ESTIMATING THE FOREST CANOPY LOSS USING SENTINEL-1 C BAND SAR IMAGES
Theme: Forest and Environmental Change

K. H. P. T. Senadeera*[1], D.R.Welikanna[2], H. M. I. Prasanna[2]
[1] Department of RSGIS, Faculty of Geomatics, Sabaragamuwa University of Sri Lanka.
Email: jprasadi4u@ gmail.com
[2] Department of Surveying & Geodesy, Faculty of Geomatics, Sabaragamuwa University of Sri Lanka
Email: drw@geo.sab.ac.lk, indika@geo.sab.ac.lk

KEY WORDS: Forest Canopy, C band SAR, Sentinel-1, Coherence, Backscatter

ABSTRACT: Deforestation could be identified as one of the main anthropogenic agent leading to an imbalance in the natural ecosystems triggering disasters in the form of landslides, floods and droughts. Recent studies show that Earth Observation (EO) data offer new opportunities for fast, reliable and accurate deforestation detection at smaller scales. Synthetic aperture radar (SAR) data has huge potential in terms of its scattering mechanism and all whether capabilities to estimate the forest canopy loss as an indirect measure of deforestation. A region that has been subjected to heavy deforestation during the past few years in North West region of Sri Lanka was focused for this experiment. Time series single polarized (VV) Sentinel-1 C band SAR data was employed in this study. The low canopy penetration capabilities of C Band SAR systems were significantly utilized in the study. Two Sentinel-1 VV polarization interferometric wide swath (IW) images from the year 2015 and 2016 covering the heaviest deforestation period of the study area were used. These images were carefully preprocessed in order to extract the backscatter intensity to perform the change detection. Coherence based change detection and Image rationing were performed to estimate the canopy loss primarily. Further analysis has been carried out in order to intensify the backscatter difference using radar texture. Second order texture measures, Homogeneity, Entropy and Angular Second Moment (ASM) were identified to give the highest correlation with the changes derived from complex coherence and image rationing. Both Coherence and Backscatter values for deforested regions are lower than those of regions with forest cover. Experimental results suggest that the Homogeneity texture has the advantage in delineating the difference between the forest and bare soil classes. The comparative results between the ground truth based referenced images generated from Google images and the SAR texture based interpretation suggests that an alarming area of 0.0207886 km2 has been changed from forest to soil.

1 INTRODUCTION

Forest cover is only 31% (FOA, 2010) of the land on our planet. It is one of the most important renewable natural resources which has a significant role in human life and environment. Forests play a major role in maintaining environmental balance on the earth. They have a prominent role in global carbon cycle, exchanging large fluxes of carbon with the atmosphere through the processes of photosynthesis, respiration and decomposition (Waring and Running, 1998).

Forest resources are important socially, economically and environmentally. Forest produces wood, protects wildlife, maintain groundwater levels, protect the soil fertility, and absorb carbon and another pollutant gases from the atmosphere. All these forest functions influence the continuity of life and have global implications (Heri et al, 1999) as well.

Deforestation is the conversion of forest to another land use type which is mainly a result of human activities and natural causes. It may involve opening of the canopy, modification of the vertical structure, habitat parameters or change of other attributes (Kariyawasam R. and Rajapakse C., 2002).

Sri Lanka is an island located in the Indian ocean within the latitude of 9°50 - 5°50 in North and longitude of 79°10-82°5 in East Geographical Coordinates and has a tropical climate (CIA, 2007). It is rich of forests because 29.9% of the total land area is belongs to the forests but Sri Lanka’s natural forest cover has dwindled from 80% to less than 16% over the last 100 years. Similarly past several years Sri Lanka faced to several natural disasters including floods and landslides. Disturbing to the natural environment due to the recent developments is the major reason behind those events. Therefore the disturbances and their consequences should be evaluated for the country. The major disturbance can be recognized as deforestation so the magnitude of deforestation and its consequences on natural processes need to be investigated. An attempt was taken in this research to understand the changes in forest cover throughout the study area using remote sensing techniques.

Remotely sensed satellite observations from space have fundamentally changed the way in which scientists study the atmosphere, oceans, land, vegetation, glaciers, sea ice, and other environmental aspects of the Earth's surface. Half a century of satellite observations of the Earth has provided dramatic pictures and is the basis for a new scientific paradigm (Earth-system science Tatem et al. 2008).Among the different satellite observation systems, Microwave Remote Sensing provides a unique opportunity to assess and monitor deforestation due its all-weather, day and night image acquisition capability unhindered by cloud cover; its potential to express surface roughness prominently; and its ability to penetrate the soil in certain cases. The major objective of this study is to parameterizing the forest canopy using C- band SAR (Synthetic Aperture Radar) images and minor objectives are Detect the existing forest canopy using Space bourn C band SAR images, detect forest canopy loss using Space bourn C band SAR images.

