COMPARISON OF INDIVIDUAL TREE CROWN DELINEATION METHOD FOR CARBON STOCK ESTIMATION USING VERY HIGH RESOLUTION SATELLITE IMAGES

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ABSTRACT: Greenhouse gas inventories and emission reduction program requires scientifically robust methods to quantify forest carbon storage in forest. Remote sensing techniques are accurate and low-cost alternatives to the field based assessment. High spatial resolution remotely sensed imagery provides viable sources and opportunities for forest inventory at an individual tree level. The study aims to compare two methods to delineate the individual tree crown to develop a model to estimate carbon stock obtained from field survey and the crown projection area derived from high resolution satellite data of 0.5 m spatial resolution (GeoEye-1). The performance of two algorithms, namely region growing and valley following of object oriented classification was compared in the dense broadleaf forest of Ludhikhola watershed, Gorkha, Nepal. The region growing of eCognition and valley following of ITC algorithms were used to delineate individual tree crowns produced a segmentation accuracy of 68% and 58% respectively. The region growing is based on finding the local minima to create the boundary and local maxima to locate the potential tree top. The valley following algorithm is also based on finding the local minima by following the shades between the valleys of the trees canopies. *Shorea robusta* trees were identified in the image using a nearest neighbor classification approach with an overall accuracy of 74%.

1. INTRODUCTION

Global warming and the climate change are pressing issues in the global environmental sector. Global warming, is witnessed by the increase in atmospheric temperature with the emission of greenhouse gases (GHG). The Intergovernmental Panel on climate change (IPCC) estimated that the global temperature will most likely increase up to 3.5^0C (three and half degrees) by 2100 (IPCC, 2003). The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007) indicates that the forestry sector, mainly through deforestation, accounts for about 17% of the global greenhouse gas emissions which is the second source after energy sector.

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change (UNFCC) to limit emissions of greenhouse gases. The global agreement on the Kyoto Protocol in 1997 focused on reducing concentrations of GHGs and CO_2 in order to mitigate global warming. The Kyoto Protocol recognized the importance of forest in mitigating greenhouse gas emissions (i.e. carbon dioxide, methane and other compounds) and included forest and soil Carbon sequestration in the list of acceptable offsets (UNFCC, 2008). The Kyoto Protocol commenced the developing countries to sign an agreement to reduce their human–induced emission of CO_2 by at least 5% below their emission levels of 1990 by 2008-2012 (UNFCC, 2008). In response to high forest degradation rates, and specially to reduce emissions from deforestation, United Nations Framework Convention on Climate Change (UNFCCC) adopted REDD (Reducing emission from deforestation and degradation) action plan (UNFCC, 2008). The REDD, considered as a relatively low cost greenhouse gas mitigation option and currently has emerged as one of the key tools for fighting carbon emission (FAO, 2009).

Forests cover almost one third of the world's land area and constitute the major terrestrial carbon pool. The Carbon storage in forest ecosystems involves numerous components including biomass, which comprises of all the organic material both above and below ground and both living and dead e.g.; trees, crops, grasses, tree litter roots *etc.* (IPCC, 2003). Forests play a critical role in reducing ambient CO_2 levels, by sequestering atmospheric carbon into the growth of woody biomass through the process of photosynthesis and also by increasing the soil organic carbon (SOC) content (Brown , *et al.*, 1994).

In order to understand and balance the global carbon budget, considerable effort has been made. The sources of carbon flows and fluxes should be known to understand successful carbon balance within the terrestrial biosphere. Estimating the carbon sinks have a high degree of uncertainty (Defries, *et al.*, 2000), as there is very limited data showing the proportion of carbon sequestered from secondary forest re-growth. Monitoring carbon in forests with high spatial variation of tree density and species composition poses major challenges. The estimation of above ground biomass is one of the potential methods widely used to acquire forest inventory. Forest inventories of above ground biomass (AGB) require intensive labour and is often time consuming. Therefore, remote sensing-based above ground biomass (AGB) estimation has increasingly attracted scientific interest (Benefoh, *et al.*, 2008; Blackard, *et al.*, 2008). A major benefit of a satellite based approach is the potential to provide 'wall- to-wall' observation of carbon stock proxies (Gibbs, *et al.*, 2007). To efficiently compensate through carbon credits, REDD is developing an approach for monitoring carbon stocks over large areas in a cost effective and operational manner. According to IPCC Good Practice Guideline, (IPCC, 2003), remote sensing methods are suitable for carbon pool estimates, particularly the aboveground biomass. Indeed the use of remote sensing (RS) has been considered as a feasible approach for the collection of such information (Foody, *et al.*, 1994).

