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Review of Flood Events in the Amur River Basin

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Abstract: Due to the topography, floodplains are widely distributed in the Amur River basin, which covers an area of 2.05×10^7 km^2. However, as a border river between Russia and China, the lack of continuous embankments and reservoirs for flood regulation in the basin is one of the reasons for the increased flood risk. The study of historical flood events is the basis for flood risk management. Two basin-wide mega-floods occurred in Amur River in 1998 and 2013. In this study, the characteristics of these two floods were detected by remote sensing combined with geographic information analysis to provide basic data support for flood risk management in the Amur River basin.

1. Introduction

The Amur River is a major river in eastern Eurasia, originating in the Khentii Mountains of Mongolia and flowing into the Sea of Okhotsk via the northern side of Heilongjiang Province in China and the south-eastern side of the Khabarovsk Territory in Russia. It is an international river whose watershed includes the territories of China, Russia and Mongolia. The basin area is 2.05×10^7 km^2. The climate of the Amur River basin is a cold temperate humid monsoon climate influenced by the cold Siberian air mass in winter and the ocean in summer, with dry winters and precipitation concentrated in summer [1]. Precipitation from April to October accounts for about 90% of the total annual precipitation, with June to August accounting for 60-70% of the total.

The basin has well-developed flood plains, but there are no continuous embankments in the river channel, except in urban areas. There are no dams for flood control and flood control facilities are inadequate. As a result, the plains are frequently flooded during the rainy season [2]. The alluvial plains in China are breadbasket areas, and those in Russia are also expected to produce grain. If floods become more frequent in the future, the impact is expected to be more severe.

Flood damage affects not only the economy, but also human psychology and health. Flood risk management is currently the most effective and fastest way to reduce flood damage. As a basic information for flood risk management, the study of past flood history is extremely important for flood control on the Amur River. However, it is difficult to collect flood information because the basin is large and covers the territories of three countries.

In recent years, basin-wide floods have occurred in 1998 and 2013, exceeding historical water level records. The aim of this study is to map the inundation areas for the 1998 and 2013 floods using remote sensing. The production of flood history maps will be the first step in reducing the damage caused by flood inundation in the Amur River Basin.

2. Data and Methods

2.1 Remote Sensing Data

MODIS is an optical sensor developed by NASA. MODIS was launched on the Terra satellite on 18 December 1999 and on the Aqua satellite on 4 May 2002. Based on the absorption and reflection characteristics of water, we chose to use the 2 and 4 (near infrared and green) bands of MODIS for extracting flood area. Because MODIS sensors are mounted on two satellites in sun-synchronous orbit and can observe the same location up to four times a day, day and night, providing data with high temporal resolution. This study used MODIS data for 269 scenes received and processed in July, August and September 2013 during the flood period.

The 1998 flood event was also included in the analysis to clarify the spatial characteristics of the inundation area based on past flood events. The AVHRR was upgraded to 5 channels (AVHRR/2) for NOAA No. 7 and to 6 channels (AVHRR/3) for NOAA No. 15 and later. The observed wavelength range is from 0.58 to 12.5 μm. The AVHRR channel 1 of NOAA14 used in this study is from 0.58 to 0.68 μm, including green to red, and channel 2 is in the near-infrared region (0.724 to 1.00 μm). The AVHRR data of 378 scenes received and processed from July to September were used to extract the flood conditions in 1998.

In order to verify the credibility of the extracted flooded areas, a topographic verification of the extracted flooded areas was carried out in this study. SRTM DEM data were used for the topographic verification. To discuss the topographic and precipitation characteristics of the floodplain, SRTM DEM data were also used together with precipitation data from the Global Historical Climatology Network (GHCND) Monthly Summaries.

2.2 Extraction and Verification of Flooded Areas

The near-infrared band and the green band were used to extract flooded areas, taking into account the spectral characteristics of water bodies, which absorb electromagnetic waves with long wavelengths; channel 1, which contains green wavelengths, was used as AVHRR does not have a green band. Fig. 1 shows a flowchart of the process of extracting flooded areas based on satellite observations. First, the region of interest (ROI) of the flooded area was selected from the no cloud image for each sensor, and the spectral characteristics of the flooded area were obtained for the two bands (channels) mentioned above. If the same area was extracted as flooded more than twice in one day, we considered it to be a floodplain. For areas that were only extracted once a day, we determined whether they were clouds or shadows. Areas that were clouded or shaded were labelled 'no flooding' and areas that were not were labelled 'flooded'. Areas that meet the conditions of both bands are designated as floodplains. The area is characterised by old topographic features within the area that are prone to ponding and make it difficult for floodwater to drain away. If more than two consecutive days were extracted as inundated areas, they were determined to be extracted as flooded areas.

