INTEGRATION OF RADAR AND OPTICAL REMOTE SENSING FOR LANDSLIDE DETECTION - A CASE STUDY OF MEERIYABEDDA LANDSLIDE IN SRI LANKA

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ABSTRACT: Landslides are significant geological hazards that can have destructive effectives on human life and property. Mostly people living in mountainous areas, and their properties, face critical danger from landslide disasters. Landslides are triggered due to unsustainable anthropogenic activities like mining, road cutting, urbanization, as well as natural causes like earthquakes and rainfall. Thus, landslide detection is an essential requirement in pre and post disaster hazard analysis. In earlier studies, landslide detection was often achieved through time consuming, cost intensive field surveys and visual orthophoto interpretation. Recent studies show that Earth Observation (EO) data offer new opportunities for fast, reliable and accurate landslide identification at smaller scales. This can contribute for effective landslide monitoring and hazard management. Sir Lanka is a tropical island comprising a heavy mountainous region in the centre. A combination of geology, unsafe land use practices and heavy rainfall from two monsoons have caused irregular landslides throughout this central hilly region. From the 65,000 km^2 of land in Sri Lanka, nearly 20,000 km^2 is prone to landslides. Hence, the objective of this work is to investigate the potential of detecting landslide areas from EO data. This research is based on the severe landslide that occurred in Meeriyabedda area in Badulla District on 29th October 2014, affecting around 330 people of 57 families and 63 buildings in Ampitikanda tea estate.

Basically, two radar and optical images before and after the event are used in order to delineate the landslide area from different processing techniques. Geometrically registered and radiometrically normalized world view II and geoeye optical images are used to implement the change detection techniques. Satellite image pixel intensity changes are extracted by calculating the Normalized Difference Vegetation Index (NDVI) and Principle Component Analysis (PCA). Further thresholding into classes of changes in connection with landslide activity is performed to discriminate the landslide area from surrounding. Two pre and post sentinel-1 images are pre-processed in order to apply pixel based classifications. Backscatter difference and the correlation coefficient between two images are examined to threshold the image to extract the changed pixels or landslide area from non changed pixels. With the inherent characteristics of radar and optical remote sensing, from the post optical image, part of the landslide area is hindered by clouds even though the analysis offers the detailed information about the rest of landslide area. Due to weather independent capability of radar images, all the landslide regions are detected. However radar suffers serious geometrical distortions specially when studying the high relief terrain areas. Moreover when consider the spatial resolution, radar has some limitations to detect small landslides than optical images can detect.

Hence this study aims to compare the detection of Meeriyabedda landslide from different change detection techniques applied to the radar and optical images before and after the event with analysing their inherent limitations for studying specially in a high relief terrain areas.

1 INTRODUCTION

Land slide is a geological phenomenon which includes extensive terrain movement resulting severe damage to the human and their property. Basically the landslide occurred when a part of a natural slope is unable to support its own weight. The gravity is the main driving force of the landslide debris flow depending on the slope of the area. Landslide occurs when the stability of the slope changes from a stable to an unstable condition. The change of the stability of a given slope can be caused by a number of factors as natural and human related activities (Weerawansha et. al, 2007; Bandara, 2005). In the last decades, there was a significant increase in landslide frequency, in concurrence with the climatic changes, improper land uses and the expansion of urbanized areas in the world (Scaioni et al., 2014).

Landslides are very familiar to the Sri Lankan community in every year. There are number of fairly large landslides occurred in Elapatha (1986), Abepura (2003), Helauda (2003, 2006), Naketiya (1998) and recently Meeriyabedda (2014), Pambahinna (2016) and Aranayaka (2016) which damage human lives, property and infrastructures (NBRO, 2016). Some highway stretches of A 4 in Beragala & Koslanda areas and Puswellawa in A5 had to extensively repaired due to landslides in last couple of decades. Further due to Watawala landslide in 1990, upcountry railway track was damaged and trains could not be operated for couple of months. From Meeriyabedda landslide 57 families were affected and 63 buildings were damaged. The Aranayake landslide buried 80 houses and more than 100 people.

Most of the landslides and avalanches are located in the mountainous area interrupting roads railways and rivers. Hence many villages are isolated and their lives and property are threatened. Although the information collection in an early stage is quite important for the disaster management phases, the access to the affected areas from the ground could be really difficult, especially to the mountainous areas. Moreover the study of landslide over extensive areas are paramount important in each disaster management phases.

