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Flood risk assessment using MLSWI by MODIS Time Series data

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Abstract: The principal purpose of this study is to describe the development and validation of an algorithm to estimate the fraction of water area within 500-m of the Moderate Resolution Imaging Spectroradiometer (MODIS) operating on the Earth Observation System Terra spacecraft. The result of this study is shown to be effective in determine the flood areas accurately in emergency response efforts as soon as possible. Estimation of a flood periphery is important to determine a fundamental hazard for risk management. This study was to accurately extract the spatial distribution of nation-wide flood risk using MODIS time series images and estimate simple algorithm for computing the flood inundation depth using Digital Elevation Model(DEM), flow direction and river network. The authors improved the accuracy of the water extent boundary using flood inundation depth (FID) data from a one year time-series of MODIS data.

Keywords: Flood risk, flood inundation depth (FID), DEM, MODIS, time-series.

1. INTRODUCTION

Floods are of increasing public concern world-wide due to increasing damages and unacceptably high numbers of injuries. Previous approaches of flood protection led to limited success especially during recent extreme events. Therefore, an integrated flood risk management is required which takes into consideration both the hydrometeorological and the societal processes.

Real-time determination of flood inundation has been limited to large-scale events such as nationwide inundation. The geographic information system (GIS) including satellite images is an effective method to interpret and analyze a nation-wide flood risk assessment. Moreover, satellite images are also necessary to analyze flood disasters. Remote-sensing images are an effective tool to determine flood inundation areas. Estimation of a flood periphery is important to determine a fundamental hazard for water risk management. Many studies have been conducted by using remote-sensing data to detect spatial and temporal changes in the extent of flood inundation, including the delineation of wetlands [1][2]. The Normalized Difference Water Index (NDWI), a satellite-derived index from near-infrared (NIR) and short wave infrared (SWIR) channels [3], is used to derive water fraction and a flood map from MODIS data. The SWIR reflectance reflects changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies, while the NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content. The combination of the NIR with the SWIR removes variations induced by leaf internal structure and leaf dry matter content, improving the accuracy in retrieving the vegetation water content [4].

The land surface water index (LSWI) use a red channel in place of NIR [1][5][6] used enhanced vegetation index (EVI), LSWI and DVEL (difference value of EVI and LSWI). However, it can be difficult to discriminate water body from clouds in the visual part of the spectrum. Also, it was not easy to extract the river width accurately because of a resolution problem in each a pixel. In this study, the proposed method was applied to extract water body from a channel reflectance by using MODIS time-series images and flood inundation depth (FID). This simple approach was to determine nation-wide inundation areas from a geomorphologic point of view, rather than a hydrological model.

The purpose of this study was to accurately estimate an inundation area based on the spatial distribution of flood hazard for nation-wide flood risk assessment using GIS data and MODIS time-series images. To determine the water extent boundary more accurately, the authors aimed to improve an extraction method of surface water with a simplified decision tree method using MODIS channel 6 reflectance (CH6) and channel 7 reflectance (CH7) acquired from a regional flooding. The improved method was then applied to the Indus River basin in Pakistan, which was selected as the prime research focus area. The selected area suffered from a huge, severe flood caused by abnormally heavy rainfall from late July to early August 2010.

2. DATA

2.1 MODIS MYD09A1

The MODIS Surface Reflectance products provide an estimate of the surface spectral reflectance as it would be measured at ground level in the absence of atmospheric scattering or absorption. MYD09A1 provides channels 1-7 at 500-meter resolution in an 8-day gridded level-3 product in the Sinusoidal projection. Each MYD09A1 pixel contains the best possible L2G observation during an 8-day period as selected on the basis of high observation coverage, low view angle, the absence of clouds or cloud shadow, and aerosol loading. Science datasets provided for this product include reflectance values for channels 1-7, quality assessment, and the day of the year for the pixel along with solar, view, and zenith angles[7].