As the flooded areas are local to the floodplain, there are no significant wave heights on the flooded surface. Elevations in flooded areas should be lower than in non-flooded areas. We validated our floodplain extraction results with DEM data. The flooded areas were verified by randomly collecting their cross sections.

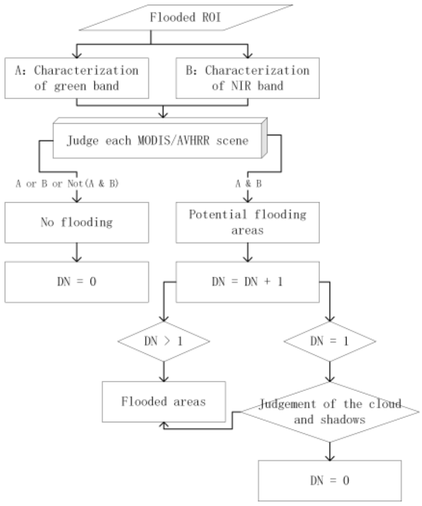

Figure 1: Flowchart for flood extraction

3. Results and Discussion

Fig. 2 shows examples of our validation of the extraction results. The flooded areas are shown in red and the original river body is shown in blue. The cross section shows the flooded elevation (including the river body) in red and the non-flooded elevation in yellow. From Figure 2 it can be seen that the elevations of our extracted flooded areas are all lower than the non-flooded areas. This proves that the accuracy of this study is reliable.

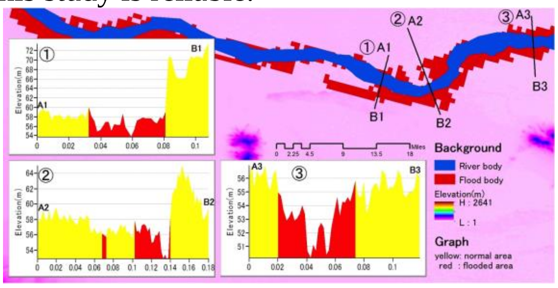

Figure 2: Sample of result verification

3.1 The Flood of 1998

Fig. 3 shows the flooded conditions of the 1998 Amur River flood based on NOAA/AVHRR data. Since the flooded areas along the river channel are relatively small compared to the basin area, the flooded conditions in the middle and lower reaches of the Amur River and its major tributaries are shown in the boxed areas. Fig. 3 shows that the flooded areas are distributed in the Nen River basin (E), the Songhua River (F), the Sanjiang Plain (B) and the middle and lower reaches of the Amur River (C and D). Although the entire river was flooded along its channel, the flooded area in the Nen River basin was observed to extend over the entire plain area. In particular, a large area of inundation was observed in the lower reaches of the Nen and around Khabarovsk in the north-eastern part of the basin.

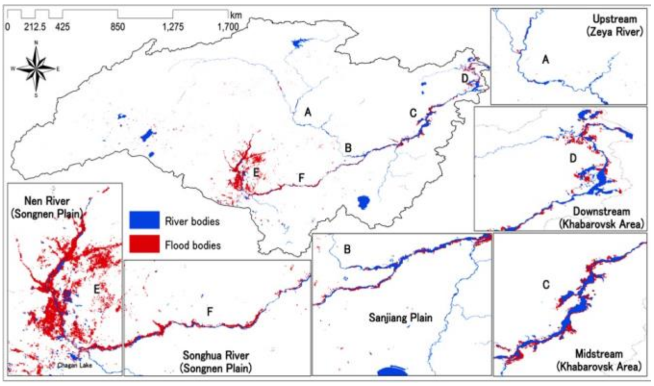

Figure 3: Flood event in 1998

3.2 The Flood of 2013

Fig.4 shows the river flooded conditions for the 2013 floods as obtained by Terra and Aqua/MODIS. As in Fig.3, the main flooded areas are shown in the boxes. The flooded areas in the middle and lower reaches of the main stream of the Amur River are larger than in the 1998 flood, and the Zeya River basin (A), an upstream tributary, is also flooded. In the Sanjiang Plain (B), the flooded areas along the Naoli River, a major river flowing through the plain, is wider than in 1998. In addition, the Ussuri River, which was not flooded in 1998, is also flooded.

