Flood Monitoring in Weifang City, Shandong Province based on Sentinel-1A SAR

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Abstract. Flood disasters pose numerous hazards which seriously endanger human life and property. Therefore, flood monitoring is essential. In August 2018, an unusual precipitation occurred in Weifang City, Shandong Province, China, causing severe flooding. By making full use of polarization information from Sentinel-1A SAR data before and during the disaster in Weifang City, we were able to employ the Doublet, Otsu and Region Growing methods towards VV and VH images to extract the water body information. To improve the accuracy of water body identification we took the intersection processing of VV and VH images before and during disaster respectively. Then we monitored the submerged area by taking overlay analysis of the results of before and during flood. The comparison analysis between these three methods and the InSAR result show that the Doublet method has the largest difference with the InSAR result and has the lowest recall and precision rate. The Otsu and Region Growing methods are equivalent, but the Otsu had a higher recall rate while the Region Growing method had a higher precision. The area of flood inundation in Weifang City based on the Otsu method is about 1892.7km², while the area of flood inundation according to the Region Growing method is about 1576.6km².

1. Introduction

Flood disasters are emergencies which have the characteristics of being short in duration but potentially causing great harm. In order to reduce the harm of flood disasters, it is necessary to make a rapid assessment of the location, extent and magnitude of the disaster. In particular, the determination of flood inundation area is the basis of disaster assessment.

Remote sensing provides an advanced tool for the assessment of flood inundation area. In recent years optical sensors, such as Sentinel-2 and Landsat-8 satellites, have been used to estimate the flooded area. However, optical sensors are passive, with the images capturing the solar reflectance of the earth’s surface or atmosphere, resulting in the sensor being unable to penetrate cloud cover [1]. When a flood occurs, the weather is often cloudy and rainy, and the optical sensor band cannot penetrate the clouds, so it is difficult to obtain effective ground information with optical sensors. This is the main disadvantage of optical sensors for monitoring flood.

Synthetic Aperture Radar (SAR) systems, such as Sentinel-1 satellites, work in the microwave band (1mm~1m). They are active sensors which emit a radar pulse and record the land surface return. Their
advantage over optical sensors is their ability to collect data through cloud cover and during the night [2-3]. A body of water acts as a specular reflector of the radar pulse, resulting in minimal signal returned to the satellite [4]. Consequently, various methods have been used within the literature to delineate water from SAR data [5-10].

Based on the Sentinel-1A SAR data released by European Space Agency (ESA), this research selects the data before and during the flood in Weifang City, Shandong Province, China in August 2018. In order to make full use of Sentinel data polarization, Doublet, Otsu and Region Growing method were applied to the VV and VH images to estimate the number of water body. Then the intersection of the two polarization images was taken to before and during disaster respectively. Finally, we got the information of water inundation through overlaying the water body of before and during disaster. By contrast to the result of InSAR method, in this paper, the recall and precision of these three methods are compared with InSAR method to determine which method is the most reliable.

2. Study Area and Datasets

The study area, Xiashan Reservoir, is part of the Weifang city, which features greenhouses in Shandong Province, China. The geographic extent of Weifang is marked by longitudes 118°10′E-120°01′E and latitudes 35°32′N-37°26′N with a total area of around 15859 km², as illustrated in figure 1. Weifang has a typical mainland monsoon climate, and the rainfall displays an uneven character with most precipitation occurring in summer. Xiashan Reservoir locates in this area, and it is the largest Reservoir in Shandong. The controlled drainage area of the Reservoir is 4210 km², with a total storage capacity of 1.405 billion m³. The region suffered from spatially and temporally variable flooding during August 2018, when storms “Capricorn” and “Gambia” brought widespread rainfall across eastern Shandong Province.

Figure 1 The geographical location of Weifang(red curve) Landsat ETM+ image and its surroundings, download from NASA Landsat Program. The yellow rectangle shows the location of Xiashan Reservoir.

Figure 2 The geographical location of Weifang Sentinel-1A intensity image. The yellow rectangle shows the location of Xiashan Reservoir.

The two Sentinel-1A SAR single-look complex (SLC) products (http://scihub.copernicus.eu) under Interferometric Wide Swath (IW) mode and the corresponding precise orbit data (http://qc.sentinel1.eo.esa.int) were collected to monitoring flooding (see Table 1). Sentinel-1 collects images in VH and VV polarization when in IW mode. Each image has a spatial resolution of about 5×20 m with double polarization. Auxiliary data includes China's county-level administrative divisions in 2010, GlobalLand30 surface classification data and SRTM-3 Version4 DEM.