Nepal being a signatory country to the Kyoto protocol is obliged and committed to acting against human induced climate change. Nepal contributes for 0.025% (MoPE, 2004) to the annual GHG emission. In recent years there is considerable decrease in deforestation rate at an annual rate of 0.06% (DoF, 2004) which shows the decreasing trend in the rate of deforestation which was 1.7% (DFRS, 1999). The decreasing trend of deforestation is certainly mitigates the negative impact of climate change at global level. These changes have occurred due to successful community-based forest management (CFM) (Acharya, 2003). REDD has recognized the efforts of Community Forest Management (CFM) and is in the process of initializing its operation in the country. Reduction of GHG emission will help the country to benefit from the carbon credits in the international carbon market. Only few studies exist that quantify such prospects which may help the community members to benefit from REDD's incentives to strengthen and promote sustainable forest management through carbon credits.

Estimates of individual tree crown area are essential for accurate carbon estimation (Gonzalez, *et al.*, 2010; Joshi, *et al.*, 2006). However identifying individual tree crowns is difficult and requires intensive labour. Researches show that there is a significant relationship between crown area and DBH. This relationship can be extended to model the relationship between crown projection area (CPA) and above ground biomass derived from DBH for accurate and efficient mapping and monitoring of carbon.

Accurate delineation of individual trees crown from imagery requires an efficient segmentation and classification method. A broad variety of software and algorithms have been developed for image segmentation. At present little is known about the performance and robustness of these methods. This can be explained by the fact that validation and comparative studies of the reported results from different classification has been scarce (Joshi, *et al.*, 2006). To obtain better understanding of the existing methods, it is necessary to compare them using the same evaluation methods. Comparative study of different segmentation is therefore of importance in order to clarify the performance of a method in the estimation of carbon stocks. Region growing and valley following algorithm are widely used for segmenting and delineating individual trees. An evaluation of different forest types using region growing (Mallinis, *et al.*, 2008) gave an overall accuracy of 81% - 93%. The study carried out by (Chubey, *et al.*, 2006; Tiede, *et al.*, 2006) to separate two forest types; coniferous and deciduous using valley following algorithm gave an accuracy of 81%. So far both algorithms have provided acceptable results in estimating forest and tree parameters. Several studies have been conducted to compare image segmentation methods using very high spatial resolution satellite (Carleera , *et al.*, 2004) but there is a limited number of studies done to compare region growing and valley following algorithm. Despite the efficient use of different segmentation method to extract information from the high resolution satellite imagery for carbon estimation, little research has been done to evaluate the accuracy and quality of the information derived from the images. This study aims to assess two methods for individual tree crown delineation and the implementation of a model to estimate carbon stocks in mid-hill forest of Ludhikhola watershed in Gorkha district of Nepal using VHSR images and object oriented classification of tree species.

2. MATERIALS AND METHODS

2.1 Study Area

The present study was carried out in Ludhikhola watershed, Gorkha, Nepal (Figure 1). It represents a typical sub-tropical forest that was exposed to high deforestation, and recently has been conserved through community forest management. Ludhikhola watershed is selected as one of the pilot projects under the REDD project as it represents the middle part of Nepal and comprises of different forest types and species. The Gorkha district covers an area of 3,610 km^2 and falls in central development region of Nepal. The Ludhikhola watershed area lies in the southern part of Gorkha district, located between $27^0$55'02"-$27^0$59'43"N latitude and $84^0$33'23"- $84^0$40'41"E longitude with an area of 5827 ha.