Frequently, the detail landslide studies are performed by the field based techniques with the use of aerial photo interpretation. However, most field techniques provide point-based discrete measurements of the landslides but do not consider any past movements. In active landslides, although the ground-based techniques can provide very precise information on displacement or deformation at very specific locations, especially in residential or areas with major infrastructures, they do not provide information on the changes due to land sliding in wider area. Moreover, the field techniques in preliminary investigations of unstable areas may sometimes not be cost effective and advisable (Javier et al., 2003; Rosin, et al., 2000).

Recently, all disaster management phases are becoming dependent on results derived from the satellite image analysis when the damage area is large and the terrain is mostly inaccessible (Tralli, et al., 2005; Voigt, et al., 2007). With the availability of a large number of Earth observation satellites with wide range of spatial, temporal and spectral resolutions and better organization to share the data in emergency scenarios, the applicability of satellite remote sensing for disaster management is promising. Specially high resolution remote sensing images have proved their potential for landslide studies such as detection of the damages area and assessment of the damage from the landslides (Guzzetti, 2004; Vinodkumar, et al., 2008), preparing an inventory of landslides (Martha, et al., 2010a), estimating the landslide volume (Martha, et al., 2010b) and monitoring landslides for early warning purposes (Van westen et al., 2003).

Optical sensors can provide information about the geographical phenomena that can be interpreted by the human directly. However the optical satellite image techniques are constrained with the observation under a cloud-cover condition and at nighttime. Synthetic aperture radar (SAR) is free from these restrictions and thus becomes more conveniently used, especially in post-disaster responses (Yamazaki et al., 2011; Rathje et al., 2008). The landslides detection using the integration of radar and optical sensors are carried frequently all over the world. However, there are more research studies to compare and evaluate the performance of radar and optical remote sensing for landslide studies using different change detection techniques with the advanced mathematical principles (Tsuchida et al., 2015; Afify, 2011).

Hence, the main objective of this study is to compare the detection of Meeriyabedda landslide from optical and radar remote sensing techniques. The back scattering characteristics of Sentinel-1, C band radar images acquired before and after the event are examined in order to extract the land use changes due to landslide. The high resolution Geoeye and worldview II optical satellite images, pre and post event scenarios are analysed for detecting the landslide area from change detection techniques.

1.1 Study Area

A severe landslide occurred in Meeriyabedda area in Kotabathma Grama Niladhari division in Haldumulla Divisional Secretariat Division in Badulla District on 29th October 2014 at around 7.30 am (See Figure 1). The impact of landslide affected around 330 people of 57 families in Ampitikanda tea estate. Total number of buildings destroyed were 63 including Houses, Kovil, Community Center, Dairy collection Centers, Boutiques, Telecommunication Center, and 3 Estate bungalows. Out of the total number of children who attend the school, 75 children were orphaned (Landslide, 2014). Immediately after the landslide, Japan International Co-operation Agency (JICA) Technical Co-operation Project for Landslide Mitigation with National Building and Research Organization (NBRO) and Disaster Management Center (DMC), Sri Lanka together carried an air survey. The main objective of this survey was for grasping the overall disaster area and identifying the effect and risk of secondary disaster as the area had heavy rain.

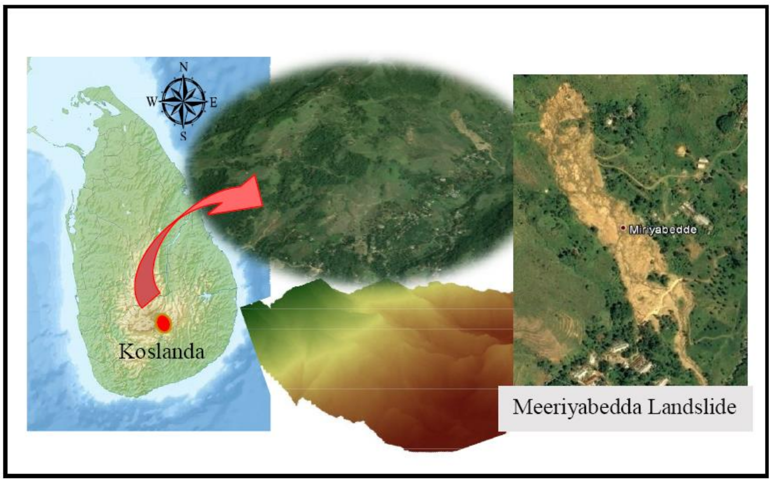


Figure 1 : Meeriyabedda Landslide in Koslanda, Sri Lanka

2 DATA AND METHODOLOGY

This study analyze the radar and optical remote sensing capabilities for the landslide detection. Hence, the information about the radar and optical satellite images that have been utilized and methodological flow followed in order to achieve expected objectives are discussed in this section.