In this study, GAMMA software is used for Sentinel-1A SAR data pre-processing, including orbit correction, multi-looking, registration, filtering, geocoding and radiation correction, and resampling. In
multi-looking processing, the apparent numbers of range and azimuth are 4 and 1 respectively, and Refined Lee filter is selected for images which not only eliminate speckle noise, but also retain image edge information. Finally, the backscattering coefficient ($\delta$) image with spatial resolution of 20 m and WGS-84 coordinate system was obtained. In this research, Xiashan Reservoir was selected as the sample areas (see figure 2).

| No. | Date           | Polarization | Resolution (m) | Information   |
|-----|----------------|--------------|----------------|---------------|
| 1   | 14 August 2018 | VV+VH        | 5×20           | Before Flood  |
| 2   | 26 August 2018 | VV+VH        | 5×20           | During Flood  |

### 3. Data processing

According to the principle of microwave scattering, the pixel value of SAR image is determined by the echo intensity of the targets. When the radar parameters are fixed and the complex permittivity changes are not obvious, the echo intensity is mainly determined by the shape and roughness of surface features. Different from the non-water body, the surface of a water body is relatively smooth and shows mainly specular reflection. Its backscattering coefficient is small, which shows dark hue in the SAR image. In this study, based on the backscattering characteristics of water pixels, Doublet, Otsu and Region Growing methods are used to extract water information from VV and VH images.

#### 3.1. Doublet Method

In 1996, Prewitt proposed the Doublet method, that is, if the statistical results of the image pixels present the obvious characters of a doublet, as shown in figure 3, the minimum value between the two peaks is selected as the threshold value to complete image segmentation. According to the backscattering characteristics of water body, the pixels whose value is lower than the threshold are regarded as water body.

![Figure 3 The principle of doublet method](image)

#### 3.2. Otsu

In this paper, Otsu method is adopted to obtain the optimal segmentation threshold $T$. According to the characteristics of backscattering coefficient of water pixel, the pixel whose value lower than the threshold $T$ is taken as water body; otherwise, it is non-water body. The threshold value acquisition formula is:

$$M(x) = \frac{\sigma^2(x)}{\sigma_1^2(x) + \sigma_2^2(x)}$$  \hspace{1cm} (1)
\( x \) is the pixel value of temporary threshold; \( \sigma^2(x) \) is the inter-clusters variances of free and no-free water bodies; \( \sigma^2_1(x) \) is the intra-clusters variance of water body; \( \sigma^2_2(x) \) is the intra-class variance of no-water body. \( \sigma^2_1(x) \) and \( \sigma^2_2(x) \) are obtained by statistics, \( \sigma^2(x) \) is obtained by:

\[
\sigma^2(x) = \omega_1 \times (\mu_1 - \mu)^2 + \omega_2 \times (\mu_2 - \mu)^2
\]

Equal to:

\[
\sigma^2(x) = \omega_1 \times \sigma^2_2(x) + \omega_2 \times (\mu_2 - \mu_1)^2
\]

\[
\omega_1 + \omega_2 = 1
\]

\( \omega_1 \) and \( \omega_2 \) are the proportions of water and non-water pixels respectively; \( \mu_1 \) and \( \mu_2 \) are pixel mean values of water body and non-water body respectively; \( \mu \) is the mean of the population of pixels.

The optimal threshold \( T \) is the corresponding pixel value \( x \) when \( M(x) \) goes to the maximum:

\[
T = \arg \{\max M(x)\}
\]

Water bodies before and after the disaster were extracted respectively and superimposed for analysis. Compared with the water bodies before the disaster, the expanded water areas after the disaster were the flood inundation monitoring areas.

3.3. Region Growing Method

The basic principle of Region Growing is that begin from several seed point, determine the growth rules and order, analysis the consistency of the surrounding pixels and the seed point, if the consistency conform to the growth rule, it is classified as growth area, if not, then discarded. The pixels which conform to the requirement become the new seed points, keep repeating the above step and the image segmentation is completed.

The effect of Region Growing method is determined by seed points and growing rules. Referring to the surface classification data of GlobeLand30, the mean value \( \mu \) and standard deviation \( \sigma \) of pixels in the water body of Weifang city was calculated. Setting \( \mu \) as the clustering center and beginning seed point, the growth rules for pixel value \( f(x, y) \) were as follows:

\[
(|f(x, y) - \mu|) < 3\sigma
\]

Then execute the algorithm to extract water body information.

3.4. Verification Method

3.4.1. Flood area extracted by InSAR method.

Coherence coefficient is the key of InSAR technology. Compared with other pixels, the surface of the water body is relatively smooth, its echo signal is weak, which is mostly gray in the image. Therefore, the fluctuation of pixel value in water region is also very small, which shows a good consistency and the coherence coefficient is also small. According to water characteristic, the appropriate coefficient threshold for phase unwrapping and suitable unwrapping level are selected to make the water area stand out in the interferometry image.

InSAR processing includes baseline estimation, interferogram generation, flattening, adaptive filtering and coherence calculation, phase unwrapping, phase/elevation conversion. After the interferogram is flattened, the interference phase expression is:

\[
\text{Phase} = \text{ATAN}[\text{Imag}(I)/\text{Real}(I)]
\]

\( \text{Real}(I) \) and \( \text{Imag}(I) \) represent real and imaginary parts respectively. Phase, \( \text{Real}(I) \) and \( \text{Imag}(I) \) were used for color synthesis to obtain the distribution of water areas. The relatively expanded water body in the disaster is the flood area acquired by InSAR method.

