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ASSESSING TROPICAL CYCLONE DAMAGE USING MODERATE SPATIAL RESOLUTION SATELLITE IMAGERY: CYCLONE SIDR, BANGLADESH 2007

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KEY WORDS: Cyclone, Natural Disaster, Remote Sensing, Post classification comparison, Damage assessment

ABSTRACT: Tropical cyclones are a common natural disaster, and are predicted to increase in intensity and frequency under future climate change scenarios in many coastal areas across the world. Satellite remote sensing can provide a capability for large area (10,000's km^2) coverage and derivation of essential map products at high to moderate spatial resolution (5 – 30 m pixels) on a regular basis weekly to monthly. These data are ideal for assessing damage produced by the cyclone and can be used to derive appropriate information for planning and directing relief efforts in a short time frames. This study developed and tested approaches for assessing multiple damages caused in 2007 by tropical Cyclone Sidr in Sarankhola upazila (151.24 km^2) in Bangladesh from moderate spatial resolution satellite imagery. Object based image classification techniques were applied to map cover types in pre- and post-cyclone SPOT 5 satellite imagery. Post classification change detection techniques identified types of land cover changes. Our results indicate that around 60% of the study area was significantly damaged by Sidr. About 31% of croplands were flooded by storm surges and with vegetation, settlements and infrastructure of the area all being fully or partially damaged. The methods developed may be used in future to assess the damages caused by tropical cyclones in Bangladesh and other countries.

INTRODUCTION

Tropical cyclones are one of the most significant and devastating natural disasters, typically generating sustained high winds, storm surges and intensive rainfall. Many of the coastal areas of the world are vulnerable to tropical cyclones and their associated storm surges (Klemas 2009). These disasters often cause significant loss of life, property and environmental damage in large-scale and are expected to increase in intensity and frequency due to a warming climate (Knutson et al. 2010). Most of the landscapes are disturbed and damaged by tropical cyclones in the affected areas. Remote sensing can be a cost effective, accurate and potential tool for mapping the damages of tropical cyclones from small to large regions to support the management approaches (Vatsavai et al. 2011).

Advances in remote sensing data and processing techniques allow us to use low (> 100 m pixels) to high (< 5 m pixels) resolution multispectral and panchromatic satellite images of the same areas before and after tropical cyclone disasters for mapping the damages. Thus, remote sensing may provide useful information to facilitate the relief process and planning in disaster management. These processes require detailed spatial information on the extent and forms of cyclone induced damage and the specific land cover and land use types affected. Change detection from classified images is a widely used technique to support this process in a remote sensing environment (Wang & XU 2010). Most previous cyclone damage studies used this technique and were followed by field damage assessment focusing on single impacts in the landscape (Bhowmik & Cabral 2013; Klemas 2009; Zhan et al. 2013). Very few studies have assessed multiple damages, such as settlement, crops land, vegetation, infrastructure damages, caused by tropical cyclones using object based classification from any form of satellite imagery.

The aim of this study was to develop and test approaches for mapping multiple types of damage (e.g. vegetation destruction, vegetation defoliation, destruction of buildings/infrastructure, damage to buildings/infrastructure, change to landforms) caused in 2007 by tropical Cyclone Sidr in Sarankhola upazila (151.24 km2) of Bangladesh using object based classification from moderate spatial resolution satellite imagery.

STUDY AREA, CYCLONE SIDR AND DATA SETS

The study area is located between 22°13′- 22°24′ N latitude and 89°46′- 89°54′E longitude, Sarankhola upazila, Bagerhat district in Bangladesh (Figure 1). The site is situated less than 3 m above sea level, surrounded both sides by the Baleshwari and Bhola rivers and is highly vulnerable to tropical cyclones (Nadiruzzaman & Paul 2013). The area is highly populated and characterized by high soil fertility and agricultural productivity. The area was severely affected by tropical cyclone Sidr in 2007.

Cyclone Sidr, a Category 4 storm, struck the southwestern coast of Bangladesh with an average wind speed of 223 km/h on November 15, 2007. It was the second-strongest cyclone to make landfall in Bangladesh since 1877. About 3406 people lost their lives by cyclone Sidr and other damages estimated nearly US$ 1.7 billion (Paul 2009). Rice and vegetable crops, tree plantations near the roadside, farmland, char, and homestead areas of Bangladesh were severely damaged by this disaster. Bagerhat, Barguna, Patuakhali, and Pirojpur districts were identified as most highly affected areas by tropical cyclone Sidr according to the Bangladesh Government.