2 STUDY AREA

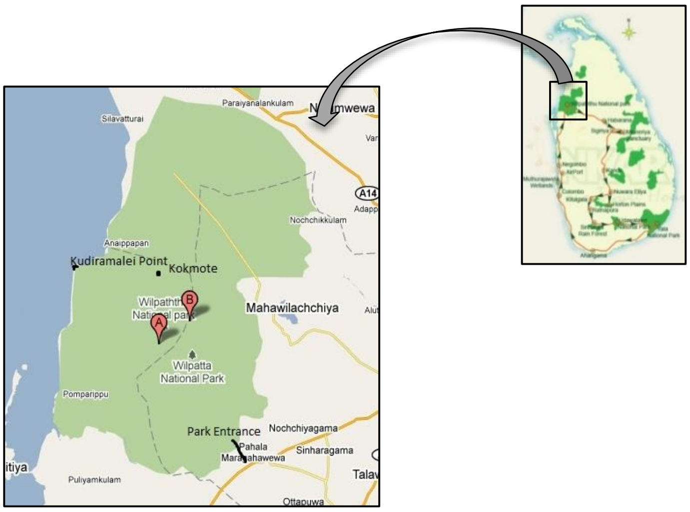


Figure 1: Location of Wilpattu National Park (Not to Scale)

This study was an attempt to reveal the deforestation in Wilpattu national park (8.4106° N, 80.0511° E) which is recently subjected to intense large-scale forest clearance. The Wilpattu national park is located in the northwest coastal dry zone in Sri Lanka, 30km west to Anuradhapura and 26km north to Puttalam.(approximately 180 km north of Colombo). The park is 131, 693 hectares in area and ranges from 0 to 152 meters above sea level. Nearly sixty lakes (Willu) and tanks are found spread throughout Wilpattu. It is the largest and one of the oldest National Parks in Sri Lanka. Wilpattu is among the top national parks world-renowned for its leopard (Panthera pardus kotiya) population (https://en.wikipedia.org/ wiki/Wilpattu_National_Park, 17.05.2017). When considering the population of administrative districts of the park, there is a significant increment of the population during past 30 years can be seen which is evident that the region was cleared for the purpose of establishing settlements.

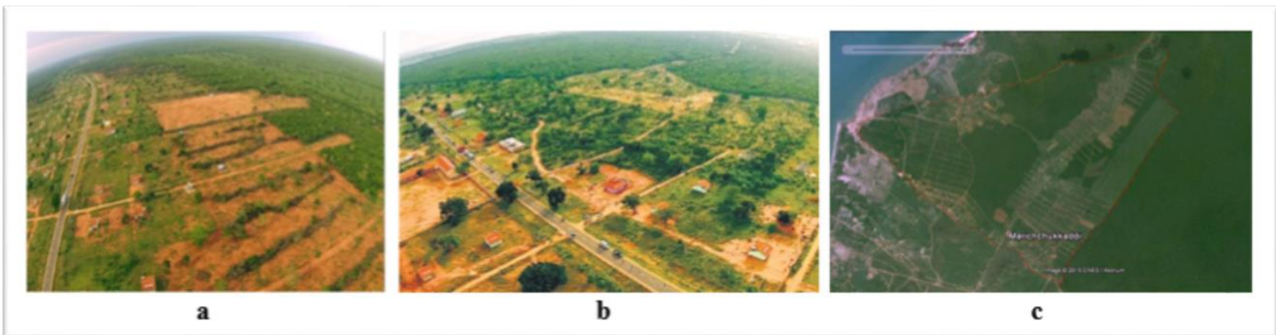


Figure 2: Deforested Regions ((a, b) Ariel photographs (c) Google earth image)

2.1 Population in Nearest Districts of Study Area

Table 1: Population of nearby districts of study area (source: Department of Census & Statistics, Sri Lanka)

Year	1981	2001	2012
Puttalam	485619	709677	762396
Mannar	105276	151577	99570
Anuradhapura	575546	745693	860575
Total population	1166441	1606947	1722541

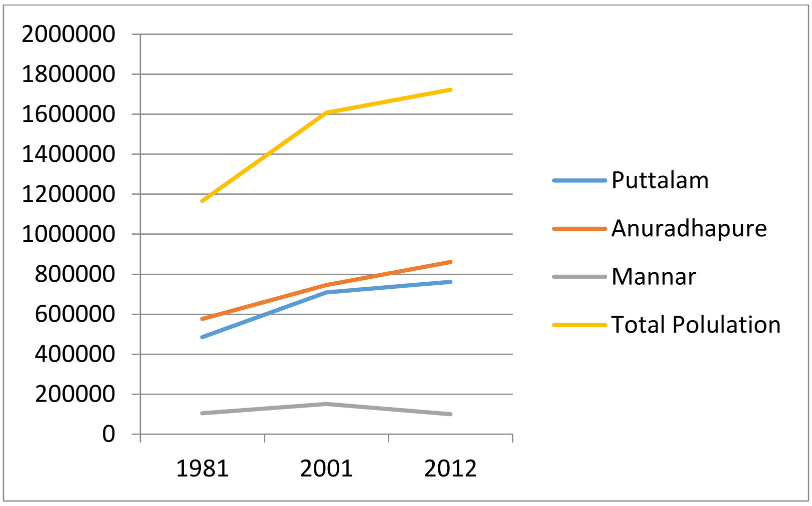


Figure 3: Population increment over past 30 years

2.2 Data

Sentinel 1 Single-Look Complex (SLC) imagery data have been selected for this study. The frequency band used in the study is C-band (4-8 GHz frequency/ 3.75 cm to 7.5 cm wavelength) and descriptions about the used data were mentioned in Table 2.Apart from RADAR images SRTM 90m DEM has been used to co-register and geocode the temporal images.

