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Monitoring the spatiotemporal dynamics of waterlogged area in southwestern Bangladesh using time series Landsat imagery

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ABSTRACT

Waterlogging is becoming a major environmental problem and challenge for socio-economic development in the southwestern part of Bangladesh. In this study, the Satkhira district was selected as the study area to quantify waterlogging area delineation. To portray these dynamics, Landsat imageries from 1973, 1989, 1995, 2000, 2005, 2010 and 2015 were used. A training dataset was generated in ArcGIS, and a supervised classification was carried out using the random forest algorithm in the R Studio. The overall classification accuracy and kappa statistics was 95% and 91% respectively. Post-classification change detection comparisons were made in QGIS to calculate the transformations of the respective land cover areas in the study site. Areas of approximately 832, 3033, 13,562, 11,547, 27,162, 40,056, and 35,606 ha were observed as waterlogged in the above mentioned years, respectively, which indicates that the acreage of waterlogged areas increased approximately 43 fold from 1973 to 2015. Moreover, the Land Use Land Cover (LULC) change matrix showed that waterlogged area was increased from 5% to 12% during 2000–2005, further rose from 12% to 18% during 2005–2010 and decreased from 18% to 16% during 2010–2015. The most water logged sub-district was Debhata (38%) while Koloroa has the lowest (4%) waterlogged area. The study is an effort to reconstruct the history to understand the dynamics of the waterlogging as past ground monitoring information is absent. Regarding environmental degradation, the government and development agencies should consider these results a critical issue in the entire southwestern part of Bangladesh.

1. Introduction

Global surface water has great importance as it affects the climate, biological diversity and human well-being (Miah et al., 2017; Pekel et al., 2016; Abdullah and Rahman, 2015; Rockström et al., 2009). However, it can become a disaster when an area is suddenly inundated and waterlogged due to various reasons. Waterlogging is the long-term inundation of areas as a result of poor drainage due to natural and or manmade causes (Shamsuddoha and Chowdhury, 2007). Globally, many countries, reported waterlogging as a problem for instance Australia (Brooke et al., 2017; McFarlane and Williamson, 2002), China (Zhang et al., 2012), India (Ritzema et al., 2008), Netherlands (Barrett-Lennard, 2003), Russia (Rukhovich et al., 2014), USA (Horowitz et al., 1995). In the southwest coastal region of Bangladesh, waterlogging emerged as a new problem at the beginning of the 21st century (Brammer, 2014; Shamsuddoha and Chowdhury, 2007). A part of the Satkhira district is located in this area and has been impacted as well. It has become a big problem in recent years due to: natural changes in river flow; raised sediment in riverbeds due to sediment deposition on floodplains protected by embankments, a lack of proper regulation and maintenance of sluice gates of the polders (circular embankments), and shrimp farming (Khan et al., 2015; Rawlani and Sovacool, 2011).

Water logging creates an anaerobic condition in the root zone (Barrett-Lennard, 2003), invites water loving wild plants (Shapiro, 1995), and makes unsuitable for agricultural operation (Kijne, 2006), accumulates toxic salts (Chhabra, 1996), lowering soil temperature (Trought and Drew, 1980). It also cause waterborne disease infestation (Beck et al., 1994), socioeconomic damage, social disruption and death (FAO, 2015). It is a pressing concern against the backdrop of climate change that is becoming worse for the people of southwest Bangladesh (Awal, 2014). The continued waterlogging has caused notable displacements, creating humanitarian challenges regarding safe water supply, sanitation, shelter, food security, and job opportunity (Alam et al., 2017; Abdullah and Rahman 2015; Awal, 2014; Salauddin and

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Ashikuzzaman, 2011; Sarker, 2012; McAdam and Saul, 2010). Socioeconomic and agricultural activities have largely been thwarted due to waterlogging (Adri and Islam, 2010, 2012). The local people are severely affected, particularly in the rainy season when peak monsoon hits the region (Awal, 2014; McAdam and Saul, 2010).

The intensity of damage is severe, For instance, over 27,000 houses were destroyed with another 43,000 houses partially damaged during the year 2011 in Satkhira alone (FAO, 2015). It is reported that loss incurred due to water logging includes the death of livestock (50), damage of crops 849 ha (completely) and 540 ha (partially). Further, 859 tube-wells were damaged, 28 schools was destroyed, 1200 shrimp farms were destroyed completely, and another 2975 shrimp farms were damaged.

Remote sensing as a monitoring system is very useful as it can provide the necessary data for investigations of land use and land cover changes, disaster monitoring, and other environmental issues (Abdullah et al., 2015, 2011; Ji et al., 2006). Pekel (2016) studied global surface water using Landsat imagery irrespective of waterlogged area. The remote sensing based waterlogged area monitoring is not common. However, there are several studies which used remote sensing as a tool to study waterlogging problem (Chowdary et al., 2008; Tralli et al., 2005; Dwivedi et al., 1999). Waterlogging area is not easily accessible. So, satellite remote sensing can be used to assess the waterlogged area with limited cost, in a short time and with a limited effort in compared to ground monitoring. In addition to that remote sensing provides reconstructing past datasets where ground monitoring across the scales was not available. So, it is an important tool which can be used efficiently in policy formulation and planning especially in data sparse situation. The study is the first attempt to monitor waterlogging area using long-term remote sensing data in Bangladesh.