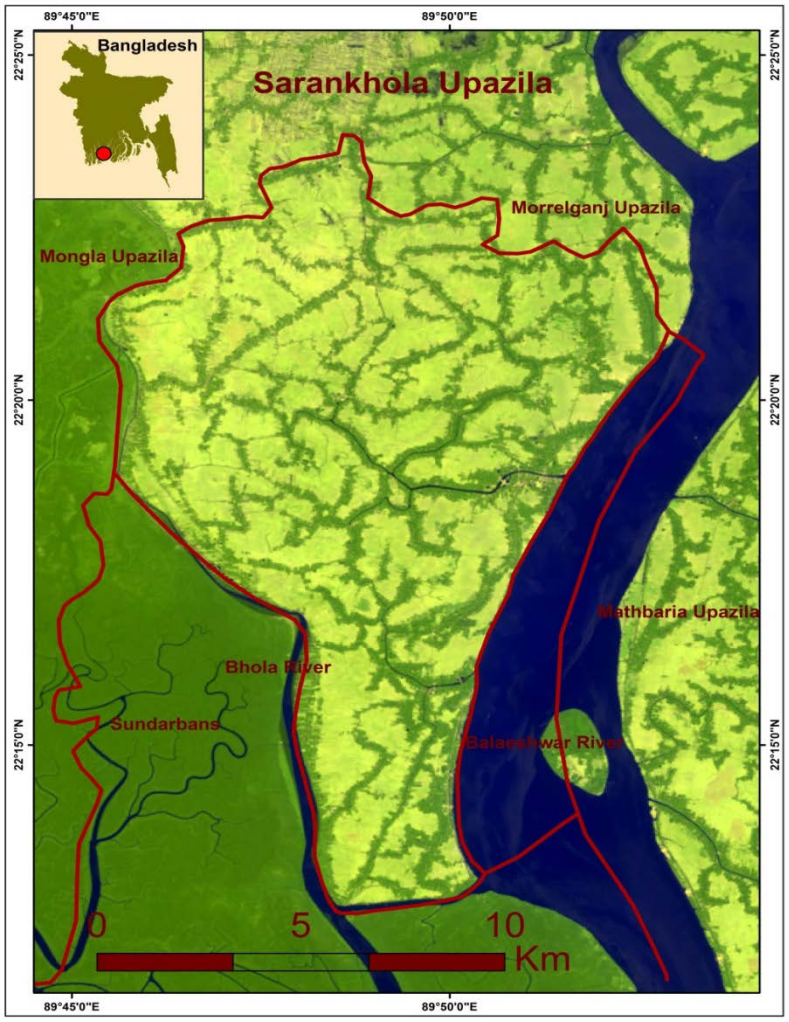

Figure 1. Study area, Sarankhola upazila under Bagerhat district in Bangladesh drawn on Landsat 8 image of 15/04/2014.

SPOT-5 images acquired on 22 October 2007, before the tropical cyclone Sidr, and 23 November 2007, after cyclone, were used in this study. Both images were at 10 m resolution with four multispectral bands. The acquired images were used for land use classification and cyclone Sidr damage detection and assessment. Others data used included very high-spatial resolution satellite images, Quickbird-2 with multispectral bands, pre-cyclone and WorldView-1 with a panchromatic band, post-cyclone. The last two images were used to generate the ground reference data for classification accuracy assessment of produced pre- and post-cyclone land use maps. The topographic map from 2012 was used for geometric correction and image registration.

METHODS

Image corrections

The image corrections were applied to produce planimetric map location and a-surface reflectance pixel values, with co-registration for changes analysis. The acquired SPOT-5 images were geometrically and radiometrically corrected, to a < 1 pixel RMSE positional accuracy and at sensor radiance values. Geometric correction was refined using ground control points (GCP) collected from the local topographic map to ensure a high degree of positional accuracy. Atmospheric correction converted the top-of-atmosphere spectral radiance image to at surface reflectance using FLAASH Atmospheric Correction Model in ENVI 5.1. A dark pixel subtraction method was also applied to transfer at-sensor to art surface reflectance values to remove additive effects. Then the pre- and post-cyclone images were co-registered.