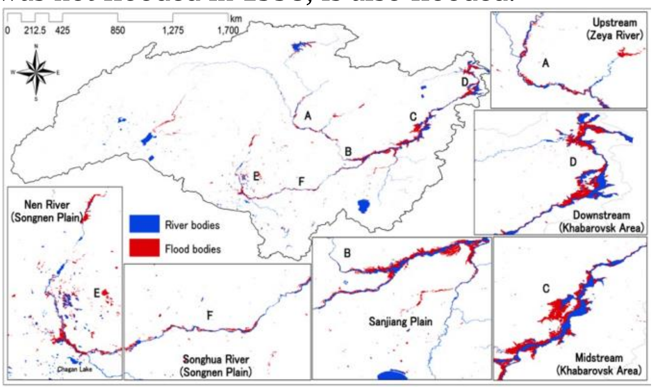

Figure 4: Flood event in 2013

3.3 Comparison of the 1998 and 2013 Floods

The major floods in 1998 and 2013 were mainly caused by the overflow of the Nen River, the Songhua River and the Amur River. In particular, there were no major floods in the middle and upper reaches of the Amur River (upstream of the confluence with the Songhua River) and the Ussuri River in the 1998 floods.

The flooded area of the basin in 1998 and 2013 was 52,883 km^2 and 47,016 km^2 respectively. The 1998 flood was larger, but mainly concentrated in the Nen River basin (Songnen Plain, E). In the 1998 flood, 26,635 km^2 of the Nen River basin was inundated, about half of the total flooded area. In the 2013 flood, the area inundated in the basin was 4,279 km^2, about one-sixth of the area flooded in 1998.

After the confluence of the Nen River, the Songhua River (F) was flooded in both the 1998 and 2013 floods. The downstream coastal area before the confluence of the Amur River (Sanjiang Plain, B) had a larger flooded area in the 2013 flood.

The Khabarovsk region of Russia, namely the middle (C) and lower (D) reaches of the Amur River, was inundated by both floods, but the flooded area was larger in 2013 than in 1998; the flooded areas in 1998 and 2013 were 15,016 km^2 and 23,005 km^2, respectively. In 2013, the flooded area in this region accounted for about half of the total inundated area.

Flood inundation should be considered from two perspectives: the amount and distribution of precipitation as an inducer and the topography as a predisposing factor. Therefore, the amount and distribution of precipitation and the topography are considered as direct causes of flood inundation.

1) Precipitation

Fig.5 shows the monthly precipitation during the flood periods (July, August and September) in 1998 and 2013, as well as the average monthly precipitation for each month from 1963 to 2013.

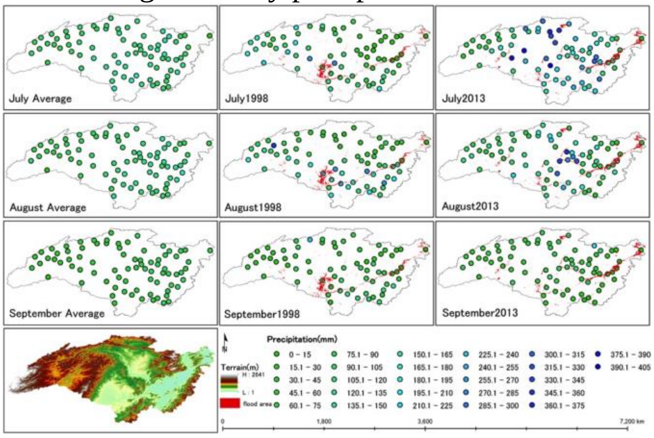

Figure 5: Comparison of precipitation

The average monthly precipitation for the whole basin during the flood period (July, August and September) was 114 mm, 104 mm and 60 mm respectively. However, in the Nen River basin (E), precipitation started to increase in July and continued until August, reaching a maximum of 40 days in these two months. In August, the precipitation area expanded and the average monthly precipitation in the basin was 1.7 times the normal. In the flooded areas of the Song Hua River basin (F), the Sanjiang Plain (B) and the middle reaches of the Amur River (C), the average total rainfall in August was 181.8 mm, 1.5 times the normal, and the number of rainy days reached up to 21. In the upper reaches of the Amur River (A), however, there was no significant change in precipitation compared to normal. In the lower reaches of the Amur River (D), precipitation did not differ from the normal year, but the 1998 floods inundated a large area. In September there was extensive flooding below Khabarovsk. The Amur is a continental river, which means that floods propagate downstream with a time lag of several weeks [3].

Precipitation was higher than normal in July and August 2013, with average precipitation in the Amur River Basin reaching 181.7 mm and 123.9 mm, respectively. In the central part of the Amur River Basin, monthly precipitation in July was significantly higher than normal from the southern to the northern part (A, B, E and F). The average monthly precipitation was 272.2 mm, 2.16 times higher than normal. The area with the highest precipitation in the basin was the mountainous area upstream of the Songnen Plain (E). There, total precipitation in July reached 384.5 mm, 3.81 times the normal. The average monthly precipitation in the Zeya River basin (A), a tributary of the Amur, also reached 328.1 mm, more than three times the normal. The maximum number of rainy days in the flooded area was 23, but precipitation decreased in August. The confluence of the upper Amur and Zeya Rivers (A: around the floodplain) and the hills in the northern part of the Songhua River (F) received more than twice the total precipitation for August, while most other locations returned to normal. The highest precipitation in August was recorded in the Upper Amur River Basin (A), where the maximum monthly precipitation reached 330.6 mm at each station. The maximum precipitation at the station with the highest precipitation was 23 days, and the other stations also had more than 16 days of precipitation.