2.1 Data

This research study was entirely depended on the optical satellite images, Geoeye and World view II and the radar images Sentinel 1 images acquired before and after the Meeriyabedda Landslide. Optical images before the event was acquired on 16th May 2013 without any cloud covers and image after the event was from 06th November 2014 with 0.114 cloud covers. It was a difficult task to find cloud free images after the event because of the prevailing bad weather conditions. All images are with the 2m spatial resolution Red (R), Green (G), Blue (B) and Near Infrared (NIR) standard colors and with the 0.5m resolution panchromatic bands. Sentinel-1 radar images before the event was captured in 19th October 2014 and after the landslide was acquired on 31st October 2014. Though the radar images are independent from the sun illumination and weather conditions, providing clear images even in the disaster situation, the feature extractions are restricted with the spatial resolution.

A 10m resolution DEM is derived from 1993 aerial photographs from the aerial triangulation. The Imagine photogrammetry tool from ERDAS Imagine 2014 (Earth Resource Data Analysis System) software is used to generate the DEM from aerial photographs. Camera Calibration, interior orientation, exterior orientation by using 25 Ground Control Points (GCPs) are performed in order to generate DEM from aerial triangulation.

2.2 Methodology

Basically, the methodology consist of two major components as the landslide area delineation from both optical and radar images using different change detection techniques. In order to extract the ground surface changes following a landslide, the satellite images before and after the event should be geometrically co-registered and radiometrically normalized enabling for pixel based analysis. The general flow chart shown in Figure 2 gives a quick look into the overall set up of this study.

Mostly in the preprocessing stage, the digital numbers (DNs) were converted into the Top-Of-Atmosphere (TOA) reflectance for both worldview II and geoeye images with their own parameters. Geometrical registration of high resolution optical images of hilly terrain areas require orthorectification to remove the effects caused by relief displacements. Hence the orthorectification of pre and post images are performed by using 10m resolution DEM derived from aerial triangulation.

In the radar imaging approach, sentinel-1 images before and after the event are radiometrically calibrated converting the original DN values of the sentinel-1 C band intensity data to the backscattering coefficients. In order to reduce the speckle noise effect and to obtain the square shaped pixels, multi look processing and image filtering using enhanced lee filter are performed. At last, two images are corrected for the terrain by using Shuttle Radar Topographic Mission (SRTM) 30m DEM for dropping the image displacement due to relief and for geometrical registration.