2.2 Flood inundation depth

Topography is an essential factor for hydrologic models to simulate flooding and runoff. One of the most obvious factors controlling stream flow is the gradient, or slope, of the stream channel. The definition of FID is the accumulated level index overflowing the banks of a main river. It is clear that FID indicates the depth due to overflowing the banks of a river and can be defined as the accumulated level index. Kwak & Kondoh [8] developed and proposed FID for basin-wide flood risk assessment at the national level. Actual calculation of FID required a dataset composed of DEM, flow direction and river network. FID was determined based on DEM and the highest water level (HWL) of the main stream, as shown in equation (1) below:

$$H\_{ij}\ FID = H\_{ij}(DEM) - H\_{ij}(HWL\ of\ river) \qquad (1)$$

where, H is the height of surface, i is the number of pixels, and j is the number of lines.

3. Methodology

3.1 Extraction of water body

MODIS channels were strongly absorbed by water, providing information on the inundation pattern. Fig. 1 illustrates that the reflectance rate of clean water was the lowest among the classification of soil, vegetation, snow, cloud and clean water (up of Fig. 1). Particularly, the authors found that the reflectance rates of CH6 and CH7 were the lowest than the other channels in the case of surface water such as clean water, muddy water, and flooded water (down of Fig. 1). Flood hazard assessment was performed by using MODIS dataset with FIL, population and land-cover data. The developed approach was to determine inundation areas nation-wide from a geomorphologic point of view, rather than based on a hydrological model. First of all, to identity spatial inundation distribution, a decision tree was used to associate each pixel with one of the two categories: water body or land surface.

For flood risk assessment, the quantitative assessment was divided into three steps. To estimate flood areas, two categories of the MODIS images, water and non-water areas, are combined to obtain the maximum water area. The water areas were considered to be normal water such as river, lake, pond, and so on, and the non-water areas are considered to be non-flood areas. The main stream in the Indus River basin and the water areas were extracted to composite images derived from 46 image dataset in 2009.

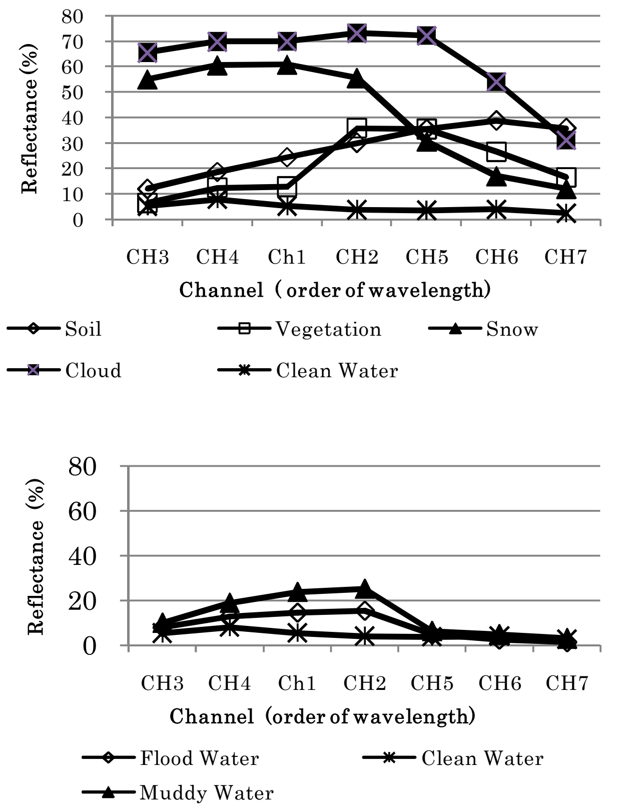

Fig. 1. Surface reflectance of MODIS land channels (up) and reflectance rate in case of surface water (down)

The MODIS channels were strongly absorbed by water, providing information on inundation patterns using Normalized Difference Index (NDI). However, the NDWI and LSWI have some weaknesses and errors to extract water bodies. For instance, the spectral reflectance rate of water is higher than that of a forest (e.g., forest = 0.14, clean water = 0.1). To assess a flood area, MLSWI was used an absorption ration instead of a reflection ration as follow; Absorption ration (A) = 1 – Reflection ration (R). The new approach also worked well to differentiate water from land under three conditions: CH7 < 10%, CH1+10% > CH2 and CH3 < 20%, where MODIS MYD09A1 land channels.