Table 2: Data used for the study

<table>
<tr><th>No</th><th>Acquisition date</th><th>Mode</th><th>Product type</th><th>Polarization</th></tr>
<tr><td>1</td><td>2015.06.04</td><td rowspan="6">IW (Interferometric Wide Swath)</td><td rowspan="6">SLC (Single look complex)</td><td rowspan="4">VV single polarization</td></tr>
<tr><td>2</td><td>2015.08.15</td></tr>
<tr><td>3</td><td>2016.07.16</td></tr>
<tr><td>4</td><td>2016.08.09</td></tr>
<tr><td>5</td><td>2016.03.18</td><td rowspan="2">VH+VV dual polarization</td></tr>
<tr><td>6</td><td>2016.09.26</td></tr>
</table>

2.3 Tools Used

For image processing SNAP tool box develop by European space agency. ENVI 5.0 and MATLAB used for further processing of SAR images and ARC map for design the output map and finally Microsoft Excel was used for analyze the results statically.

3 METHODOLOGY

Basically the methodology consists of two major sections. First the preprocessing of satellite images and secondly applying change detection techniques to the radar images to extract the surface changes due to deforestation. The pre and post satellite images were subjected to the same preprocessing methods and all the images were geometrically co-registered before change detection algorithm were applied. The General flow chart is shown in figure 4 which gives a quick look into the overall set up of this study.

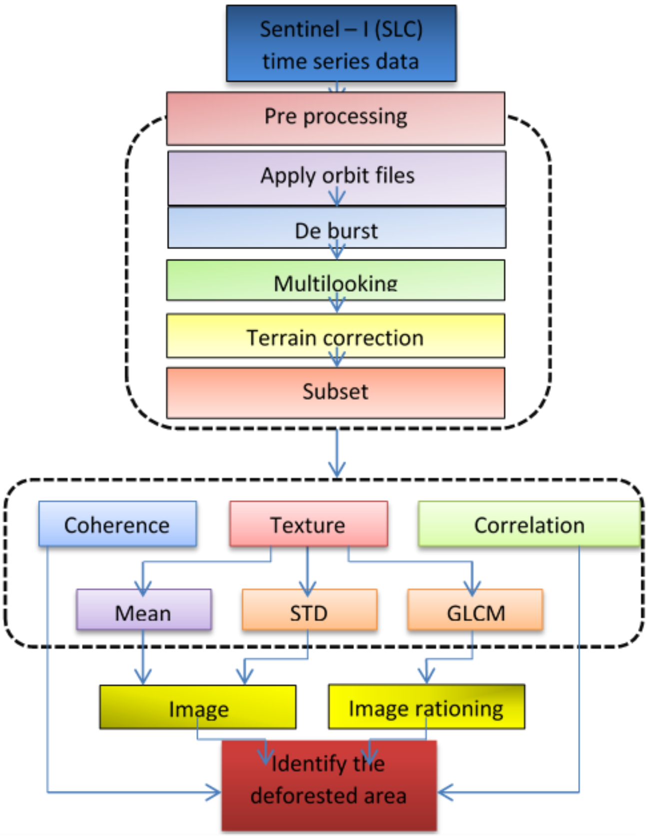


Figure 4: Conceptual methodology of the research

4 ANALYSIS & RESULTS

Two data sets were downloaded as single polarization and dual polarization. The acquisition dates the datasets were mentioned above. The results obtained for both polarizations were lay head together.

4.1 Coherence Analyzing

The complex coherence is a technique that can be applied for RADAR images in order to measure the degree of resemblance of RADAR phase between two SAR images of the same area. It measures the correlation between the backscatter and the phase of the temporal image pair which may contain valuable information about the land cover. Coherence image can be used to find the changed areas because it gives high coherence values for unchanged areas and low coherence value for changed areas.