Evaluation. Comparing the results of three monitoring methods and InSAR method, the accuracy was evaluated by using recall rate and precision rate. The higher the recall rate, the higher the reliability of the extraction results; the higher the precision rate, the higher the monitoring accuracy.

\[
I = \frac{s(W_c) \cap s(W_e)}{s(W_c)}
\]

\[
P = \frac{s(W_c) \cap s(W_e)}{s(W_e)}
\]
\[ P_p = 1 - P \]  

\( I \) is the recall rate; \( P \) is the precision rate; \( P_p \) is the false alarm rate; \( S(W_r) \) is the pixel set of flood zone processed by InSAR; \( S(W_e) \) is the pixel set of flood zone processed by three methods.

4. Results

4.1. Doublet Method Result

Histograms were made from the VV and VH polarization modes of the Xiashan Reservoir before and during the disaster. As shown in figure 4, the four histograms all show obvious double-peak shapes. According to the histogram statistical results, determine the thresholds of the VV polarization data in the Xiashan Reservoir before and during the disaster were -15.69dB and -16.22dB. Therefore, the number of water pixels in the Xiashan Reservoir before the disaster was 324891; The number of water pixels of the Xiashan Reservoir during the disaster was 645489. Under the VV polarization mode, the number of flooded pixels in the Xiashan Reservoir was 320598. For VH polarization, the threshold to be extracted in the Xiashan Reservoir before the disaster is -24.15dB, so the number of water pixels in the Xiashan Reservoir before the disaster was 320598; The extraction threshold of the water body during the disaster was -22.79dB, so the number of water pixels in the Xiashan Reservoir during the disaster was 654361. Therefore, under the VH polarization mode, the number of flooded submerged pixels of Xiashan Reservoir was 266424; the flooded submerged areas extracted under the two polarization modes of VV and VH were intersected to obtain the flood extraction results of the two-peak method. Therefore, the flooded pixels number of Xiashan Reservoir based on the doublet method totalled 254379.

![Figure 4](image)

4.2. Otsu Result

The Otsu algorithm determined that the thresholds for the extraction of water regions in the Xiashan Reservoir before and during the disaster were -14.52dB and -16.21dB under the VV polarization; the thresholds for the extraction of the water regions before and during the disaster are -24.78dB and -20.41dB under the VH polarization. In the intersection of VV and VH, the numbers of water pixels from before and during the disaster were 297098 and 514379 respectively. The total number of flooded pixels of Xiashan Reservoir based on the doublet method was 217281.
4.3. Region Growing Result

For the VV and VH polarization data, the area of the water body was extracted using the Region Growing method and the intersection processing was performed to obtain the flooded water body (Figure 7). According to the monitoring results of the Region Growing method, after intersected processing, the total number of water pixels before the disaster of Xiashan Reservoir was 337919, and the total number of water pixels during the flooded was 535481. Finally, the end result was 197562.

5. Discussion

The flood inundation area of Xiashan Reservoir obtained by the doublet method, the Otsu method, and the Region Growing method were compared with the inundation area determined by the InSAR method,
as shown in Figure 8, and evaluated according to their advantages and shortfalls, as shown in the Table 2. The results show that the monitoring results of the doublet method are the most different from those of the flooded area obtained by the InSAR method, and the recall and precision rate are the lowest, so the detection result by Doublet was the worst. Because the doublet method is a completely statistical-based method, the threshold span before and during the disaster is large, and it has a high level of uncertainty; the Otsu and Region Growing methods have similar monitoring results, and the Otsu method has a higher recall rate but the accuracy was a little worse. On the contrary, the Region Growing had a higher accuracy, but the recall rate was lower. Due to Otsu being directly based on the threshold for monitoring, it is easily affected by the noise. The Region Growing method better avoids some noise effects because the seed point is selected as appropriate as possible, but it may also miss the detection of some local water bodies. The inundated area of Weifang City is 1892.7 km² and 1576.6 km², estimated by using Otsu method and Region Growing method respectively.

Table 2 The flood monitoring precision of Xiashan Reservoir

| Method       | $S(W_r)$ | $S(W_o)$ | $S(W_r) \cap S(W_o)$ | I/% | P/% | $P_r$/% |
|--------------|----------|----------|-----------------------|-----|-----|---------|
| Doublet      | 231527   | 254379   | 150987                | 65.2| 59.4| 40.6    |
| Otsu         | 231527   | 217281   | 182098                | 78.7| 83.8| 16.2    |
| Region Growing | 231527   | 197562   | 160876                | 69.5| 81.4| 18.6    |

6. Conclusions
In this study, based on sentinel-1A SAR data released by ESA and making full use of polarization information, we used the doublet, Otsu and Region Growing methods to monitor the flooded area of Weifang City in August 2018. We processed the intersection of VV and VH results to obtain more accurate flood coverage area. The results show that the detection effect of statistics-based doublet method performed the worst, with a very low recall rate and accuracy. The recall rate of the Otsu method was slightly higher than that of Region Growing method. Sentinel-1 data, as an open source data set, has good utilization value in thunderstorm season, especially when cloud coverage is large. Moreover, the characteristics of dual polarization information provide abundant information sources for flood monitoring.

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