Object based approach for image classification

An object based approach was used to classify land cover from SPOT-5 satellite images of pre- and post-cyclone Sidr from the study area. Ten land cover classes were used: (1) bare land; (2) closed water bodies; (3) debris; (4) dense vegetation; (5) ground with crops; (6) ground without crops; (7) infrastructure; (8) open water bodies; (9) settlement; (10) sparse vegetation. The ability of object based approach to incorporate multiple spatial scales in the analysis through multi-scale segmentation process was essential to classify the land covers more accurately. The segmentation and classification procedures were carried out using Trimble eCognition Developer software v. 9.0. The workflow for this approach is presented in Figure 3.

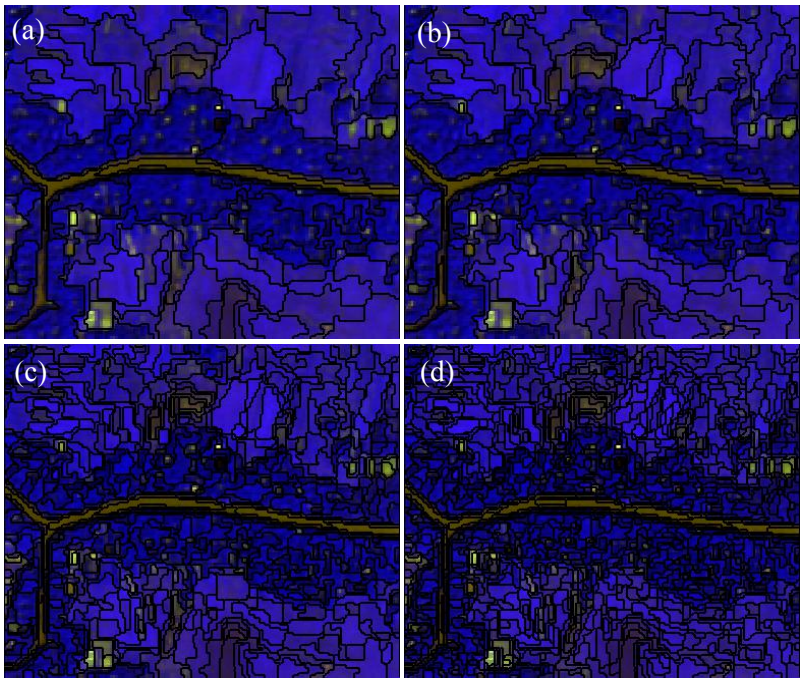

Figure 2. Example of scale factors used for segmentation in the study: (a) scale: 40; (b) scale: 30; (c) scale: 15; and (d) scale: 10.