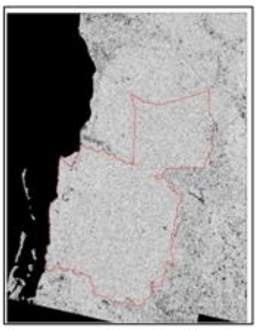


Figure 5: Coherence between images of 2015.06.04 and 2015.08.15 VV

Figure 6: Coherence between images of 2015.06.04 and 2016.07.16 VV

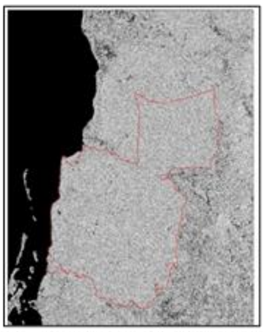


Figure 7: Coherence between images of 2015.06.04 and 2016.08.09 -VV

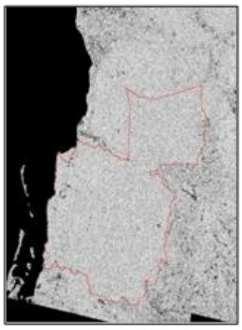
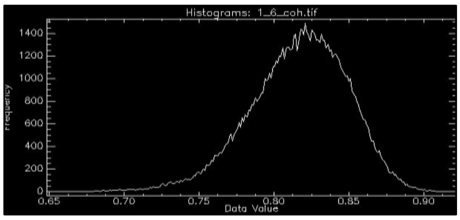


Figure 8: Coherence between images of 2016.03.18 and 2016.09.26 -VH

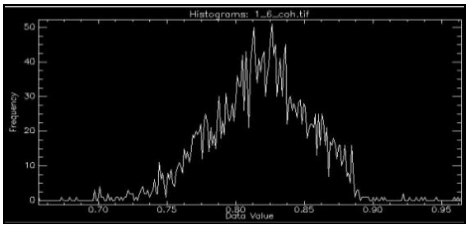
☐ Maximum Coherence (1) ■ Minimum Coherence (0) ☐ Wilpattu boundary

The results of the study show the extent of change observed in each image is gradually increasing coherence images from Figure 5 to Figure 8. For analyzing the coherence value for the study area it was selected four regions from the coherence map as water, low forest cover, dense forest cover and deforested area. For the selection of these areas it was first prepared the shape files by digitizing Google earth image and then required regions were extracted from the coherence image. Then the Histogram for coherence (between two images acquired in 2016.06.04 and 2016.09.26) plotted for the above four regions are as shown below.

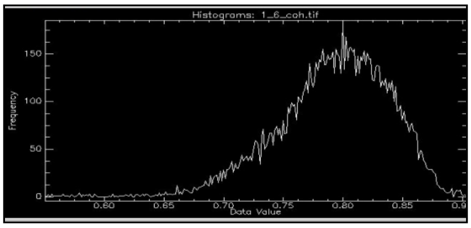
1. Histogram for Dense Forest Cover



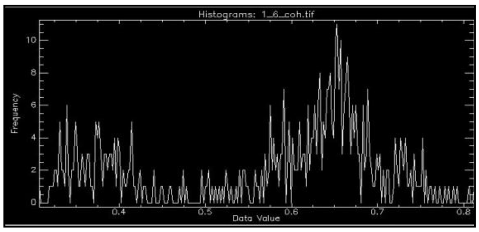
3. Histogram for Water



3. Histogram for Moderate Forest



4. Histogram for Deforested region



In these histograms, it can be observed that higher values exist for water; dense forest cover and low forest cover classes and lower values for deforested region. It is because prior to deforestation

These areas were subjected mainly to a volume scattering and after deforestation the bare soil was subjected to surface scattering. In these two incidents the scattering mechanism is different and so it gives different backscatter values. This causes the low correlation between two incidents thus low coherence.

A high coherence can be observed only for unchanged areas. When it is considered the area within the boundary of Wilpattu National park, there also a high coherence exists. So this area can be considered as an unchanged area. But this coherence value is not equal to 1, since theoretically forest cover has less coherence value due to their temporal behavior and because of the temporal decorrelation of two data sets used for the analysis.

4.2 Image Rationing

Theoretically in image rationing method, the black colour represents the unchanged areas while white colour represents changed areas (Figure 9 to 12). According to the image ratio analysis of sentinel I (SAR) C band images; there is a very limited deforestation can be observed within the boundary of Wilpattu national park which is not strongly significant. But it can be observed deforestation outside the boundary of Wilpattu. This result was also concluded according to the results of Coherence and Change detection methods.

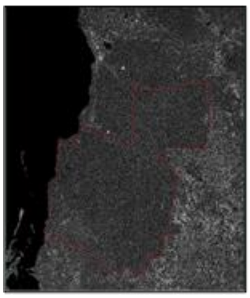


Figure 9: Rationing between images of 2016.06.04 and 2016.08.15

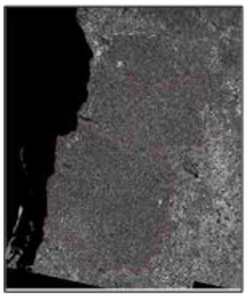


Figure 10: Rationing between images of 2016.06.04 and 2016.07.16

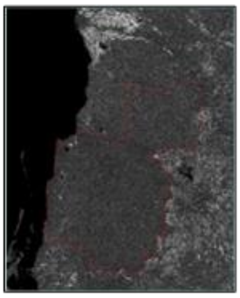


Figure 11: Rationing between images of 2016.03.18 and 2016.09.26

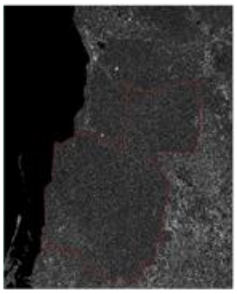
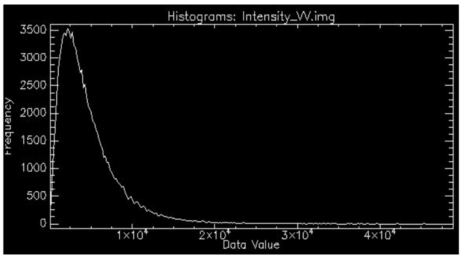