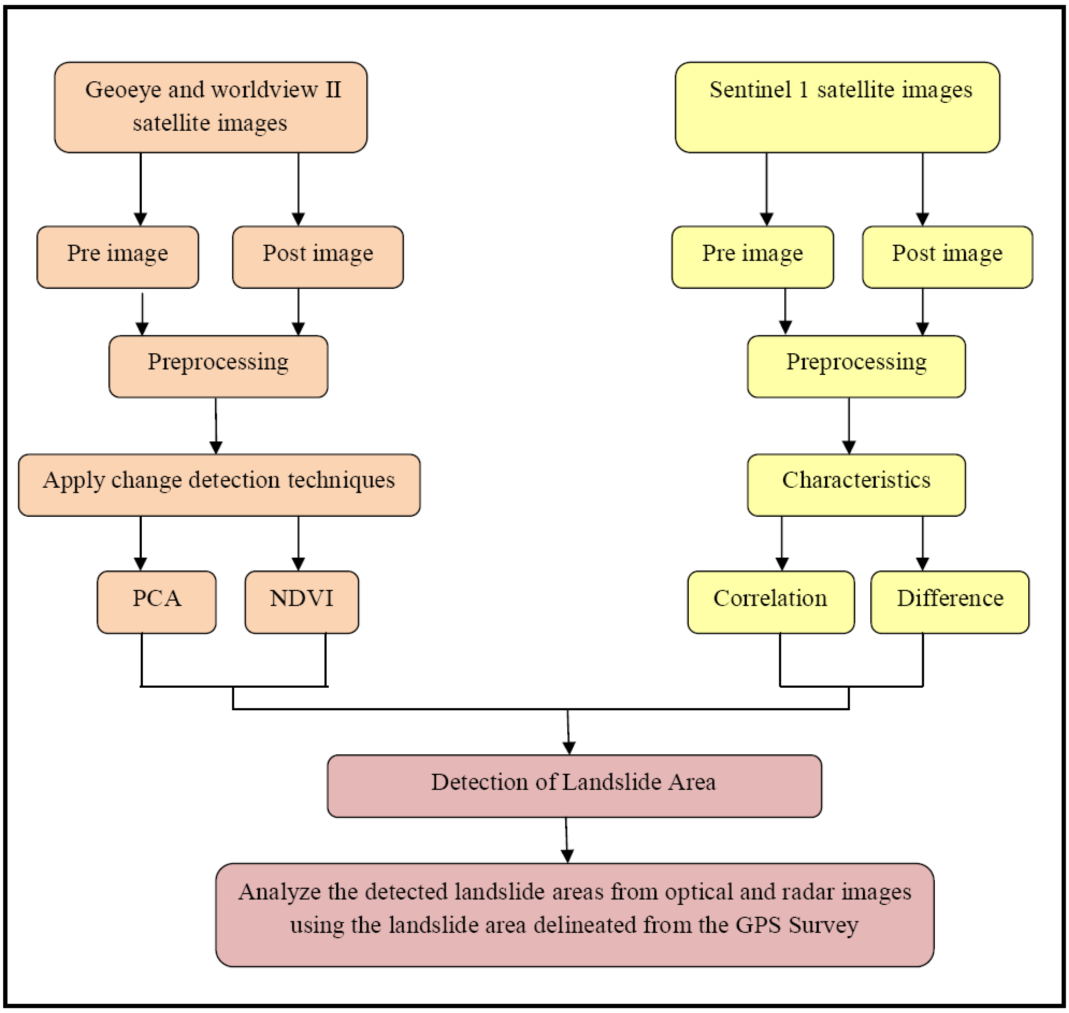


Figure 2 : Conceptual Methodology of the Research

Afterward, PCA and NDVI change detection analysis for optical images and the mathematical relationships for analysing the change, the correlation and difference parameters for radar images are calculated for delineating the area from landslide disaster. Detected landslide areas are then compared with the area extracted from the ground based GPS surveying.

3 LANDSLIDE DETECTION FROM OPTICAL IMAGES

Mostly, a landslide displaced significant portion of landmass in mountainous regions. As it cause for changing some geomorphological setting, identification of such changes are difficult only from spectral domain alone using satellite or aerial data sets. The common noticeable element after the occurrence of landslides is the loss of vegetation and exposure fresh rock and soil. With the high resolution images used in this study, it can be interpreted that some buildings, roads and part of vegetation with trees are collapsed (See Figure 3).

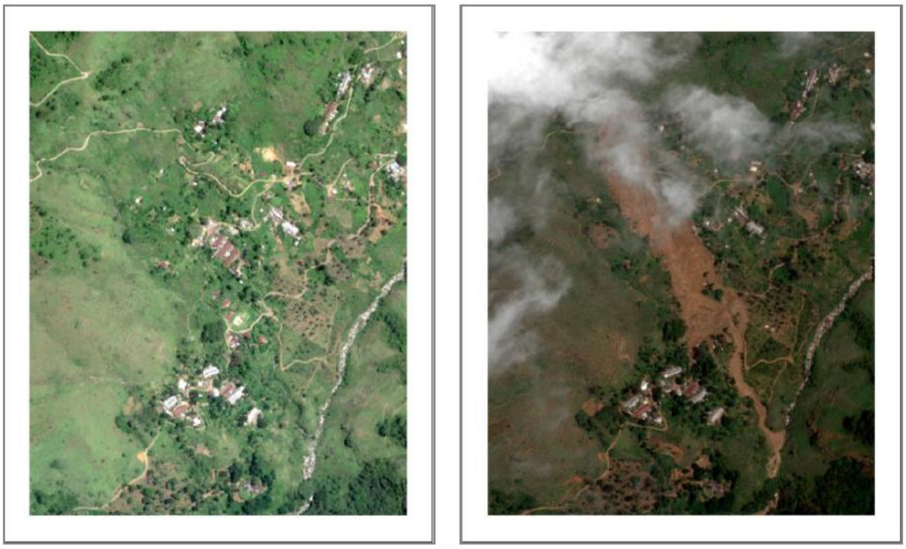


Figure 3 : Worldview II satellite image, before and Geoeye image, after Meeriyabedda landslide

This unique property of a nature of landslide is taken in to consideration for the detection of damaged areas by using PCA and NDVI change detection techniques.

