ESTIMATION OF RIVER DISCHARGES WITH REMOTELY SENSED IMAGERY

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ABSTRACT: The transport of the sediment, carried in suspension by water, is central to hydrology and the ecological functioning of river floodplains and deltas. River discharge estimation is useful for demonstrating this information. In this study, we extracted MODIS reflectance values from a pixel near the river mouth after carrying out the simple atmospheric correction method, then applied single regression analysis to reflectance values and the *in situ* discharge of Monobe River in Kochi prefecture, Japan. MODIS images and *in situ* data were taken from January through December, 2004. As a result, Monobe River, robustly positive relationships between the discharges observed *in situ* and remotely sensed MODIS reflectance data in the region of river mouth were found throughout the year. In addition, we estimated the monthly discharge from the MODIS reflectance with the regression formula. As a result, *in situ* average discharge was well estimated. In the near future, we will apply the proposed method to Mun river in Thai land.

1. INTRODUCTION

The transport of sediment by water in rivers plays an important role in hydrology and the ecological functioning of river floodplains and deltas. River discharge estimation is useful for describing this phenomenon. In addition, if low-cost and continuous river discharge estimation becomes available, it is expected that communities with fewer financial resources such as those in developing countries could easily use this information for constructing effective flood control infrastructure such as dams and levees. One measure generally used for recognizing sediment transport is suspended sediment concentration (SSC), the mass of sediment entrained within a unit volume of water. Satellite remote-sensing technology is useful in tracking spatial and temporal variations in SSC, especially in regions containing large, remote or complex hydrologic environments where *in situ* observations are not practical or sufficient. Most researches attempting remote sensing of SSC have constructed empirical relationships between reflectance and *in situ* measurements monitored at the same time in the field [*Curran and Novo*, 1988; *Nellis et al*., 1998; *Woodruff et al*., 1999; *Islam et al*., 2001; *Schmugge et al*., 2002; *Miller and McKee*, 2004; *Hellweger et al*., 2006; *Shi and Wang*, 2009]. In addition, suspended sediment concentrations (SSC) normally show a robust empirical relationship with such hydraulic flow parameters as discharge and velocity [*Leopold and Maddock*, 1953; *Maidment*, 1993]. These facts raise the possibility of directly estimating river discharge or velocity from reflectance remotely sensed by satellite.

Although the number of researches addressing the above-mentioned issues is not large, *Pavelsky and Smith* [2009] estimated surface flow velocity from remotely sensed reflectance in the Peace-Athabasca Delta (PAD) in Canada. In that study, SPOT and ASTER images were used for analyzing surface flow velocity, but the time resolution of these sensors was not sufficiently high. In addition, SPOT and ASTER images are more or less expensive for frequent usage.

In our study, MODIS (MODerate-resolution Imaging Spectroradiometer) images are used for estimating river discharge. MODIS images are taken every day and can be used for free. Although it is an advantage of observation by MODIS that it can take images once a day, the narrow width of target rivers means that the spatial resolution of this sensor is too low to extract reflectance data directly from the pixel corresponding to the place *in situ* discharge observations have taken place. In order to solve this problem, in this study, we extracted MODIS reflectance values from a pixel near the river mouth, then applied single regression analysis to reflectance values and the *in situ* discharge data that were gathered the same days the satellite images were taken. In addition, we estimated the monthly discharge from the MODIS reflectance with the regression formula.

2. STUDY AREA AND USED DATA

.In this study, the river studied was the Monobe River, which run through Shikoku Island, the fourth-largest island in Japan, located in the southwestern part of the country as shown in Figure1. Monobe River have very clear water. This river had been designated “the most limpid river in the Shikoku Island” by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan.

All in situ measurements of river discharge were corrected by MLIT. In the Monobe river, discharge data was taken once a day throughout 2004 at Fukabuchi (point A in Figure 1).

To assess the reflectance in the Monobe River, 61 images were acquired throughout 2004. In this study, band 1 (red) Level 1B images, which are radiometrically and geometrically corrected by NASA, were used. The relationship between SSC and the red band of the spectrum has often been utilized in past studies [*Curran and Novo*, 1988; *Nellis et al*., 1998; *Woodruff et al*., 1999; *Islam et al*., 2001; *Schmugge et al*., 2002; *Miller and McKee*, 2004; *Hellweger et al*., 2006; *Shi and Wang*, 2009]. In addition, past studies have suggested that reflectance values from one sensor acquired on a number of dates can be successfully combined without biasing the relationship between SSC and reflectance. Therefore, we applied single regression analysis to the entire reflectance data and *in situ* discharge data in each river.