Figure 12: Rationing between images of 2016.06.04 and 2016.08.09

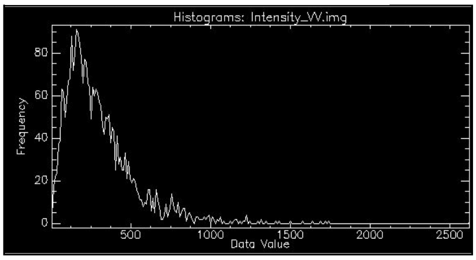
Wilpattu boundary
No change
Maximum Change

Preprocessed image of 2016.09.26 was used for backscatter analysis to assess the characteristics of radar backscatter values for different land cover types. The observed graphical plots are as follows,

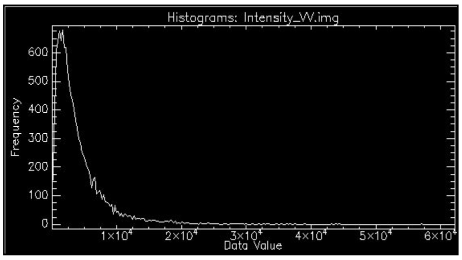
1. Histogram for Dense Forest Cover



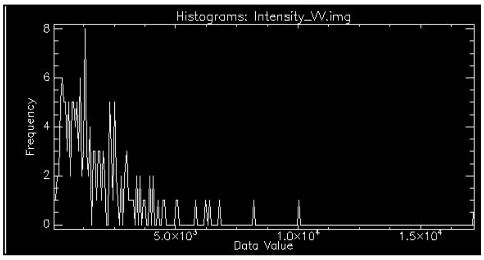
2. Histogram for Water



3. Histogram for Low Forest



4. Histogram for Deforested area



Mean back scatter value for above four land cover types were calculated and it was concluded that mean backscatter for deforested regions are lower than the both dense and low cover forest regions. The reason behind this observation could be the loss of the volume scattering effect due to the canopy removal or changes with the deforestation. And also the backscatter value for water indicated a low value relative to other study regions. The reason for this is the phenomenon of Specular Reflection where water acts like a specular reflector due to the dielectric properties of the water. Due to the smoothness of the water bodies it will be deflected all the RADAR waves reaching its surface out of the receiving antenna thus have low backscatter energy to the radar image comparing to the background features.

4.3 Texture Analysis

When it is compared the results of coherence estimation and change detection, it can be observed a similarity in the results of both procedures. In both result sets, limited deforestation can be observed within the boundary of Wilpattu. Therefore it was attempted to identify accurately a deforested area outside Wilpattu boundary using Texture analysis and Correlation Coefficient inorderto observe the nature of the backscatter of an area with deforestation. Two data sets were selected; 2016.06.04 as pre image and 2016.08.09 as post image to be analysed in Matlab and GLCM for Texture analysis.