3.1 Principle Component Analysis

The Principal components analysis is a technique that can be applied for multispectral and hyperspectral remotely sensed data as a method of data compression. PCA allows redundant data to be compacted into less bands. The bands of PCA data are non-correlated and independent. Hence, interpretation of such bands or components easier than the source data.

In this research, PCA is performed for the post and pre images of the Meeriyabedda separately. All the principle components from pre and post images are analysed in order to delineate the landslide area from surrounding. Then the color composite image is generated by assigning Red, Green and Blue colors for appropriate bands so as to identify the damaged areas from the Meeriyabedda landslide. After many trials, it was found that by assigning Red color for the PCA2 from the post image and Green and Blue for the PCA1 from pre image, the landslide component can be extracted. Red color indicate the principle component of the post image than in pre image means the change due to the landslide (See (a) in Figure 4).

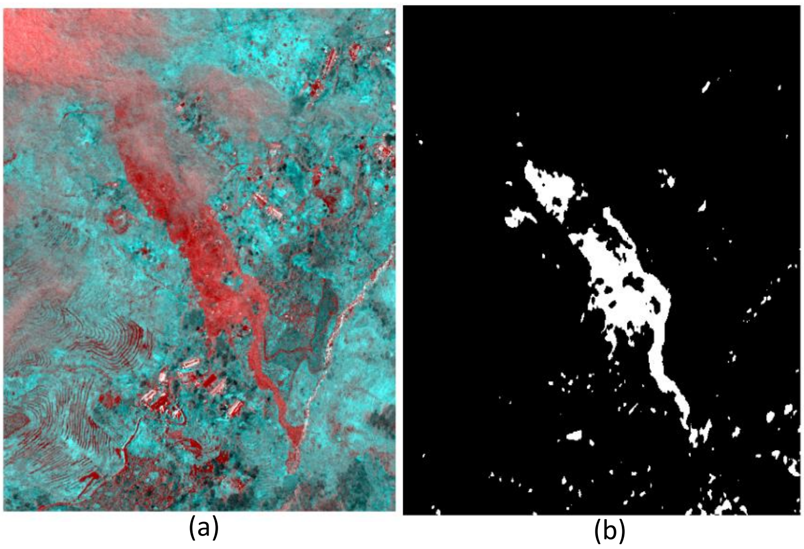


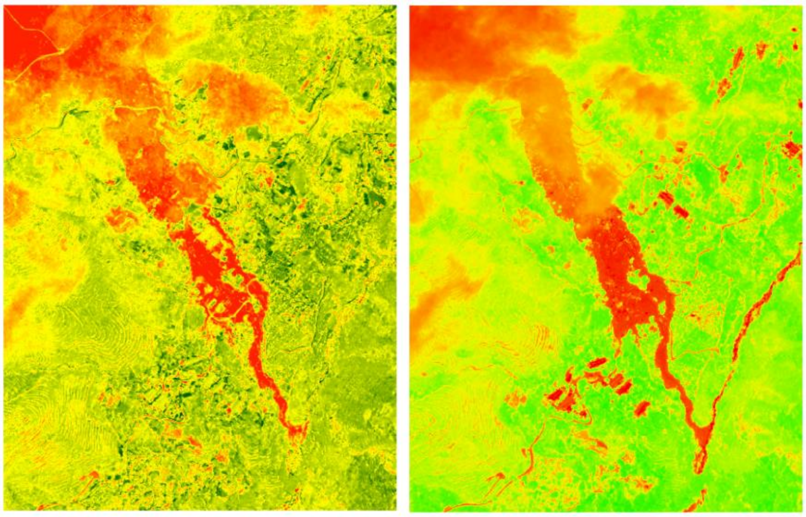
Figure 4 : Landslide detection from PCA applied for high resolution optical images

Next attempt was to calculate principle components for the difference image that obtained by subtracting the reflectance values of pre image from the post image. All the possibilities for extracting the landslide area as a change from the post image was investigated. The difference between PCA1 and PCA4 gives the better discrimination of reflectance values from disaster region. Hence, by applying the threshold value (difference > 0) for the PCA1 and PCA4 difference image, it was able to detect the landslide area from surrounding (See (b) in Figure 4).