2.2 Research Methods

A diagram of the applied method is shown in Figure 2. The research method of this study was divided into three parts pre-field work, field work and post field work. The sampling design was done and the images were fused prior going to the field. In the field the DBH and crown diameter were collected and the tree were identified in the printed picture in different sampling plots. The post field comprises of data analysis to compare the two methods for delineating individual tree crown and model development for carbon estimation.

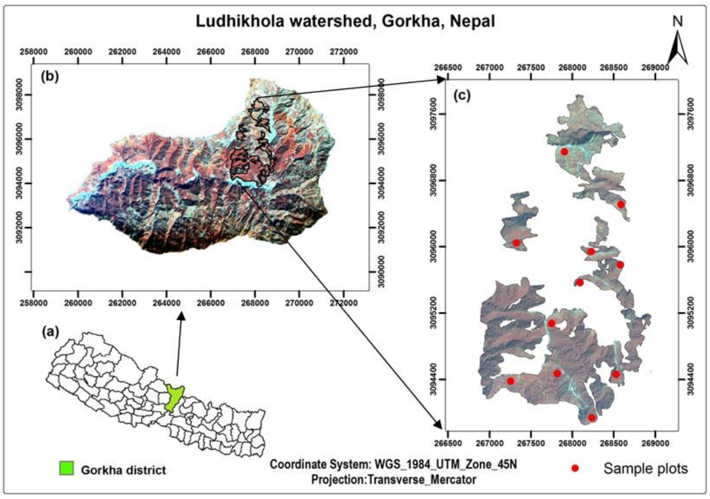

Figure 1: Location of the study area.

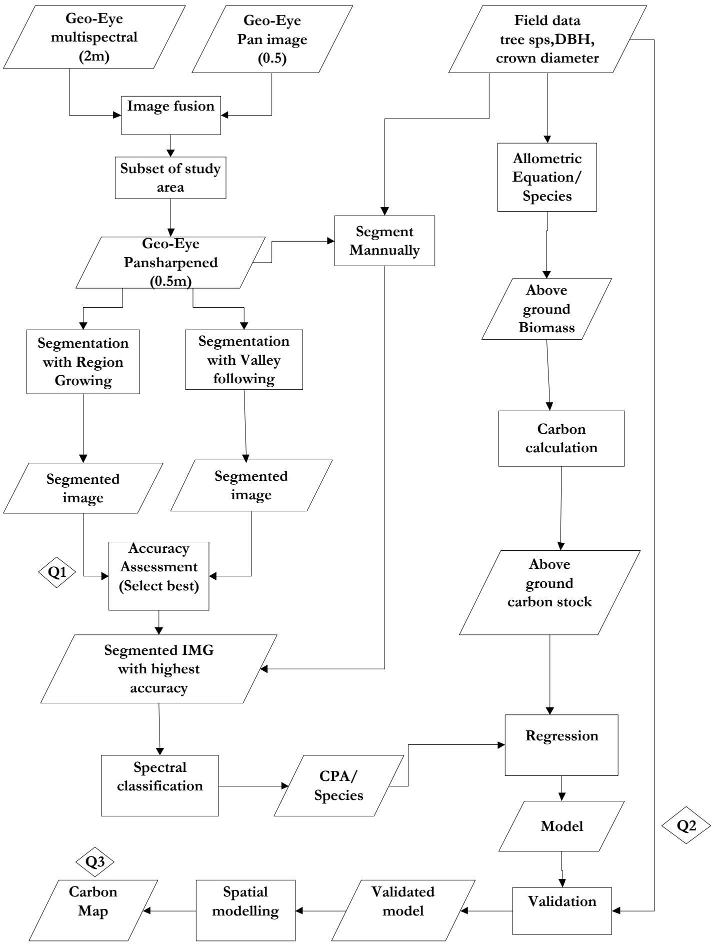

Figure 2: Research Method.

A high spatial resolution GeoEye-1satellite image is the main data used. It was acquired on 02 November, 2009, and time was GMT 5: 13. A topographic map of 1:50000 scale was used in this research too.

