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RESEARCH PAPER

Flood monitoring and damage assessment using water indices: A case study of Pakistan flood-2012

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Abstract This paper uses Normalized Difference Water Index (NDWI) of McFeeters (1996), Water Index (WI) introduced by Rogers and Kearney (2004), referred to as Red and Short Wave Infra-Red (RSWIR) and WI suggested as the best by Ji et al. (2009), referred to as Green and Short Wave Infra-Red (GSWIR) for delineating and mapping of surface water using MODIS (Terra) near real time images during 2012 floods in Pakistan. The results from above indices have been compared with Landsat ETM+ classified images aiming to assess the accuracy of the indices. Accuracy assessment has been performed using spatial statistical techniques and found NDWI, RSWIR and GSWIR with kappa coefficient (κ) of 46.66%, 70.80% and 60.61% respectively. It has been observed using statistical analysis and visual interpretation (expert knowledge gained by past experience) that the NDWI and GSWIR have tendencies to underestimate and overestimate respectively the inundated area. Keeping in view the above facts, RSWIR has proved to be the best of the three indices. In addition, assessment of the damages has been carried out considering accumulated flood extent obtained from RSWIR. The information derived proved to be essential and valuable for disaster management plan and rehabilitation.

1. Introduction

Pakistan is a flood-prone country with a history of widespread and repeated flooding that causes loss of lives, substantial damage to property, infrastructure, loss of agricultural crops and land (Sardar et al., 2008). It has two dominant types of floods i.e. riverine and flash. The riverine flood, mainly originating from glacier melt as well as extreme weather events, is predictable which in result allows sufficient time to react whereas the converse is true for flash floods. Flash floods, originating from extreme weather events, have relatively less duration but intensity and impacts are severe. These floods normally occur during the South Asian monsoon period between July and September.

The country has been continuously experiencing major floods since 2001. The major flood in 2010 inundated an area of 70,238 km^2 and affected around 884,715 homes (Haq, 2010). In 2011, another major flood caused an inundation of

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21,200 km^2, affected 5.88 million people, 1500 km of road network, 382 km of railway tracks, 498 km^2 of forests and 16,440 km^2 of agricultural land (Haq et al., 2012). In this year, moderate scale rains have been observed, starting from August and intensified in September, resulting in huge economic losses, destruction of ecological sources, food shortage and starvation of thousands of people. During the first half of September, widespread rains were experienced throughout the country, which severely affected the areas of Punjab, Sindh and Balochistan provinces. During 06–11 September, Jacobabad, Larkana, Sukkur, Thatta and Tharparkar in Sindh received heavy rains resulting in flood. In addition, rains in Balochistan not only brought disaster in Balochistan but also the districts of Sindh received devastating flash floods due to hill torrents in the Suleman range. In Punjab, Rahim Yar Khan, Sahiwal, Okara, Jehlum, Mandi Bahaudin, DG Khan and Rajanpur experienced extensive and continuous downpour from 08 to 12 September. The available daily rainfall data of 8 districts for the months of August and September are given in Table 1(a) and (b).

Estimation of Land surface water (area), which includes rivers, lakes, wetlands and flood inundated areas, plays an important role in the evaluation of the water cycle. With global climate change and the growing influence of human activities, river changes (Xu, 2004; Xia and Zhang, 2008), shrinkage of wetlands, glacier melting (Chen et al., 2007), flooding, and other spatial and temporal distribution changes in surface water resources are increasingly highlighted. A variety of studies have been focused on impact assessment to flood disaster on different groups of people and communities (e.g., Schmuck-Widmann, 1996; Rashid, 2000; Rasid and Haider, 2003) and found the poor people to be hardest hit (IPPC, 2001).