In 2013, precipitation in the middle (C) and lower (D) reaches of the Amur River was below normal, but the flooded area was larger than in 1998. This may be due to the spread of floodwaters from the upper reaches of the Amur and its major tributaries, the Songhua and Nen river basins.

2) Topography

The slope distribution in the Amur River basin is shown in Fig.6. The extracted flooded areas almost correspond to alluvial plains. The slope of the flooded areas is almost always less than 0.2 °, indicating that floods are concentrated on gently sloping plains and cause flooding.

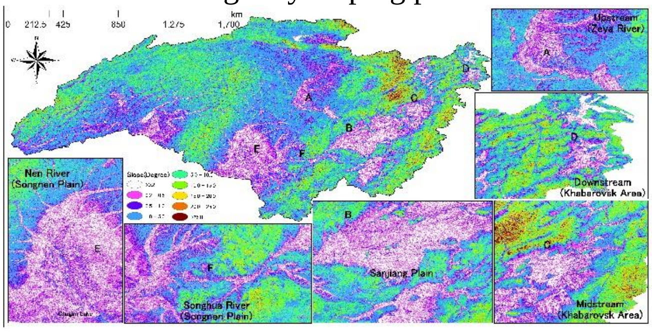

Figure 6: Slope of the Amur River basin

The Songnen Plain (E) is an alluvial plain formed by the Nen River and the Songhua River, and is flat with a slope of less than 0.5 °. Many old river channels (between natural embankments on both sides of the river) are scattered across the plain due to the transition of the river channel, and the lowlands behind the natural embankments are well developed. The floods in 1998 and 2013 were caused by the old river channel becoming a flood channel. In particular, in 1998, the upper reaches of the Songnen Plain experienced prolonged and continuous precipitation, causing flooding to spread to the lowlands behind the plain. The Sanjiang Plain (B) and the middle and lower reaches of the Amur River (C and D) have similar characteristics to the Songnen Plain and are prone to flooding.

In the Sanjiang Plain (B) and the middle and lower reaches of the Amur River (C and D), the slope of the plain is almost the same as that of the floodplain, about 0.2 °. In these areas, the distribution of remnant wetlands and old river channels is less pronounced than in the Songnen Plain, and the plateaus are well distributed near the rivers. The plateaus are well distributed near the rivers. Therefore, it is assumed that the flooded areas could not expand and the rivers inundated the coastal areas severely.

The flooded areas has two narrow areas. One is the valley bottom plain (F) between the Songnen and Sanjiang plains of the Songhua River, and the other is the confluence of the Amur and Zeya Rivers (A). Although the slope of the plains is less than 0.4 °, the water flowing from the mountains on either side of the plains did not cause widespread flooding in 1998 and 2013. This is because the river has a drop in elevation of about 3 to 20 m from upstream to downstream on the plains (B, C, D, E) and a drop of about 40 m over a short distance in the gorges (A, F), and the river channel slope increases in the gorges, increasing the water transport capacity.

4. Conclusions

The Amur River is a continental river with a large catchment area. As continuous embankments have not been constructed along most of the Amur River, flood risk management is an effective means of mitigating flood damage. Although flood history is a criterion for determining flood risk, it is difficult to collect flood information for the entire Amur River basin due to its large catchment area. The basin-wide floods exceeding historical water level records occurred in 1998 and 2013. Based on the empirical fact that flooded areas are more likely to be flooded again, a spatial analysis of flooding was conducted for the entire basin using remote sensing.

Floods in 1998 and 2013 caused extensive damage in the Amur River basin. As a result, we were able to identify flood-prone areas in the Nen River basin, the Songhua River basin, and the middle and lower reaches of the Amur River. Although the flood maps developed in this study are by no means complete, we were able to establish a procedure for improving the flood maps by accumulating flood inundation experience in the future.

The amount and distribution of precipitation as a trigger for flooding was analysed using the flood maps. The results showed that precipitation and its distribution were strongly related to the distribution of inundation areas. This suggests the possibility of predicting inundation areas based on precipitation observations in the future.

This is probably the first study of flood history in the Amur River basin. The flood history maps for the two flood events developed in this study can be used as a basic reference for future flood management.

Acknowledgments

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