3. RESULTS AND DISCUSSIONS

VHRS imagery can be used to obtain the viable sources and opportunities for forest inventory at an individual tree level. Available algorithm for the individual tree crown delineation gives an ample opportunity for providing the tree-based forest inventory. The valley following method is based on following the valleys in the shaded area to delineate the individual tree crown using the local minima, or "valleys" which are used to construct absolute crown boundaries. The comparatively lower accuracy (58%) of valley following may be due to the fact that in the open forest area (in some areas) the grass reflects a similar properties as tree crowns and thus are segmented as a big crown by the algorithm. Region growing was found to over segment crowns in densely planted areas. This is since there is an influence of canopy structure on reflectance. The canopy structure in study area forest is complex causing overlapping and intermingling situation, creating difficulty in delineation of individual crown, resulting in over segmentation. The result of the comparison of two segmentation approaches shows that the individual tree crown delineation using valley following algorithm was less accurate compared to the region growing. Both the method focused on finding the local minima but region growing also used local maxima to detect the tree top. The result demonstrated that the valley following tends to miss small crowns which can be found by region growing. The region growing is more flexible in detecting tree crowns of different size, as it is possible to set up parameters by the interpreter itself unlike valley following, where parameters for the crown size cannot be set.

The non-linear model was developed to explain the relationship between CPA from the segmented image and the carbon stock calculated from the ground measurement. The result shows 0.67 R^2 in *Shorea robusta* and 0.70 R^2 for other class. The developed model shows that though the DBH of the trees is increasing with uniform rate while the rate of increase of CPA is diminishing with the competition and crowding in the natural forest condition. This implies that the carbon stock will be increasing despite the slow rate of increment in crown projection area. The model was validated with the test data set and the RMSE was calculated for estimated and observed values which show the error of 30% and 18% for *Shorea robusta* and others respectively. The less RMSE thus predicts that the model can be utilized to estimate the carbon stock in the Ludi damgade. The analysis thus made it clear that the model derived using VHR imagery was significant and CPA can be regarded as a good predictor to explain the carbon stock.

The model was validated using two statistical methods which is coefficient of determination and RMSE. Model was validated using the test dataset, the coefficient of regression gave the R^2 = 0.60(n= 10) for *Shorea robusta* and for others the R^2 =0.82(n= 10). Although, the developed model was reasonable for other species but not for *Shorea robusta*. The coefficient of regression for *Shorea robusta* was weak (R^2= 0.60) result as shown in Figure 3. The RMSE calculated to validate the model gave the error percentage for the calculated and predicted which was 30 % for *Shorea robusta* and 18 % for other species which explains that the developed model can accurately predict 70% of carbon stock from *Shorea robusta* and 82% for other class.

The two models mentioned were used to map the carbon stock of Ludi damgade community forest. A total of 31 $MgCha^{-1}$ was obtained from the Ludi damgade CF. The carbon stock per tree range from more than 200 to 800 kg/tree. Due to small trees mostly the range of carbon stock was in 200 kg/tree. Map of estimated carbon stock in Ludi damgade CF is shown in Figure 4.

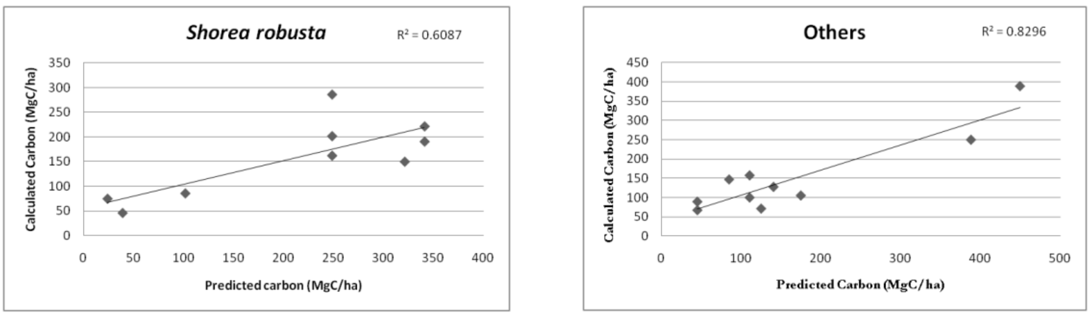

Figure 3: Predicted v/s Calculated validation samples of *Shorea robusta* and Others