Although it is an advantage of observation by MODIS that it can take images once a day, the narrow width of target rivers means that the spatial resolution of this sensor is too low (250m in band 1) to extract reflectance data directly from the pixel corresponding to the place *in situ* discharge observations have taken place. In order to solve this problem, in this study, we extracted MODIS band 1 reflectance values from a pixel near the river mouth (point B in Figure 1), then applied single regression analysis to reflectance values and the *in situ* discharge data that were gathered the same days the satellite images were taken. That way, if our method proved effective, discharge estimation with MODIS could be applied to any narrow river.

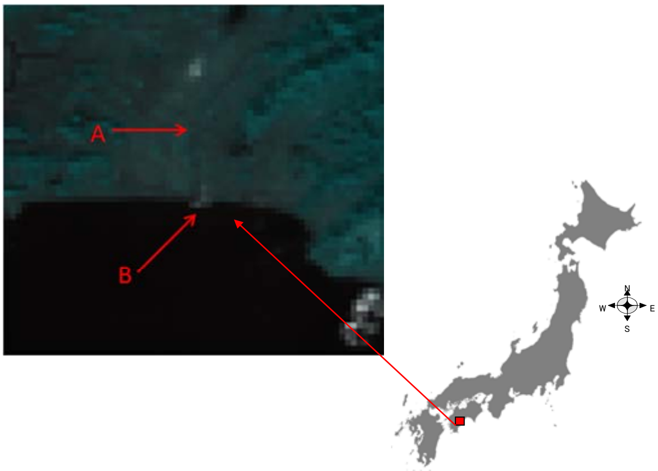

Figure 1. Location of Monobe river and the MODIS images

3. A SIMPLE ATMOSPHERIC CORRECTION METHOD WITH DARK PIXEL

In many previous studies that have estimated SSC from satellite images, some atmospheric correction method was used for accuracy enhancement. Therefore, in this study, which performs analysis closely related to the estimation of SSC, it was expected that some sort of atmospheric correction method was required. To remove the effect of the atmosphere from the analysis results, we used a simple atmospheric correction method with dark pixel

3.1 Characteristics of Radiation Transfer in Water

If the SSC in river water is raised by an increase of river discharge, the amount of backscatter will increase because solar radiance is partially reflected by suspended sediment. Therefore, the water surface reflectance value in rivers containing high levels of SSC becomes higher than that of rivers with low SSC. To estimate the river discharge, we calculate backward from the water reflectance value. Satellite sensors such as MODIS observe radiation from the Earth and convert it to DN values. However, these values contain effects that are not related to increasing or decreasing river discharge such as atmospheric radiation and direct reflection by the water surface. For accurate river discharge estimation, we need to remove these effects by an atmospheric correction method.

3.2 Selection of Dark Pixel

The atmospheric effect is eliminated by obtaining the difference between original pixel and dark pixel value. In this study, the dark pixel, which has the lowest reflectance value in the coastal area, was used. However, the view angle of MODIS is so wide that the thickness of the atmosphere would change if a pixel located far from the river mouth was used for extracting the lowest reflectance value. Therefore, in this study, the area where the pixel used for extracting the dark pixel could be chosen was the lowest reflectance value in the coastal area roughly limited to the offshore area in the middle distance from point B shown in Figure 1.

4. RESULTS

Figure 2 shows the scatter plots of remotely sensed reflectance (corrected and pre corrected) and *in situ* river discharge. Discharge and satellite images were taken during 2004 (3^{rd} January to 27^{th} December, 61 data points). The unit of original discharge data was m^3/second. It can see that a positive relationship between reflectance of MODIS band 1 and *in situ* discharge throughout a year. And also, the robustness of the relationship was obviously strengthened by applying atmospheric correction.

We also estimated the monthly average river discharge of Monobe River with the regression formula. Figure 3 shows scatter plots of estimated monthly average discharge and monthly average discharge of observational days. The estimated discharge obtained with the corrected regression formula was more accurate than the discharge obtained without correction.

