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Flood mapping using Sentinel-1 SAR Imagery: Case study of the November 2017 flood in Penang

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Abstract. The Sentinel-1 SAR image by the Europe Space Agency (ESA) in the Copernicus Programme is an open source data which offers good data to develop flood inundation mapping. The flood inundation mapping is essential information for local authority personals or researchers to develop flood inventory map. The objective of this study is to develop a flood inundation mapping on November 2017 event to assess its use as potential flood inventory mapping data in Penang. The threshold method was carried out using Sentinel-1 image to extract the flood map. This method is pixel value used to separate the grey image into two parts. The flooded and non-flooded areas can be identified by separating the backscatter lower than the threshold value. The results revealed that the flood inundation maps are able to be extracted out from Sentinel-1 images.

1. Introduction

Malaysia is very fortunate to be freed from natural disaster such as volcano, typhoon and earth quake [1]. However, Malaysia still experiencing natural disaster which is mainly flood and landslides. There are two type of floods occur in Malaysia; monsoon flood and flash flood. The existence of the flood events have been predicted to increase due to improper planned urban development [2]. In recent years, fast urban development within floodplain area can cause higher runoff and decreasing river capacity. This would lead to increase in flood frequency and magnitude. The impact of flood leads to death, huge economic cost, and floods could carry pathogens into urban environments and cause microbial development and diseases [3]. The flood modelling is important in flood management to identify sites in high-risk flood zones, analysing the condition of drainage system and reduce impact of the flood. Before develop the flood modelling, flood inventory map and a set of flood causative factors need to identified [4]. The information in flood inventory maps is including the size, coverage and trend of the inundated areas which is useful for local authority for flood management.

2. Geographic Information System (GIS) and Remote Sensing (RS)

Recently, the integration of Geographic Information System (GIS) techniques and remote sensing (RS) data, worked very effective to deal with the complexity of spatial flood modelling. Remote sensing systems have been widely known as useful resources to offer cost and time efficient situational awareness over large areas in case of natural disasters [5]. In Malaysia, the area is mostly covered by clouds during the rainy season and optical RS cannot be used due to this condition [6]. In disaster management, radar has added a new dimension by produce real-time and accurate information [7].

Synthetic aperture radar (SAR) is an active remote sensing system which able to make data collection on a day and night under any weather conditions which is suitable for flood mapping [5]. In recent years, the SAR data are increasingly applied to natural hazards' researches, either by themselves or in combination with data from other remote sensing sensors [7]. Figure 1 shows the flood location in Penang on 5th November 2017.

Figure 1. Flood images in Penang on 5th November 2017 (photo credit Majlis Bandaraya Pulau Pinang)

Rahmati and Pourghasemi [8] found that it is important to acquire information about the floods that have occurred in the past the in flood susceptibility analysis. The flood events in the past and present are keys to a future spatial prediction for susceptibility model, a flood inventory map is essential for such a study. According to Tehrany and Jones [9], inventory maps can be used for different purposes in natural disaster management such as flood and landslide. The inventory map is including the documentation and record keeping, damage and cost assessments, as an initial stage in further flood assessments etc. Previously, the data collections of flood events were using traditional surveying techniques. However, these techniques were requiring the more time and resources, high-priced, or sometimes impossible for data collection and monitoring of the ground-based at the time of catastrophic flood events [10]. Due to these problems, the application of airborne and space-borne remote sensing techniques was used for monitoring and mapping the inundated areas affected by flood hazards [11,12]. According to Sadek and Li [13], the integration of remote sensing data and GIS technique are able to produce rapid and precise mapping of the flood impacts and their models during or a short time after the flood event at different spatial and temporal resolution using multispectral or SAR images. Sadek and Li [13] also stated that modern remote sensing can delineate the flooding areas easily compare to the traditional surveying techniques. The remote sensing data become popular recently and it is hugely been developed for delineation the flood inundation areas with high accuracy [14].