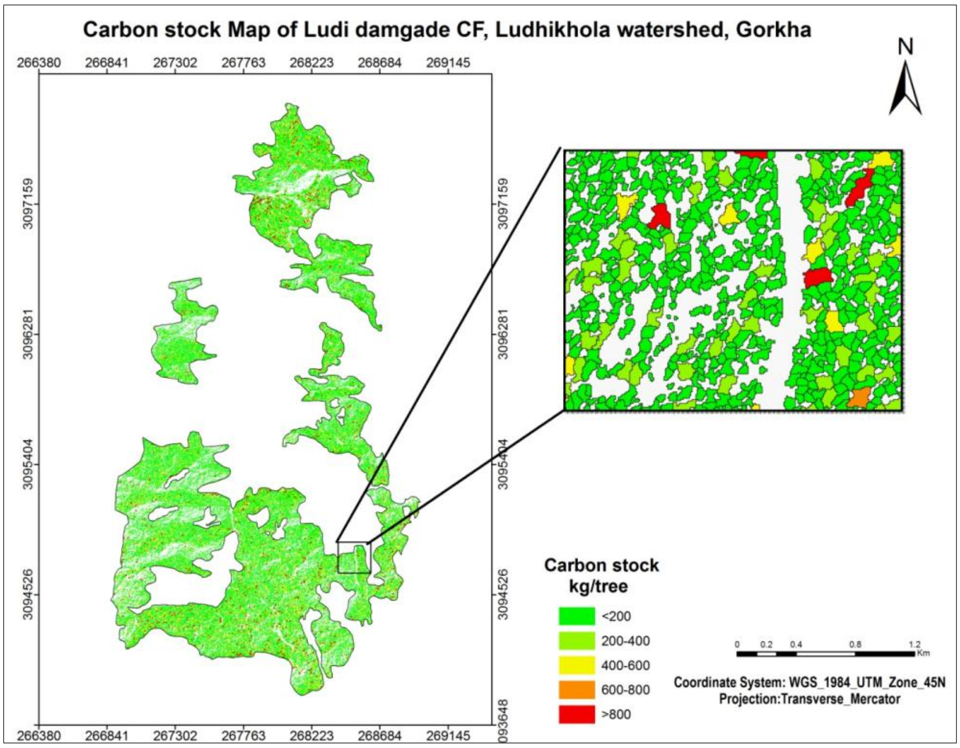

Figure 4: Map of estimated carbon stock per tree in Ludi damgade CF

4. CONCLUSIONS

This study concludes that the region growing algorithm outperforms the valley following method in identification of individual tree crowns. The observed difference in accuracy, however, was not substantial. It also concludes that the VHRS in combination with the above mentioned method can be used to estimate the carbon from the CPA. The results show high potential for the application of satellite images for forest inventory. The following conclusions are arranged to answer research questions of this study

Which of the methods investigated, region growing or valley following algorithm, is more accurate in delineating individual tree crown?

Region growing was found to be more accurate in delineating the individual tree crown which gave an accuracy of 72% using 1 to1 delineation and 68% using D-index compared to valley following 61 % using 1to1 delineation and 58% using D-index.

With which accuracy level can we classify the different tree species using object oriented classification?

The two species classes (*Shorea robusta* and others) using nearest neighbour classification were classified with 74% accuracy and 0.48 Kappa statistic.

Is there a significant relationship between the CPA and above ground carbon stock? How accurate is a regression model developed to estimate carbon stock using CPA?

The non-linear relationship between CPA and carbon stock was found to be significant at ($p<=0.05$). The model developed for 2 class *Shorea robusta* and others resulted in relatively reasonable R^2 (0.67 and 0.70) along with the RMSE 30% and 18% respectively.

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