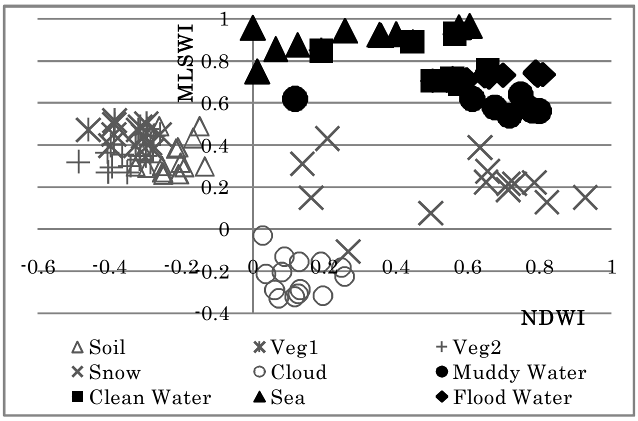

Fig.2. The index comparison of a land classification between MLSWI and NDWI for extracting flood areas

Equation (2) is a simple algorithm for identifying inundation areas by using combination of the NIR (841-875mm) with the SWIR (1628-1652mm).

$$\mathrm{MLSWI} = \frac{A_{SWIR} - R_{NIR}}{A_{SWIR} + R_{NIR}} \quad (2)$$

As shown in Fig. 2, MLSWI can detect flood areas better than NDWI. MLSWI shows indices over 0.5 when detecting bodies of water, clean water and muddy water in flood areas. On the other hand, NDWI cannot distinguish water from land especially when the area contains snow cover, which shows indices of over 0.5. Second, the authors overlaid the FIL data and the extracted water areas which are covered two water areas (stream and flood areas) derived by MLSWI. It was considered as a major influencing factor on flood areas. The accumulated FIL of the target pixel was raised at 1 meter intervals. The calculated FIL provided a basis to estimate the flood extent areas of flood levels and inundation line in lowlands and near-zero gradients along the stream per 500 m-mesh. Potential FIL was conducted to identify flood inundation height and inundation probability. Finally, the flooded-area data obtained based on MODIS images and FIL are coupled with population and land cover datasets to estimate disaster damage. For each scenarios of the damage, the respective inundation depth and areas were obtained by extreme flood event, because FIL was a extreme analysis to the calculated results. Therefore, each exposed object can be linked to a distribution risk map related to potential FIL. FIL improved the simulation to clearly show that people living in the lowlands are more affected than those in other places. The land-cover data also improved it to identify flood risk per classification and enable damage estimation per 500 m mesh. Population and land cover classification schemes were proven very useful to assess flood damage over lowlands.

4. Result

Based on the flood water extent results, the authors conducted to identify expected flood inundation depth per 250 m-mesh. The periphery of flooded areas is directly correlated with an inundation depth around the river. Therefore, it was clear that flood inundation depth (FID) indicated the depth due to overflowing the banks of a river and can be defined as the accumulated level index. From Fig. 2 (Indus River basin), it can be concluded that, the FID of inundation area has a value ranging from -1 m to 9 m. Examining the relationship between FID ranges and MODIS images under the flooding, it was found that the inundation area was extracted 70253 pixels, 4390.8 km2 in the Indus River basin from late July to early August in 2010. For instance, the inundation area under the condition of FID = 0 m was estimated to be 31444 pixels, about 4390.8 km2. The inundation area under the condition of FID = 1 m was also estimated to be 8622 pixels, about 538.9 km2. The inundation area under the condition of FID = 2 m was also estimated to be 6468 pixels, about 404.3 km2. In detail, the right of Fig. 2 shows the enlarged view of a partial Punjab Province, Pakistan.

5. CONCLUSION

This is a case study considering the independence of the data sources and the resolution of the data available at the national level. Although flood is controlled by various risk factors, the flood vulnerable area was extracted from GIS-derived data such as FID and satellite images. To conclude flood risk assessment, the authors focused on improvement of the accuracy in determining a vulnerable inundation area using a simplified decision tree method based on MODIS time-series images in the Indus River basin, Pakistan. This new approach can be a very useful tool in emergency response efforts since it can conduct extreme value analysis and predict when and in what size a flooding event may occur. The water extent area can be classified a category of land cover for flood risk assessment affecting nation-wide flood damage based on FID. In the future, the authors are planning to improve the proposed assessment to be applicable on a national, as well as, global level.

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