2.1 Image Thresholding Methods

The image thresholding method is using pixel value to separate the grey image into two parts or more [15]. The flooded and non-flooded areas can be identified by splitting the backscatter lower than the threshold value. This method is very suitable and fast to generate water bodies from SAR images [16]. Tavus [17] stated that the low values indicate to the water, while for high values indicate to the nonwater class. Two threshold techniques were used by researchers which are global and multilevel. For global technique, the value is constant over the whole image [15]. Then, for the multilevel or adaptive techniques, the value is some area over the image. Usually, the recognition of water in SAR image has been carried out by selecting the thresholds in the intensity image.

3. Methodology

3.1 Study Area

In 4th November 2017, Penang was hit by flash flood. Davies [18] reported that at least 7 people have died and over 10,000 evacuated when flood event in Penang and Kedah in peninsular Malaysia. According to Davies [18], heavy rain was recorded from 3rd November 2017 and 06th November 2017, with 458 mm of that total falling in 24 hours to 6th November 2017. During this event, 7412 peoples have been evacuated from their homes in Penang. Figure 2 shows the location of study area in Penang. This research only focuses flood event in urban area in Penang which is Timur Laut District.

Figure 2. The location of study area in Penang

3.2 Data

For this study, the Sentinel-1 data was obtained in 5th November 2017 during the flood event 4th to 6th November 2017. Figure 3 shows the Sentinel-1A image obtained from ESA website. The European Space Agency (ESA) launched the Sentinel-1 on 3rd April 2014 and Sentinel1-1B on 25th April 2016 [19]. It has a dual-polarization capability (VV: vertical transmitting- vertical receiving; and VH: vertical transmitting- horizontal receiving) which is a SAR C-band (5.405 GHz) radar satellite and produce the a geometric resolution (10 m) image [20]. Ezzine et al. [20] stated that the Sentinel-1A is suitable for mapping the flood water due to the sensitivity on standing water. Additionally, the sensors of Sentinel-1 can provide the benefit of obtaining images of the Earth's surface through clouds, day, and night. Table 1 shows the detail of Sentinel-1A data of study.

Table 1. Sentinel-1A data for study

Product	Sensor Type	Mode	Type	Acquisition Date
S1A_IW_GRDH_1SDV_20171105T230320	Sentinel-1A	Interferometry Wide swath (IW)	Ground Range Detected (GRD)	5th November 2017

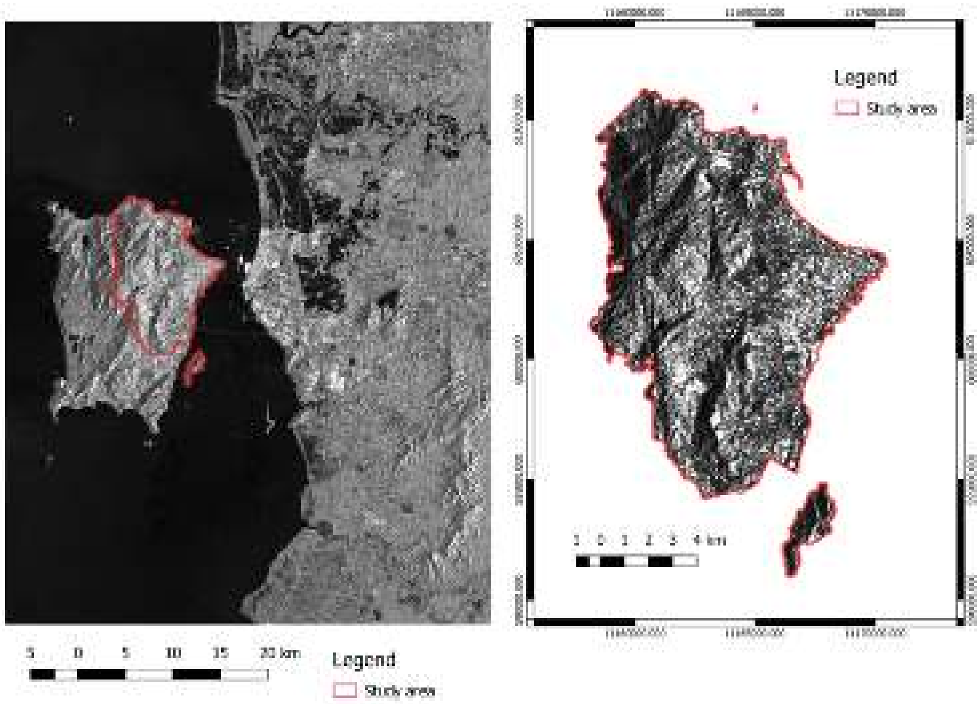

Figure 3. Sentinel-1A image obtained from ESA website and subset image of study area