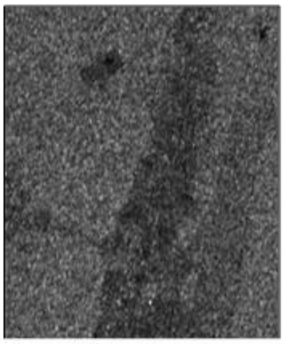


Figure 13: Original image

Figure 14: Standard Deviation texture

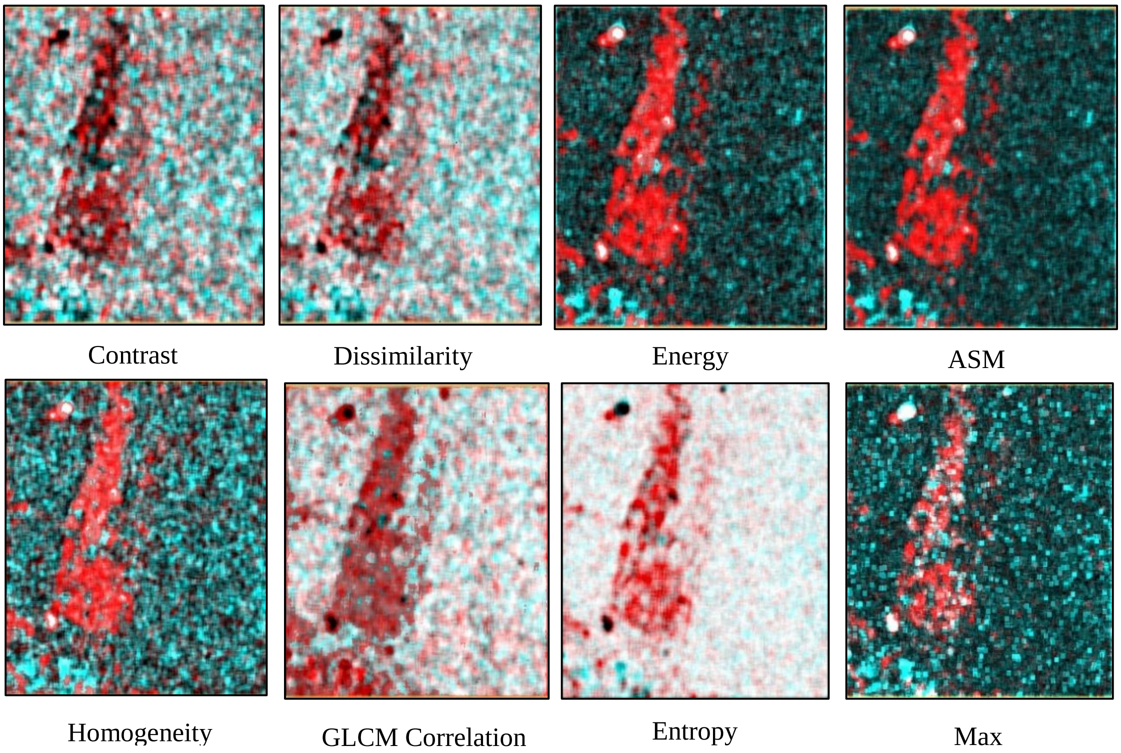
Figure 11: Mean texture

Though it can be observed a considerable backscatter variation in the original image (Figure 13) for canopy and bare soil, in the obtained mean (Figure 15) and STD (Figure 14) texture images it was unable to observe a considerable backscatter strength variation. It is because, the above images obtained as Mean texture and Standard deviation texture represent less scattering variations. It can be due to smoothing of the RADAR image during Mean and STD texture image formation and due to the change of values of the all pixels according to the deforestation of the area causing an elimination of the effect of the mean.

4.4 GLCM Analysis

The results of the texture analysis done in SNAP, GLCM were subjected to RGB visualization in order to distinguish the bare soil and canopy. The RGB visualized texture images were as follows. RGB visualization in Figure 16 has the following color combinations.

Red: Post Texture image - 09.08.2016
Blue, Green: Pre Texture image - 04.06.2015



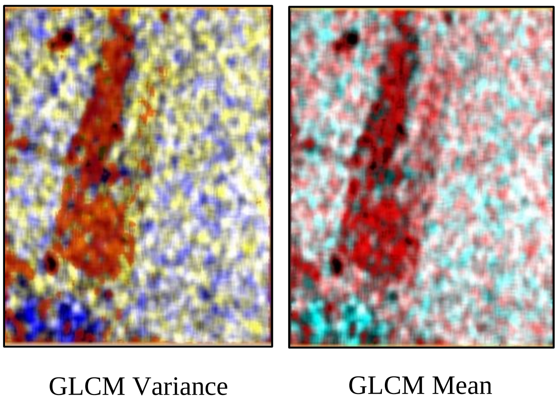


Figure 15: RGB Visualizations of GLCM texture images

This combination can be used to distinguish between areas that are related to the bare soil (Deforested area) and canopy. The areas which were altered during this time period are represented in Red as the post image was selected for the red channel, while the white color depicts the area where no change had been occurred which means that the backscatter of the area is same. So the red patches in texture images were corresponding to the bare soil and other area representing the canopy cover.

Though in theoretically, the regions which are not deforested should be in white color, (since there is no any change had been occurred in those areas) they were not, because of the temporal behavior of the forest canopy and temporal decorrelation of two data sets used for the analysis.

Based on a visual study of the above results it was clear that the most appropriate texture for the identification of deforestation is Entropy and ASM (Angular Second Moment). Then the next experiment was to find the appropriate method statically for that, the respective images obtained in RGB visualization were used to mask out the bare soil using a threshold binarization. Then the areas of each mask out region were calculated. The table 3 shows the resulted area from texture images.

Table 3: Calculated area for different texture images

Texture image	Area (Km^2)	Area Difference
Max	2.061	-0.7832115
Contrast	1.300	-1.5442115
ASM	2.996	0.1517886
Entropy	3.126	0.2817886
Energy	3.290	0.4457886
GLCM Correlation	4.206	1.3617886
GLCM Variance	3.195	0.3507886
GLCM Mean	1.602	-1.2422115
Homogeneity	2.865	0.0207886
Dissimilarity	4.964	2.1197886
Energy	3.290	-0.7832115