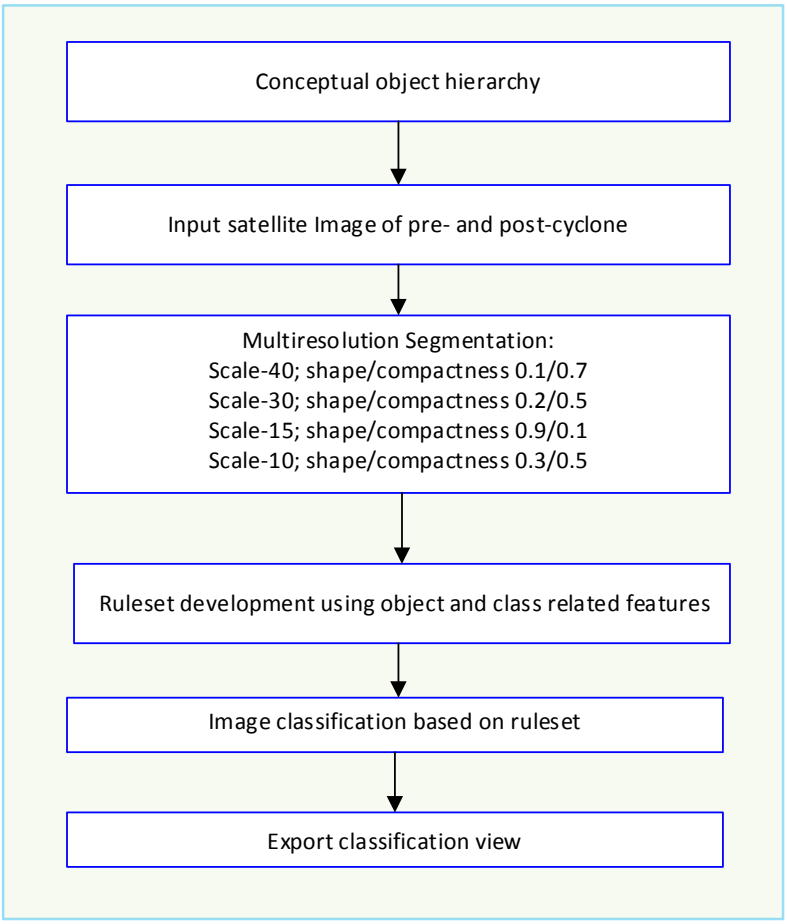

Figure 3. The context of this study and workflow of object based approach

Segmentation divides the imagery into homogenous image segments (or objects) with regard to their spectral or spatial characteristics, which become the processing units in the classification process (Kamal et al. 2015). The segmentation algorithm is a bottom-up region merging technique starts with one pixel objects and by many subsequent steps small image objects are merged into larger objects (many pixels) (Zhou et al. 2008). The sizes of objects are controlled by user defined scale factors. Before starting the segmentation, we developed the conceptual object hierarchy which is essential for multiscale mapping in object based approach. Then, we segmented two different dates SPOT-5 images separately using same scale factors: 40; 30; 15 and 10 (Figure 2) based on conceptual object hierarchy. We used the multi-resolution segmentation algorithm in this study. Different scale factors were used to delineate land cover classes on images and selection of appropriate scale factors were conducted by visual interpretation of segmentation results.

Once the segmentation was done, we developed separate rule sets for pre- and post-cyclone SPOT-5 images to classify land covers. These rule sets contains class membership functions with associated thresholds and were built on expert knowledge of object characteristics obtained in the field and from high spatial resolution satellite images of the study area.

Change Detection

Post-classification comparison change detection algorithm was used to investigate the land cover changes between pre- and post-cyclone Sidr classified images for damage assessment. Post-classification has been successfully used by a number of researchers for tropical cyclone impact assessment (Dewan & Yamaguchi 2009). Cross tabulation analysis was performed to analyze the spatial distribution of land cover changes.

RESULTS AND DISCUSSION

Land cover classification

The results of object based classification of the two SPOT-5 images demonstrated the ability of object based approach to successfully integrate expert knowledge and a conceptual scene model in the ruleset to classify the land cover with a high degree of accuracy from moderate spatial resolution satellite images (Figure 4). The overall classification accuracy was 94% for pre- cyclone and 93% for post cyclone images, respectively. A trial-and-error approach and visual inspection of the results were employed to determine the most appropriate threshold values of object and class related features for classifying every single land cover. The input bands used for rule based classification were NDVI, brightness, mean nir, mean red, length/width, area, shape index, , relative border to, relative area of and border index