3.3 Processing and Validation

In this study, the Sentinel-1A data acquired in 5th November 2017 during the flood event was used to develop flood inundation map. The SNAP software was used to pre-processing the Sentinel-1A data. The pre-processing procedures are including radiometric calibration, speckle filtering, terrain correction, sub-setting the SAR image, and re-projection. After pre-processing, the threshold method (binarization) was used verify the flooded areas and non-flooded areas. Then, the flood inundation map will validate by using confusion matrix. This method is widely used to validate the image classification especially for remote sensing data. Figure 4 shows that the flow chart of methodology to produce flood map using Sentinel-1A data.

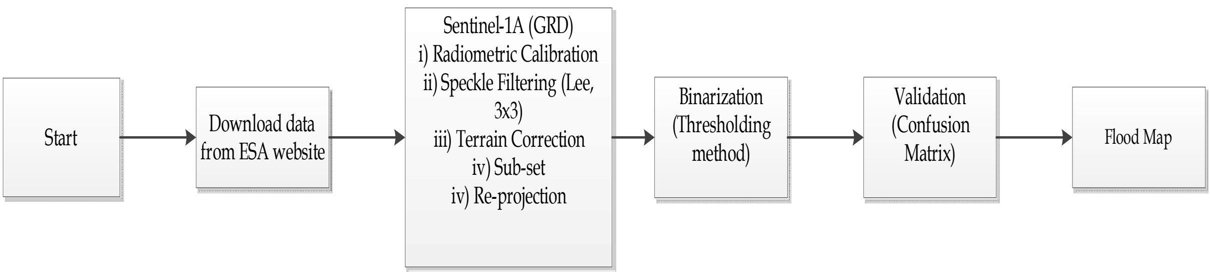

Figure 4. Flow chart of methodology

4. Results and Discussion

In urban areas, the study by Tavus [17] found that it is very difficult to detect the flood due to radar shadow, smooth surfaces, and steep incidence angle. The shadow areas and high density building areas would produce no backscatter which is appeared in dark-grey colour on map. This can cause confusion between flooded areas. The flood inundation mapping of study area was successfully produced by using threshold method. The threshold method is simple and easy for verify the flooded area from Sentinel-

1A image. It also shows that the Sentinel-1A data also able to produce the urban flood mapping. Figure 5 shows the flood inundation mapping of study area by using Sentinel-1A data.

