watershed area. The municipalities of Eschbourg, Brumath and Dossenheim-sur-Zinsel are the most affected floods areas [5].

![Study area of Grand-Est with Sentinel-1 & 2 coverage areas.](image-url)
For this research, 11 images of Sentinel-1 IW GRD from short-term periods in 2017 and 2018, with short range intervals, minimum interval is 1 day, and maximum interval is 22 days have been downloaded (Table 1). Coverage areas of images used can be seen in Figure 1 with their ID number. Post-events images of Sentinel-2 are only used for qualitative assessment due to no images are available during the flood events. For quantitative assessment, flood reference map produced by ICUBESERTIT is used [16]. The map is produced within the framework of the EUGENIUS H2020 project (European Group of Enterprises for a Network of Information Using Space). The project provides regional (local) small and mid-size flood monitoring service based on the combined exploitation of Copernicus satellite data (especially Sentinel-1 and Sentinel-2) and local data [8].

### Table 1. Images used.

| ID | Track number | Levels | Sentinel-1 acquisition | SAR Acquisition Mode | Information | Track number | Sentinel-2 acquisition | Cloud cover |
|----|--------------|--------|------------------------|----------------------|-------------|--------------|------------------------|-------------|
| 1  | 66           | L1 GRD | 10/10/2014             | Descending           | Dry         | /            | /                      | /           |
| 1  | 66           | L1 GRD | 15/03/2015             | Descending           | Dry         | /            | /                      | /           |
| 2  | 139          | L1 GRD | 04/12/2017             | Descending           | Dry         | /            | /                      | /           |
| 2  | 139          | L1 GRD | 16/12/2017             | Descending           | Dry         | /            | /                      | /           |
| 3  | 15           | L1 GRD | 19/12/2017             | Ascending            | Dry         | /            | /                      | /           |
| 4  | 139          | L1 GRD | 22/12/2017             | Descending           | Dry         | /            | /                      | /           |
| 5  | 15           | L1 GRD | 31/12/2017             | Ascending            | Dry         | /            | /                      | /           |
| 6  | 88           | L1 GRD | 05/01/2018             | Ascending            | Flooding    | /            | /                      | /           |
| 7  | 15           | L1 GRD | 06/01/2018             | Ascending            | Flooding    | /            | /                      | /           |
| 8  | 88           | L1 GRD | 11/01/2018             | Ascending            | Dry         | /            | /                      | /           |
| 8  | 88           | L1 GRD | 23/01/2018             | Ascending            | Flooding    | /            | /                      | /           |
| 6  | 88           | L1 GRD | 29/01/2018             | Ascending            | Dry         | /            | /                      | /           |
| 4  | 139          | L1 GRD | 20/02/2018             | Descending           | Dry         | /            | /                      | /           |
| /  | /            | /      | /                      | /                    | /           | 108          | 24/07/2018             | 0.72%       |
| /  | /            | /      | /                      | /                    | /           | 108          | 03/08/2018             | 0.64%       |
| /  | /            | /      | /                      | /                    | /           | 108          | 28/08/2018             | 4.05%       |

### 3. Methodology

The general methodology is described in Figure 2. The detection of the surface water and the calculation on the probability of occurrence are carried out on the Sentinel-1 images time series with the Water-S1 method presented in [2]. The detected surface water in the form of posterior probability maps are combined using decision level methods. The fused result is called permanent surface water. In order to obtain temporary surface waters, we subtract posterior probability maps, which have been labelled, with permanent surface water. The results are then evaluated.
3.1. Detection of surface waters to obtain posterior probability maps

The processing of Sentinel-1 images time series is based on rapid mapping method called the WaterS1 method described in [2]. The first step consists of the application of precise Sentinel orbits, the radiometric calibration of the SAR images to Sigma-nought images, the multi-looking, the filtering of speckle, and terrain relief is applied in the Sentinel Application Platform/SNAP [10, 17].