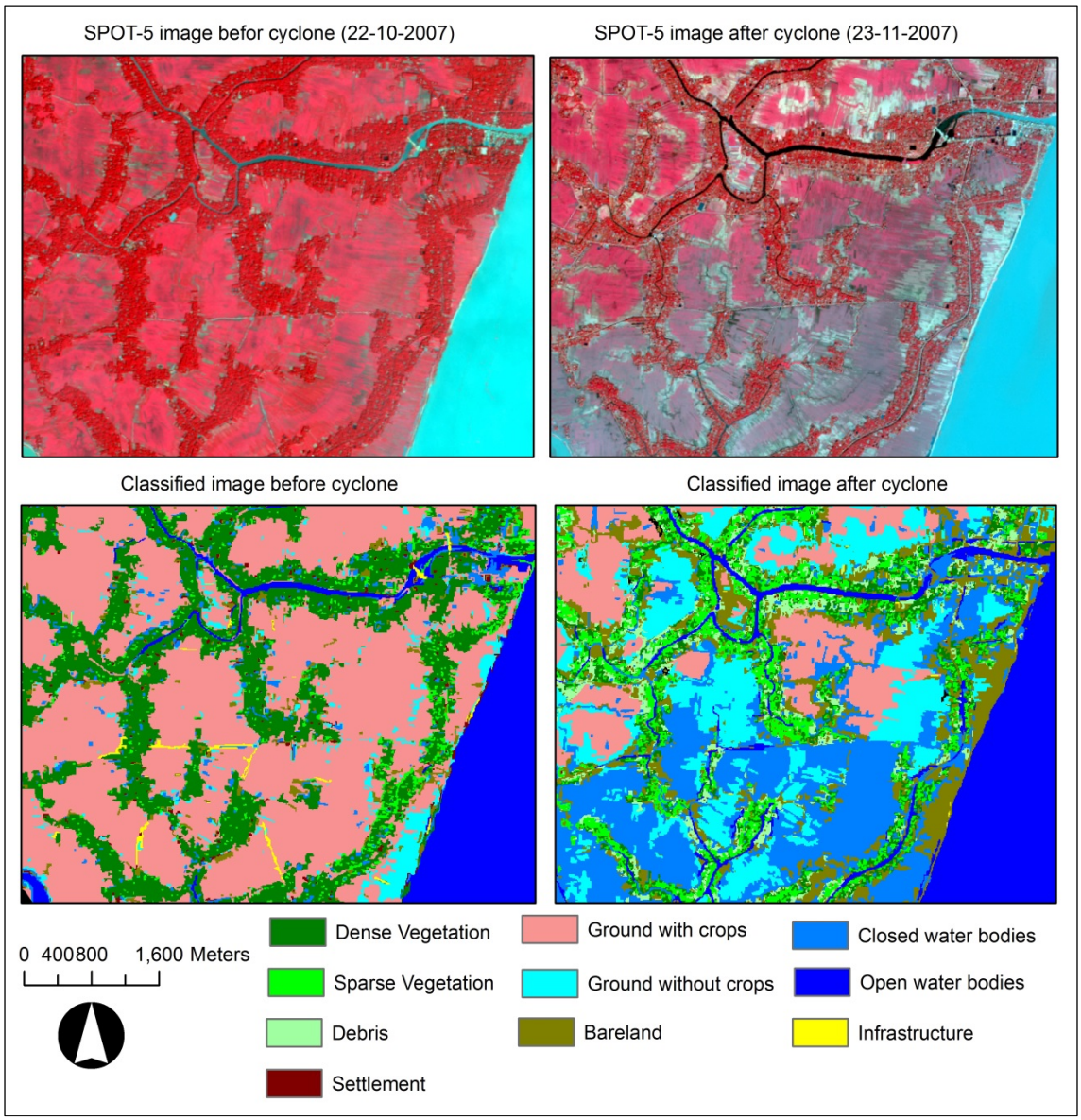

Figure 4. Portion of area of study site showing pre- and post-cyclone images acquired on 22nd October 2007 and 23rd November 2007 respectively with the used classification schemes.

Damage analysis

The post-classification comparison provided very useful information on changes between the pre- and post-cyclone land cover classes to assess the damage. It was assumed that within 30 days interval between two images, the changes occurred in the study area land covers just only for tropical cyclone Sidr. The descriptive statistical analysis is performed from the change matrix to quantify the degree and extent of damage of a particular land cover type due to cyclone in the study area. The results indicate that around 60% of the study area was damaged moderately to highly by the impacts of tropical cyclone Sidr. This was indicated by class transitions from settlement, infrastructure, dense vegetation and ground with crops to debris, bare land, sparse vegetation, ground without crops and closed water bodies. Major damage was identified for infrastructure, settlement, dense vegetation, sparse vegetation and cropland (Figure 5). 80% of settlement areas were damaged due to destructive wind, whereas infrastructure was damaged by 85%. The impact of cyclone was also significant on vegetation classes, having changes by 82% in dense vegetation and 84% in sparse vegetation. Around 31% cropland area was flooded by cyclone induced surge water and totally damaged. Closed water bodies increased significantly in extent due to cyclone surge water flooding of various land covers by 30 sq. km after the cyclone which was 3 sq. km before the cyclone. The area covered by debris was 0.04 sq. km before the cyclone and it was increased by 12.68 sq. km after the cyclone which clearly represents the huge damage caused by the cyclone Sidr. Most of the debris came from vegetation, settlement, cropland and infrastructure which are the result of destructive wind. Some minor abrupt changes have been noticed, but it was in acceptable ranges.