Modern techniques of remote sensing provide tremendous potential for monitoring and managing dynamic changes in large surface water bodies; extracting hydrological parameters, and modeling the water balance (El Bastawesy, 2015; El-Gamily et al., 2010). McFeeters (1996) proposed the Normalized Difference Water Index (NDWI) using Near Infrared (NIR) and green channels of Landsat that can delineate and enhance open water features. Xu (2006) modified the NDWI proposed by McFeeters (1996) by substituting the middle infrared band for NIR band. The NDWI defined as (refl (0.86 µm) – refl (1.24 µm))/(refl (0.86 µm) + refl (1.24 µm)), was introduced by Gao (1996) for extracting vegetation liquid water. Rogers and Kearney (2004) introduced NDWI using red and Short Wave Infra-Red (SWIR) channels of Landsat TM. Xiao et al. (2005) defined a Land Surface Water Index (LSWI) using NIR and SWIR bands of MODIS. Ouma and Tateishi (2006) proposed a new Water Index (WI) for shoreline edge extraction using a logical combination of Tasseled Cap Wetness (TCW) index and NDWI using Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) data. Wu et al. (2008) introduced a new combinated method for extraction of water body information using ETM+. The method is based on combining the spectral relationship between different bands with the TCW index and removing other objects from the mask image using maximum likelihood classification methods. Li and Zhou (2009) presented a method for Mountain area Enhanced Water-body Identification (MEWI) through the Normalized Difference Vegetation Index (NDVI) and red band of MODIS. Ji et al. (2009) used spectral data to simulate the satellite sensors data and calculated the simulated NDWI in various forms and concluded that the calculated NDWI from (Green – SWIR)/(Green + SWIR), where the SWIR is a region from 1.2 to 1.8 µm, has the most stable threshold. Ling et al. (2010) used the Combined Index of NDVI and NIR for Water Body Identification (CIWI) aiming to extract coastal wetlands water information using Landsat TM images. Lu et al. (2011) proposed an integrated water body mapping method through combination of difference between NDVI and NDWI (NDVI–NDWI) with slope and NIR band using HJ-1A/B satellite images.

In this paper, we have selected three water indices proposed by McFeeters (1996), Rogers and Kearney (2004) and Ji et al. (2009). The methods selected in this study are due to their generality in delineating and enhancing surface water features. The high temporal resolution of MODIS images used in this study played a major role in monitoring the 2012 floods in Pakistan. The paper recommends the best of the three mentioned indices for mapping flood inundated areas and to assess the damage caused by the 2012 floods in the country.

2. Study area

The study area includes 20 adjacent districts of the Baluchistan, Khyber Pakhtunkhwa, Punjab and Sindh provinces of Pakistan ranging from 26°5′13.9″ to 33°13′2.21″ in latitude and 67°6′52.68″ to 72°0′15.86″ in longitude (Fig. 1). On average the mountainous area of the study area receives 200–960 mm rain annually and rest of the area, which is mostly plain, receives 180–460 mm rain annually.

3. Methodology

Five images of MODIS onboard the TERRA satellite acquired in 0.5 km resolution through NASA's website "http://rapidfire.sci.gsfc.nasa.gov/realtime/", have been used as a main input to map flood inundated areas. Images have been geo-referenced using the header file allied with the data. The study area has been extracted from the images using District administrative boundaries. Cloud shadow was frequently identified as water, by most water indices. So careful removal of cloud shadow using visual interpretation has been carried out. Cloud masking has been performed using NIR (band 2 of MODIS) by clipping the image that has reflectance above 0.7 as the spectral reflectance of cloud is greater than 0.7 in NIR region.

Flood mapping has been carried out using NDWI, RSWIR and GSWIR as shown in Eqs. 1–3 respectively by setting the threshold from 0 to 1. Two images of Landsat ETM+, having path 152, row 041, of September 17, 2012 and October 03, 2012, have been acquired for accuracy assessment of the results obtained through mentioned indices. A standard supervised maximum likelihood classification of Landsat ETM+ images has been performed. Validation of the classification has been performed by visual interpretation of Landsat ETM+ images using false color 543 composite. Contingency matrix and its allied statistics (i.e. overall accuracy, producer's accuracy, user's accuracy and kappa coefficient (κ)), reported at Congalton (1991), have been performed for accuracy