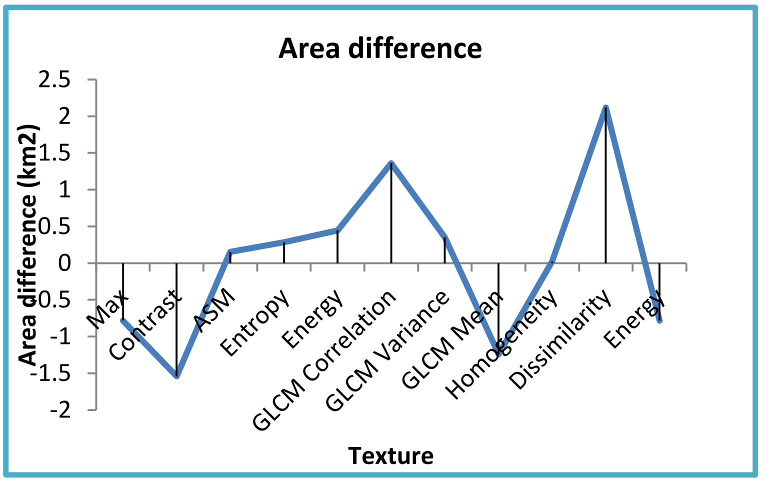
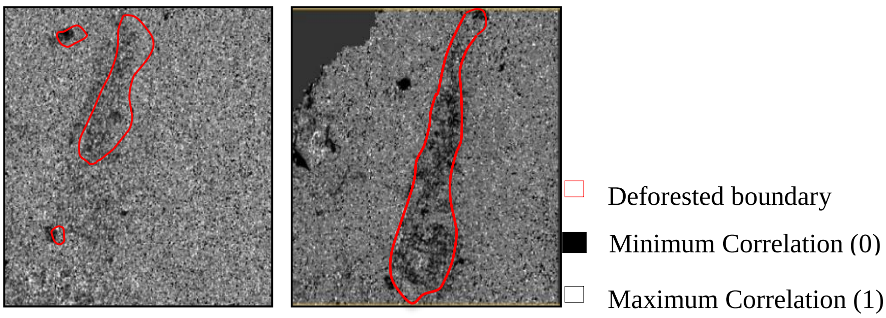


Figure 16: Area difference between w.r.t. to texture

Actual area of the bare soil was calculated by digitizing the Google earth image because the time and cost allocated for the research limited the field observations. The obtained rough area was 2.84421145 km^2. Detected bare soil areas are numerically compared with the area derived from Google earth.

The comparison of these results shows that Homogeneity is more suitable to detect the bare soil from forest area and the error for the area is 0.0207886 km^2. Entropy and ASM also gives better results for the statistical analysis. The graph for the deviations is as follows, The negative values of the graph shows the areas where the obtained area is less than the actual value while the positive values shows the areas where the obtained area is higher than the actual value. Therefore according to this analysis it can be shown that Max, Contrast, GLCM Mean and Energy are texture images representing the areas less than the actual value and ASM, Entropy, Energy, GLCM Correlation, GLCM Variance, Homogeneity and Dissimilarity are texture images representing the areas higher than the actual value.

4.5 Correlation Coefficient



VV Polarization *VH Polarization*

Figure 17: Correlation coefficient image

In order to extract the changes due to the deforestation, the correlation coefficient and the difference between two radar images were calculated for Wilpattu area. The reduction of the correlation coefficient is mainly expected from the damaged area as radar illumination changes. Seasonal changes of forest canopy and vegetation patches can influence to the results since the temporal difference of two images being higher than one year. The results were obtained for Correlation coefficient is show in Figure 18.

It is obvious that, the area detected from co polarizing approach provides the least percentage of accuracy than cross polarizing approach, because as mainly the volume scattering within a forest canopy is highly sensitive to the cross polarization which is effect on RADAR images than the co polarization. Figure 19 shows the relationship between the correlation and difference of two radar images before and after the event by examining the characteristics of radar backscatter values in altered deforested area. In theoretically, if any changes of geographical phenomena were occurred in between these two image acquisitions, the less correlation (< 0) or minus relations have been defined the change.

By using backscatter analysis, it can be concluded that the area was damaged consists low backscatter value than the canopy area. Hence, the backscatter value is decreasing from pre image to post image. So, even the difference between images represents a minus value and that is describing about the changes of the areas. By considering above two concepts, change pixels were extracted by selecting the minus areas of the scatter plot (figure 19) by the Region of Interest (ROI). The possible range of deforestation is interpreting between the correlation coefficient vs. difference and the extracted deforested areas after masking are illustrated Figure 20.

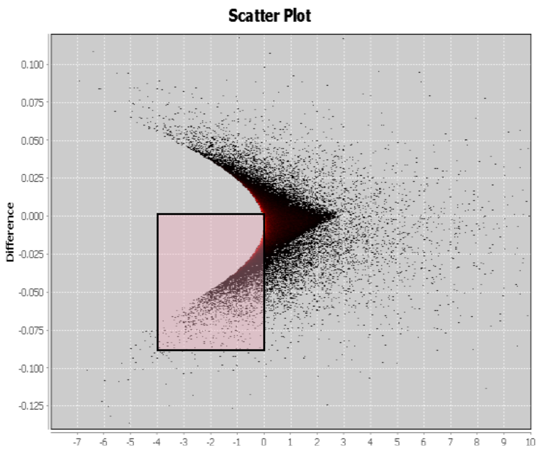


Figure 19: Scatter plot between correlation coefficient and Difference image for VH polarization pre and post images.