3.2 NDVI

The study area was basically consisted of some buildings, roads and part of vegetation with trees. Thus, it can be noted that, the landslide cause the reduction of NDVI values due to exposure of bare soil. Since the pre-event image was taken in May 2013 and the post-event was in November 2014. Hence, the NDVI supposed to be increased in the most pixels. If the NDVI was decreased, landslides might be occurred in the corresponding area. Thus it is assumed that the pixels with reduced NDVI values after the event can be considered as the landslide area. The clouds existed in the post-event image was disturbed for better delineating the landslide area.

In order to extract the vegetation damages due to landslide and the vegetation changes within the time period, NDVI ratio is calculated using NIR and Red band combination [(NIR-Red)/(NIR+Red)] for the post image and the difference image separately. NDVI difference image identified the main change features as cloud patch and the landslide region. However, the boundary is not clearly extracted because of the buildings inside the landslide damaged area has not recognized as changes in difference image. Because, the image pixels for buildings in pre image and debris flow in post image are not really different. (See (a) in Figure 5). The NDVI post image basically identified the cloud patch, the landslide area and the additional buildings developed within this time period (See (b) in Figure 5).



(a) (b)

Figure 5 : Landslide detection from NDVI analysis for high resolution optical images

4 LANDSLIDE DETECTION FROM RADAR IMAGES

The backscatter values of radar images are highly dependent on the radar viewing geometry. Due to side looking configurations, the intensity images are highly affected by the incidence angle of radar to the earth surface. Specially, in mountainous regions where topographical effects are most prominent, radar intensity images are mostly suffered from typical topographic effects of layover, foreshortening and radar shadow. Hence, careful consideration has to be taken while selecting the appropriate radar images for a mountainous study area. Because, the slope angle and the orientation of the slope with respect to the radar illumination are different depending on the locations.

The radar images used in this study is mainly the freely available Sentinel-1 images with C band and VV polarization. While looking at the timely radar images before and after any disaster situations, radar images are independent from the sun illumination and weather conditions, providing cloud free clear images. Meeriyabedda landslide in Koslanda area was occurred in 29th October 2014. It was able to obtain the free radar images from 19th October 2014 and 31st October 2014 for analysing them to detect the landslide area. However, due to limitations of spatial resolution and spectral characteristics of radar images, visual image interpretations for feature extractions are destructed (See Figure 6).

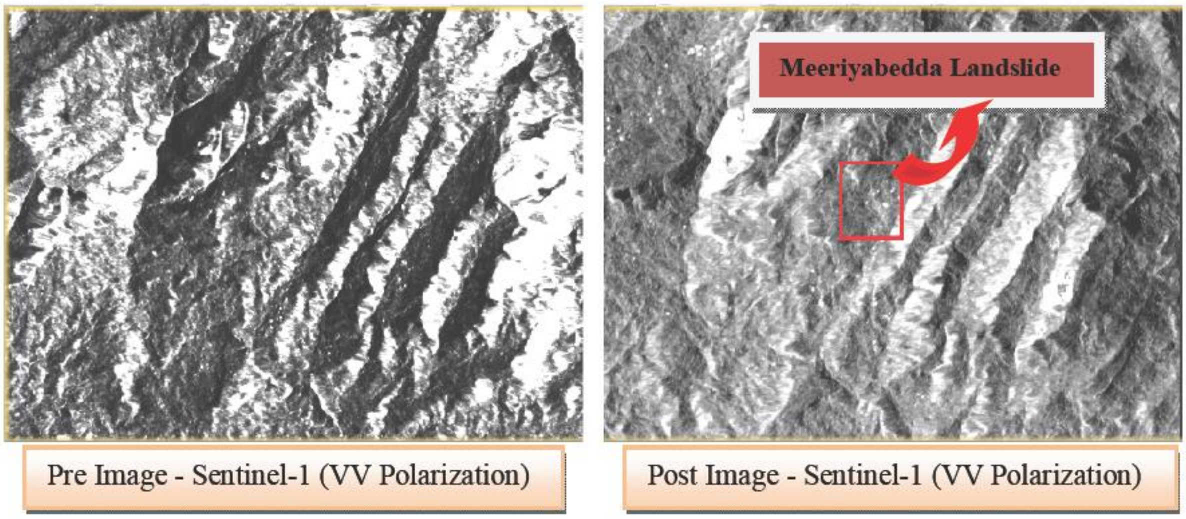


Figure 6 : Radar Images before and after the Meeriyabedda Landslide

Two images pre and post disaster event are radiometrically calibrated and multi look processing was performed so as to reduce the speckle noise and to obtain the square shaped pixels. Speckle noise was reduced again using enhanced lee filter. Finally, radar images are geometrically corrected for the terrain by using 30m SRTM DEM that are freely available. After completing all the pre processing stages for correcting two images that are geometrically co-registered and radiometrically balanced, change detection techniques are applied with the intension of extracting the damage areas from Meeriyabedda landslide.