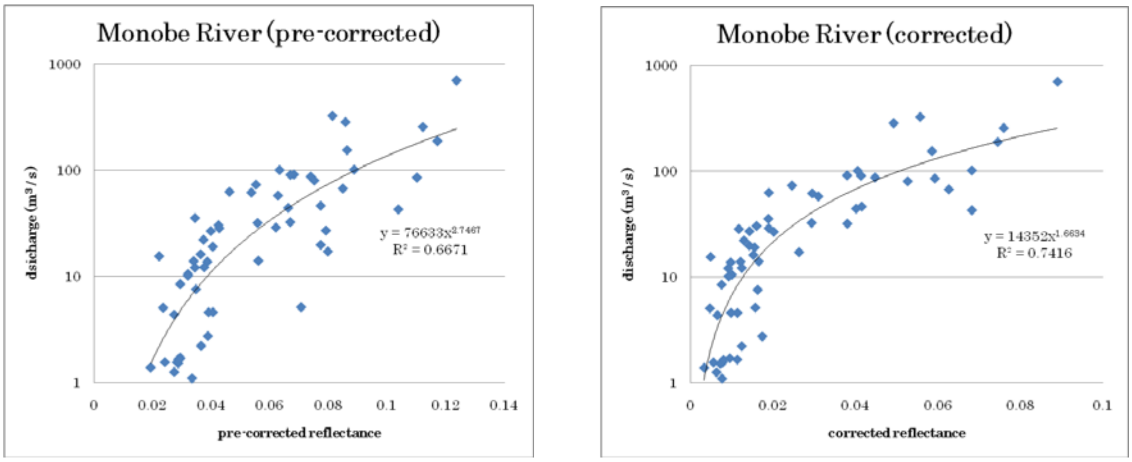

Figure 2. Scatter plots of MODIS reflectance (corrected and pre-corrected) and *in situ* river discharge at Monobe river.

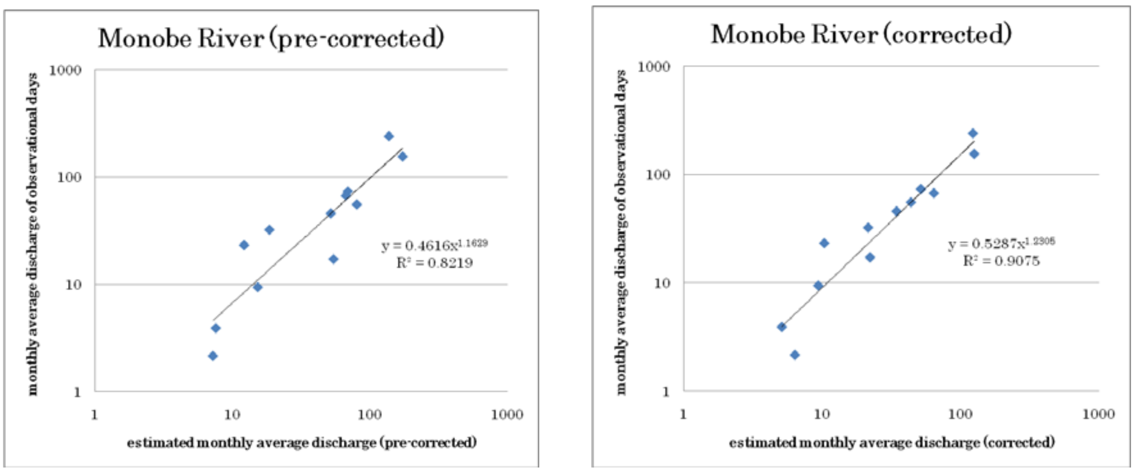

Figure 3. Scatter plots of the estimated monthly average discharge and the original monthly average discharge at Monobe river.

4. DISCUSIION AND CONCLUSIONS

There are two principal conclusions to be drawn from these analyses. The first is that there is a strong statistical relationship between discharges observed *in situ* and remotely sensed MODIS reflectance data in the region of river mouth. Also, the accuracy of discharge estimation became much stronger by adopting an atmospheric correction method.

The second is that by using the regression formula obtained with discharge and reflectance value (with correction or not with correction), we can estimate monthly average discharge. The accuracy of the estimation was especially high in estimating average discharge with the corrected regression formula. Also, the number of monthly data showed little effect on the accuracy of estimation.

These results suggest that we may be able to estimate river discharge using MODIS or satellite sensors with low special resolution. This will enable communities with limited financial resources to gain discharge information for use in various applications via continuous, low-cost river-flow analysis. An important challenge for the future that will improve the accuracy of the analysis will be to adopt the tank model to comprehend the transport of water and sediment, with parameters such as distance between river mouth and observational point, amount of precipitation, and length of time elapsed since precipitation occurrence.

Furthermore, in the near future, we are planning to apply the proposed method to Mun river in Thai land.

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