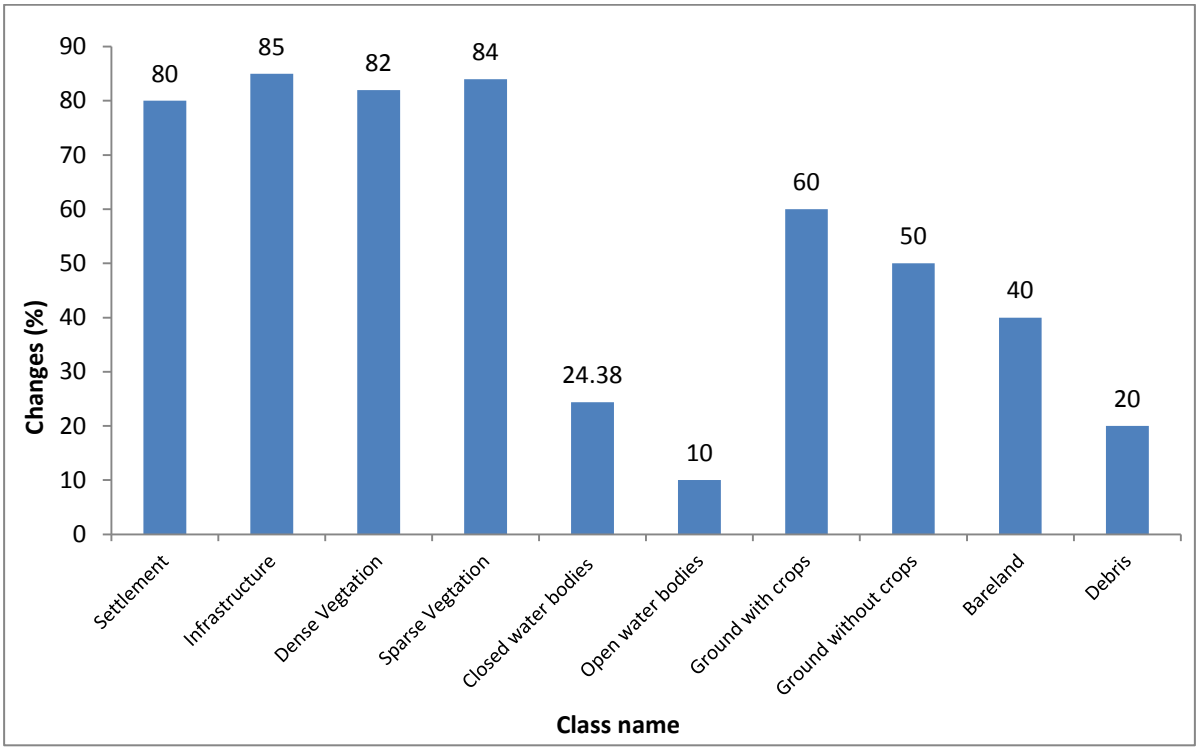

Figure 5. The percentage of changes of land covers caused by tropical cyclone Sidr in the study area

Classification accuracy and damage validation

An accuracy assessment of classification results was performed using reference data generated from high resolution Quickbird-2 and WorldView-1 images of pre- and post-cyclone respectively. A stratified random sampling technique was used to generate minimum 50 points per cover class for confusion matrix. The overall accuracies for pre- and post-cyclone image classification were 94.10% and 92.20% consequently and the kappa statistics were 93.20% and 91.50%. The damage assessment results have been verified by published damage reports produced by local administration and non-government organizations by field surveys and found excellent similarity with them.

CONCLUSION & FUTURE WORK

This study demonstrated the capability of a remote sensing approach for assessing multiple damages produced by the cyclone using object based classification from SPTO-5 images. In particular, moderate spatial resolution SPOT-5 images were suitable for mapping pre- and post-cyclone land covers in the study area with a high degree of accuracy and indicated the usefulness of object based approach in this work. The verified damage results were satisfactory. Further development of rule-based classification is essential in order to more accurately classify the land covers especially after the cyclone. Evaluation of the damage results also needed to justify directly from field reference data just immediately afterward the cyclone event.

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