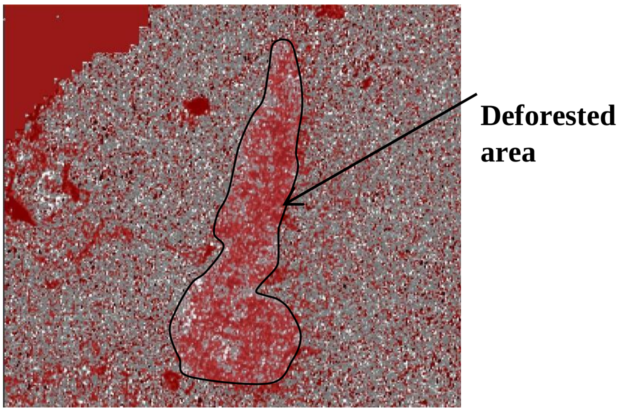


Figure 20: Extracted deforested areas from the scatter plot of Difference image for VH polarization pre and post images.

The correlation between change detection methods and texture images were calculated by using statistical analysis tool in Arc GIS 10.1. It appeared that there were high correlations between image difference and the correlation coefficient with texture images while the correlation between Coherence and image rationing were very small.

Table 4: The correlation between change detection methods and texture images

	Complex Coherence	**Image rationing**	**Correlation Coefficient**	**Image Difference**
Contrast	0.14490	0.07979	0.33804	0.30518
GLCM Covariance	0.01676	0.11833	0.23634	0.28444
Energy	-0.17517	-0.13440	-0.49700	-0.42481
Entropy	0.15050	0.18993	0.35766	0.28965
Homogeneity	-0.05361	-0.07818	-0.21257	-0.21571
Max	-0.12747	-0.07119	-0.22993	-0.21103
GLCM Mean	0.12002	0.13281	0.35090	0.41977
GLCM Variance	0.14133	0.11819	0.34636	0.39384
Dissimilarity	0.12828	0.08791	0.35377	0.32241
ASM	-0.17079	-0.10498	-0.35701	-0.32576

When consider about the highest value which are represented in Complex Coherence, Image rationing and Correlation Coefficient, that have given by Entropy. So it can be concluded that Entropy is most suitable to identify the deforested area by using these three change detection methods.

5 CONCLUSIONS

Complex coherence, correlation coefficient, image differencing and images rationing techniques were applied for two sentinel 1 SAR C band images before and after the event. There is a very limited deforestation which is not strongly significant inside the boundary of Wilpattu National Park. But it can be observed some deforestation outside the boundary of Wilpattu. This was concluded according to the results of Coherence and Change detection methods.

Texture analysis concluded that Entropy is most suitable to identify the deforested area since it gives the highest correlation with change detection methods.

The interaction of RADAR signal with the real earth features as dense vegetation cover, deforested and water is different to each other. By taking this fact in consideration, back scatter analysis was performed. The results showed that mean backscatter for deforested regions is lower than the both dense and low cover forest regions while the backscatter value of water indicated very low relative to the other regions due the phenomenon of specular reflection.

Finally results of the study proves that the single polarization C-band RADAR imageries are capable of estimating the deforestation in area,

6 REFERENCE

Brandt TSO, Paul M. Mather, *2000*, Classification Methods For Remotely Sensed Data Second Edition, Boca Raton, FL 33487-2742, pp 1 -38.

Dahdal B., 2011, The use of interferometric space borne RADAR and GIS to measure peat subsidence in Indonesia, University of Leicester, pp 113-114

Giri Tejaswi, March 2007 , Manual On Deforestation, Degradation, And Fragmentation Using Remote Sensing And Gis, Strengthening Monitoring, Assessment And Reporting On Sustainable Forest Management In Asia (Gcp/Int/988/Jpn), pp 5-6

Kariyawasam K.M.H.R. , Rajapakse C., July 2014, Impact of Development on deforestation in Sri Lanka: An analytical study, IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT) e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 8, Issue 7 Ver. II (July. 2014), PP 35-39

NRCAN, Viewing Geometry and Spatial Resolution , Retrieved January 08, 2017, from http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-airphotos/satellite-imagery-products/educational-resources/9341

NRCAN, RADAR Polarimetry Retrieved February 18, 2017, from http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational resources/ 9275

Rahman M.M., 2010, Mapping tropical forest cover and deforestation using synthetic aperture radar (SAR) images, at Springerlink.com pp 113-121

Samuel W., Jackson C.R., September 2004, Principle of Synthetic Aperture Radar, SAR Marine users' Manual, NOAA/NESDIS , pp 1-23

Sentinel1 user Handbook Retrieved January 15, 2017, from https://sentinel.esa.int/

Vyjayanthi N., Jha C. S., Murthy M. S. R., Yadav D.K., Singh L. October, 2008, Forest Biomass Estimation and Forest Structure Analysis of Deciduous Forests Using SAR Data, Indian Space Research Organisation, Hyderabad ,pp 1 -14