In Satkhira, insufficient efforts have been made to address the problem of waterlogging. Most of the study area is based on non-spatial data. Although the waterlogging sometimes induced large scale disasters in the regions, research initiatives for addressing the problem have not been taken into account so that specific policies can be tailored to minimize the risks and maximize the benefits for individuals, households, and communities. Therefore, the study was aimed to quantify the waterlogged area of southwestern Bangladesh using time series analysis of Landsat satellite imagery to formulate proper monitoring of waterlogged area in the southwest coastal region of Bangladesh.

2. Materials and methods

2.1. Study area

Areas waterlogged are not well documented in Bangladesh. However, visual observation of satellite imagery revealed that Satkhira is one of the most vulnerable area in Bangladesh. Hence, the study site was chosen. Satkhira is a southernmost coastal district of Bangladesh that is a part of the Khulna division. This district is bounded on the north by the Jessore district, on the east by the Khulna district, on the south by the Bay of Bengal and the west by India. It lies between 21°36' and 22°54' north latitudes and between 88°54' and 89°20' east longitudes (Fig. 1). The district consists of seven sub-districts. Low elevation characterizes the district. Historically, the district is vulnerable to waterlogging. Hence, the district is chosen as the study site.

2.2. Satellite data acquisition

The Landsat imagery was downloaded from the USGS Global Visualization Viewer website. Satellite data for the years of 1973, 1989, 1995, 2000, 2005, 2010 and 2015 were collected for the month of March. Cloud-free surface reflectance product of Landsat was downloaded for the study. Different vegetation index products, e.g., NDVI, EVI, were also downloaded. The main characteristics of the remotely sensed imageries are given in Table 1.

2.3. Data processing

The Satkhira district boundary (shape file) was chosen as an area of interest (AOI) in the study. All of the downloaded bands were batch clipped using python scripts in the QGIS environment (QGIS, 2015). All of the clipped layers were then stacked and bricked as a multiband raster image for each year considering a "No data value" as − 9999.

All of the multiband images were then set as False Color Composite in ArcGIS. Then, training points were generated (Fig. 2) for three predefined "classes" e.g., land, waterlogged and river, to quantify the waterlogged area and land area. Approximately 450–600 training points were generated based on the image classification requirements and post classification refinement. The training data were generated using GPS data collected on the ground, visual observations, and high-resolution ancillary data.

2.4. Image classification using the random forest algorithm in R

Random forest is a non-parametric method in which a regression tree (CART) and classification are used to model or predict multi source data with nonlinear response variables. RF have the best performances among the CART methods (Prasad et al., 2006). Random forest has been used in various applications, including predicting soil type (Lemercier et al., 2012), soil organic carbon content (Kheir et al., 2010), basal area and trees per hectare (Hudak et al., 2008), and Satellite image classification (Youssef et al., 2016; Rodriguez-Galiano et al., 2012; Bosch et al., 2007; Pal, 2005). Image classifications were done using the random forest algorithm in the R software (Studio, 2016). Required packages were loaded first in R Studio. Then, a working directory containing all of the image files was set. The training dataset for classification was loaded. Using those training data, surface reflectance (SR) imagery, digital elevation model (DEM) data and vegetation index, the random forest model classifications were generated. Finally, the model was applied to the whole scene. Flowchart of the study is shown in Fig. 3.

For the supervised classification using the "Random Forest" (RF) algorithm, where the number of levels for each tuning parameter was three, the data were split into 70% training data and 30% validation data, and the number of cross-validation resamples during model tuning was five. After the code had been run, the confusion matrix, statistics, and the overall statistics including accuracy and kappa (Table 2) were obtained. Finally, the regulated output was obtained.

2.5. Change detection through QGIS

The change detection analysis was conducted in QGIS SAGA using the cross-classification and tabulation tool. The change detection procedure was used for land use land cover change (LULC) during three intervals: 2000–2005, 2005–2010 and 2010–2015. This technique produced a description of the main types of change in the study area. Cross tabulation analysis on a pixel-by-pixel basis facilitated the determination of the quantity of conversions from a particular land cover class to other land use categories and their corresponding area over the period evaluated. A new thematic layer containing different combinations of "from–to" change classes was also produced.

3. Results

Waterlogging is becoming a big problem in southwestern Bangladesh. Fig. 2 shows that the waterlogged area was 3033 ha, 13,562 ha, 11,548 ha, 27,162 ha, and 35,606 ha in the years 1989, 1995, 2000, 2005, and 2015, respectively. The lowest waterlogged area occurred in 1973 (832 ha), and the highest occurred in 2010 (40,056 ha), which was 0.37% and 18% of the total area of the Satkhira