Then, a statistical modified Split-Based Approach (SBA) is used to tile the input images into squared non-overlapping blocks and to select the tiles for class modelling. The strategy for tile selection consists of choosing only the image tile which contains some portions of surface water based on Hartigan’s dip statistic (HDS) value [11]. Class modelling is performed by applying Finite Mixture Models (FMM) [1]. The model parameters for each tile are calculated, then global sets of parameters are defined, and posterior probability is computed. Finally, a labelling using Bilateral Filtering is applied to the posterior probability maps [14]. The filtered posterior probability maps are then used as input data for image fusion.

3.2. Extraction of permanent surface water using decision-level fusion rules

The extraction of permanent surface water is based on decision-level fusion rules. The process applied Bayesian approach, based on the operator sum (Equation (1)).

\[ P_{\text{fusion}}(x) = P_A(x) + P_B(x) \]  

Where \( P_A \) and \( P_B \) are the posterior probability maps. A threshold of 90% is used to differentiate the ‘permanent surface water’ (posterior probability > 90%) from other classes (posterior probability <90%).
3.3. Extraction of temporary surface water
Temporary surface water bodies are extracted from each single date of Sentinel-1 image by applying the “permanent surface water” map resulted from fusion method as a mask (subtraction).

3.4. Evaluation
Flood reference map produced by ICUBE-SERTIT is used as the reference product for the evaluation. All the quantitative assessments are based on the calculation of confusion matrices and of indicators such as the Overall accuracy, the F-measure, the True Positive Rate (TPR), the False Positive Rate, and the Omission and Commission error.

4. Results
Temporary surface water is detected with focus on floods delineation. Using permanent surface water as mask, temporary surface waters are extracted from each single date. Based on reference data, floods are detected on 23rd January 2018, yet based the observations, there are also floods in 5th and 6th January 2018. Thus, quantitative evaluations for floods areas are only performed for inundation result on 23rd January 2018 (Table 2) with flood map produced by ICUBE-SERTIT as reference data.

| Table 2. Quantitative evaluation of floods areas from Sentinel-1 single date image (23/01/2018). |
|---------------------------------------------------------------|
| **Overall Accuracy** | **F-measure** | **True Positive Rate** | **False Positive Rate** | **Omission error** | **Commission error** |
|---------------------------------------------------------------|
| 98.76% | 0.90 | 86.50% | 0.43% | 13.50% | 6.91% |

The assessment from floods areas of 23rd January 2018 results give good F-measure, True Positive Rate, and omission error. In a qualitative point of view, with the visual interpretation in Figure 3, floods along Zorn River are detected successfully with false positive and false negative appear only in the border area.

![Figure 3](image)

**Figure 3.** Floods result from single date 23rd January 2018.

A monitoring analysis of temporary surface water is presented in Figure 4. During the short-term period, temporary surface water areas normally not exceeding 400 ha. Two peaks of temporary surface water areas are observed in 5th and 6th January 2018, also 23rd January 2018, reached more than 900 ha. For all the inundation period, flood reference map is only available for the 23rd January. Then to complete the visual assessment of this monitoring, we decide to collect data reference based on news media (Moreau, 2018) with floods photos. For instance, Figure 5 shows photos taken on 5th and 6th January 2018 showing flooded road at the exit of Krautwiller and floods between Krautwiller...
and Wingersheim. This visual interpretation highlights the relevance of our extraction for small areas, next to the river.

Figure 4. Dynamic changes of temporary surface water areas (ha).

Figure 5. Floods detection on 5\textsuperscript{th} and 6\textsuperscript{th} January 2018.

5. Conclusion
Using Sentinel-1 as free SAR data with wide area monitoring capabilities, temporary surface water can be extracted during the short-term period. The quantitative evaluation shows relevant results with overall accuracy of more than 98\%, F-measure provides value 0.9, also very low False Positive Rate and commission error. There is also temporary surface water monitoring in those three months period in order to observe dynamical change in Zorn River area. These results are encouraging and the first step for monitoring Zorn River area and disaster management.

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