4.1 Correlation and Difference

In order to extract the changes due to the landslide, the correlation coefficient and the changes between pre-and post-event radar images are calculated for Meeriyabedda landslide area. The reduction of the correlation coefficient are mainly expected from the landslide damaged area with some radar illumination changes. Seasonal changes of forest canopy and vegetation patches cannot be expected as the temporal difference of two images are only few days.

With the purpose of examining the characteristics of radar backscatter values in landslide area, Figure 4 plots the relationship between the correlation and difference of two radar images before and after the Meeriyabedda landslide. In theoretically, if any changes of geographical phenomena are occurred in between these two image acquisitions, the less correlation (<0) or minus relations are defining the change. It can be visually interpreted that the area was damaged consist of some buildings and vegetation. Hence, the backscatter value is reducing from pre image to post disaster image. So, even in the difference image minus values are describing about the change areas from the scatter plot. By taking all concepts in to the consideration, change pixels are extracted by selecting the Region of Interest (ROI) from the minus areas of the scatter plot (See figure 7). The possible range of landslides in the correlation vs. difference plot and the extracted landslide areas after masking are illustrated.

In the case of radar images for mountainous regions, the radar backscatter value is highly affected by the orientation and the angle of fore slopes, more than surface materials and conditions. Due to different illumination conditions, thus it is difficult to extract the areas that are changed only due to landslide disaster. However, the damaged area due to landslide can be mask out from the radar images than the change detection techniques applied to high resolution optical images.

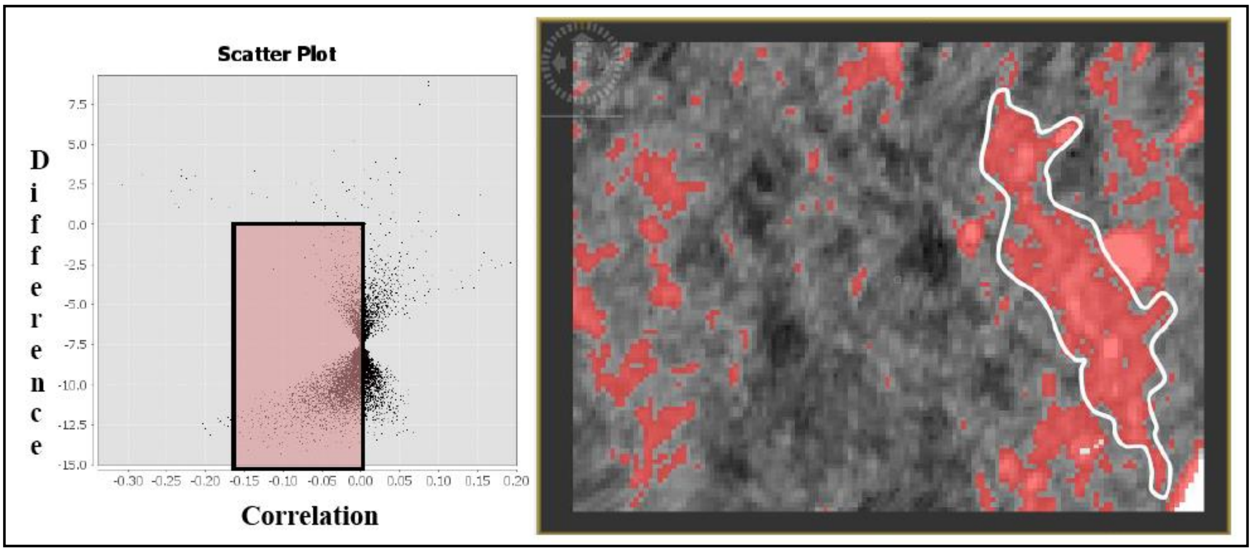


Figure 7 : Areas detected as change from 19th - 31st October 2014 from correlation and image difference domain

5 RESULTS ANALYSIS

In this research, the main objective was to detect Meeriyabedda landslide from radar and optical remote sensing techniques by applying different change detection methods. Basically, the PCA and NDVI change detection techniques were applied for two high resolution images before and after the event used in optical approach. The correlation and difference theory was applied for the Sentinel-1 radar images in order to extract the change due to landslide.