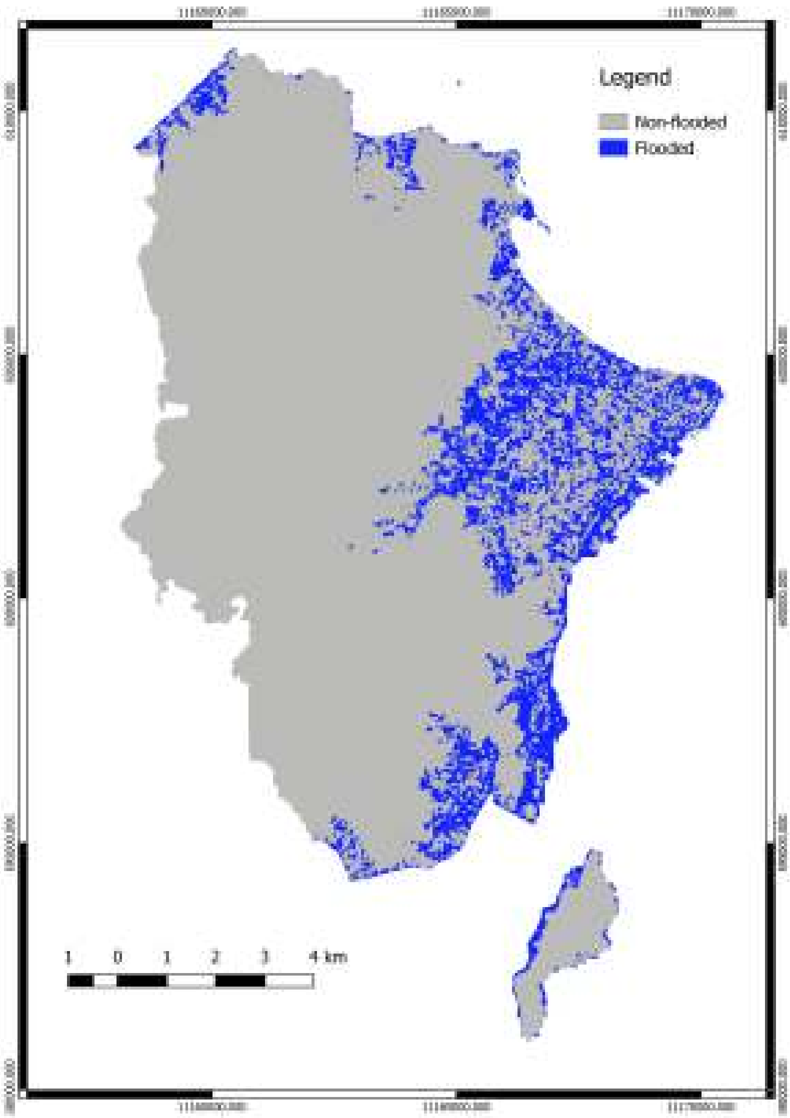

Figure 5. Flood inundation mapping of study area

For validation data, the confusion matrix was used to validate the accuracy of image classification. This method was widely used for image classification which is study by Elkhrachy [15], Mohammadi et al. [21], Kalantar et al. [22], Pradhan et al. [23], and Zhang et al. [23]. Threshold method can be analyse by using a simple cross-tabulation of the mapped class label against that ground control points data, provides an obvious foundation for accuracy assessment [24]. According to Kalantar et al. [22], this method provides the detail of model classification accuracy and also give useful info of model performance. Kalantar et al. [22] also stated that the confusion matrix also helps researchers to verify whether the system is misidentifying the two classes or fittingly classifying them. According to Mohammadi et al. [21], the overall accuracy formula shows in equation 1 and the kappa coefficient formula in equation 2.

$$OA = \frac{1}{n}\sum P_{ii} \tag{1}$$

where;

OA	Total Accuracy
n	total test pixels
$\sum P_{ii}$	total correctly classified pixels

$$K = (OA - \frac{1}{q})(1 - \frac{1}{q}) \tag{2}$$

where;

OA	total Accuracy
K	kappa coefficient
q	unclassified pixels

According to Pradhan et al. [23], confusion matrix method is able to establish the overall accuracy, producer accuracy, user accuracy, and kappa coefficient. In this study, 70 ground control points were recognized from field survey. These 70 ground controls points were used for validation. Table 2 shows the accuracy result of image classification using confusion matrix. The kappa coefficient of this study was found to be 0.776, at the 91.43% overall accuracy.

Table 2. Accuracy assessment using confusion matrix

	Producer's accuracy	**User's accuracy**
Non-flooded	0.882	0.789
Flooded	0.925	0.961

5. Conclusion

Urban flood mapping is complicated compare to river flooding due to its heterogeneity and spectral diversity [23]. The high building and high density of building can affect the accuracy of flood mapping. This is due to double bounce returns, when the radio waves reflect off the streets, and then off the buildings, and back to the radar [26]. The study also found that very difficult to detect the flood due to radar shadow, smooth surfaces, and steep incidence angle. The shadow areas would produce no backscatter value same as radar on smooth water surfaces. However, the Sentinel-1A data still able to produce the flood inundation mapping rapidly and easily. This would help the government agency in disaster preparedness, mitigation plan and make the evaluation of flood damages. The accuracy of mapping also shows that the Sentinel-1A is able to produce overall accuracy 91.43% and kappa coefficient 0.776. This result shows that the simple threshold method is able to generate high accuracy mapping and proved its efficiency in detecting the flood in urban area.

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