The interaction between NIR, Red and Green standard color bands in optical images with the real earth features as vegetation and manmade is different to each other. By taking these facts in consideration, PCA and NDVI analysis are performed. Validating the results from analysis are paramount important to confirm the significance of the applied methodology. In this process, detected landslide areas are numerically compared with the area derived from GPS field surveying technique. GPS survey was carried using LICA handheld GPS with the positional accuracy of 3m for extracting the landslide boundary in July 2015. At that time, the field surveying in the landslide area was able to carry on as because of the area was free from the disaster risk. Table 1 contain the percentage of the accuracy of area detected as landslide from difference change detection techniques when compared with the area from GPS survey.

Table 1: Comparison of the detected landslide area from optical and remote sensing techniques with the area from GPS survey

Change Detection Techniques		Landslide delineated area (Hectares)	Accuracy (%)
GPS survey		**8.0692**	**-**
OPTICAL	Principal Component Difference	5.048	63
	Color Combination of Principal Components	6.1179	76
	Post NDVI	5.7268	71
	NDVI Difference	5.2163	65
Radar Images Analysis		6.968	86

It is very obvious that, the area detected from optical approaches provide the least percentage of accuracy than radar method as mainly because of the cloud effect on optical images specially in a disaster situation with prevailing weather conditions. This study compares the results obtained by using area calculated from GPS survey. The damaged area from the GPS survey was 8.0692 hectares. The accuracy percentages from optical methods are ranging from 63% to 76%. The color combination of PCA derived from two images identified the landslide area damage better than the other optical approaches. By proving the radar capability in the study of disaster, the landslide area detected from Sentinel-1 images showed the better percentage of accuracy than any optical methods. It is around 86% when compared with the reference area (See Table 1).

6 DISCUSSION AND CONCLUSION

This research study investigated the capability of radar and high resolution optical images to extract Meeriyabedda landslide from different change detection techniques. The native characteristics of radar and optical images for landslide studies and the capability of different change detection techniques with respect to the area like Meeriyabedda to determine the change due to landslide are examined. In a approach of using high resolution optical images, PCA and NDVI change detection techniques for the worldview II (pre event) and geoeye (post event) are applied.

In the image analysis using PCA, the influence of clouds has been slightly reduced when compare with the other optical based methods. Because, some of cloud pixels and landslide pixels depart to the two different principal components. However, the influence of total cloud effect is difficult to be avoided. The principle behind the NDVI difference technique also a well method to detect some changes due to landslide. However, it is limited that this method is more adoptable to identify changes over vegetation or forest covers. In the NDVI difference image, some pixels inside the landslide have been identified as unchanged pixels, even though it is clearly observed that those pixels should be related to the damaged area. The reason for this is, those pixels are covered by buildings before landslide occurring, thus higher NDVI differences cannot be expected from those pixels. However, there are some advantages with that limitation because most of manmade properties which were damaged by the landslide can be clearly identified in NDVI difference image. So, these results are very useful for rescue efforts like survivors finding. Post NDVI image clearly extract the most part from the landslide, but it is difficult to directly state that the post NDVI result is more accurate than the NDVI difference image because it does not indicate any change. However, if there are any prior knowledge about the land use in the area and if any changes are occurred in a vegetated region, then the post NDVI image provides better clues about changes due to landslide in the study area.

Main difficulty of change detection using optical images is having clouds of some areas because clouds hide some important information and clouds are also classified as changes. In case of SAR images for mountainous regions, the backscatter is highly affected by the incident angle and angle of slopes, more than the type surface materials and their conditions. Further, radar back scatter change with the illumination conditions of the time of data acquisition due to side looking configurations. Hence, the appropriate radar images have to be selected and used for the change detection analysis. However, this study aims to use freely available 10m resolution C band sentinet-1 images with VV polarization for detecting the Meeriyabedda landslide. It was difficult to perform the pre-processing of radar images in pre and post event with the freely available sentinel1 images to better suited for the change detection analysis. However, it could be able to obtain the expected accuracy for the landslide area delineation by using a subset that includes the Meeriyabedda landslide.

According to the validation results, PCA has produced better results than other optical methods because all available bands are utilized in the analyzing process. However, by the advantages of radar in disaster situation with prevailing bad weather conditions and timely information in smaller scale, radar remote sensing techniques have been proven the suitability for disaster studies. Hence, it can be concluded that the radar remote sensing for landslide detection is promising but the detection of landslide from PCA in optical techniques are also can accepted even though both techniques have their own limitations.

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