Estimation of Above Ground Biomass and Carbon Stock using UAV images

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KEYWORDS

Above Ground Biomass, Carbon Stock, Pinus Wallichiana, Photogrammetry, UAV

ABSTRACT

Forests have a vital role in maintaining global climate stability by removing greenhouse gases like carbon dioxide from environment. Estimation of carbon stock is crucial in quantifying the amount of carbon that is present in the forest. The estimation of forest biomass and carbon stock through field measurements is a challenging and time-consuming task. Here in this scenario, our study aims to estimate carbon stock in a forest area using the hybrid technique i.e., aerial survey and ground survey. We used low-altitude remote sensing data acquired by UAV to estimate biomass and carbon stock in an efficient way compared to the traditional techniques. We developed an orthomosaic from the collected aerial imageries and manually delineated tree crowns to obtain crown projection area (CPA) for the entire study area using GIS tools. Our study area contained a mixed species with Pinus Wallichiana to be the dominant species while other species are negligible. Using field-measured tree height and diameter at breast height (DBH) as input, we estimated above-ground biomass (AGB) with an allometric equation and then used a factor value to estimate carbon stock or above-ground carbon (AGC) for six sample plots. Next, we developed a relationship between CPA and carbon stock and validated it by comparing the carbon stock values obtained from the allometric equation for the remaining four sample plots. Among the various developed model, 4th order Polynomial model was chosen due to its highest coefficient of correlation. After the model validation was done the AGC of whole study area was obtained by using the CPA delineated manually from the orthomosaic image. The total AGC and AGB obtained for our study area which was about 7 hectare was 210.7480 tons and 448.4 tons respectively.

1. INTRODUCTION

Forest plays a vital role in keeping the soundness of the global climate. Trees play a pivot role in removing large amount of Carbon dioxide (CO_2), Green House Gases (GHG) from the atmosphere as they develop themselves consuming the carbon and storing those carbon in the biomass of their stems, branches, roots, leaves, etc. So, through the sustainable management of forests, we can reduce CO_2, GHG from the environment (WHRC, 2011). Forest can act both as carbon consumer as well as carbon emitters depending on how we manage the forest. If forest is burned by any means, then forest act as a carbon emitter and if forest consume the carbon for growing then they act as a carbon consumer. Forest biomass is a significant component of worldwide carbon emission estimations. However, such estimations require accurate and viable methods to estimate Above Ground Biomass (AGB). The above ground carbon in tropical forests represents about 40% of total carbon stocked in forests worldwide (Gibbs et al., 2007) .There is a significant sum of carbon present in the forests of Nepal as about 40% of total area of Nepal is covered by Forests (Oli & Shrestha, 2009) Biomass estimation of Forest ecosystem empowers us to appraise how much CO_2 can be concealed from the atmosphere by the forest. AGB and Carbon Stock estimation can be done through field measurement, remote sensing, and GIS methods (Vashum, 2012). For the biomass estimation a statistical relationship is established between the ground-based measurement and the information extracted from the Unmanned Aerial Vehicle (UAV) imageries. In any case, the most reliable strategy for the assessment of biomass is through cutting of trees and weighing of their parts, which is tedious and costly for large regions (Nordh, 2004) . This destructive method is frequently used to approve other less obtrusive and less expensive techniques such as measurement of carbon stock using remote sensing (Nordh, 2004) . The non-destructive method for AGB assessment includes measuring different parameters such as: diameter at breast height (DBH), height of the tree, volume of the tree, wood density, crown projection area (CPA), etc. and calculating the biomass using allometric equations which are developed for biomass estimation by laying out the relationship between different above mentioned parameters for different tree species (Ravindranath & Ostwald, 2008) .Different equations have been created by different researchers for the assessment of biomass of different tree species. Remote Sensing techniques offers a method for assessing AGB in which a statistical relationship between satellite extracted tree parameters and ground based measurements are used. The information obtained involving a UAV based platform has a high functional adaptability regarding cost, time and repeatability contrasted with the satellite-based platform and conventional manned photographic operations. Among all the biophysical parameters of the tree, DBH is one of the fundamental parameters to assess biomass and carbon since it makes sense of over 95% variety in biomass (Gibbs et al., 2007) .Therefore, this study aimed to assess the estimation of AGB and Carbon Stock using high resolution UAV images through regression models and allometric equations.

2. MATERIALS AND METHODS

2.1 Study area

The forest area of Gosaithan, Banepa Municipality, Nepal has been selected. The forest has large area but only 7 hectare is chosen for our study as this area contains major *Pinus Wallichiana* tree species. The climate of study area is classified as warm and temperate. Other tree species such as Schima Wallichi and Alnus Nepalensis are also present, but they were negligible interms of height and density i.e., other species had the coverage of just 1% compared to *Pinus Wallichiana.*

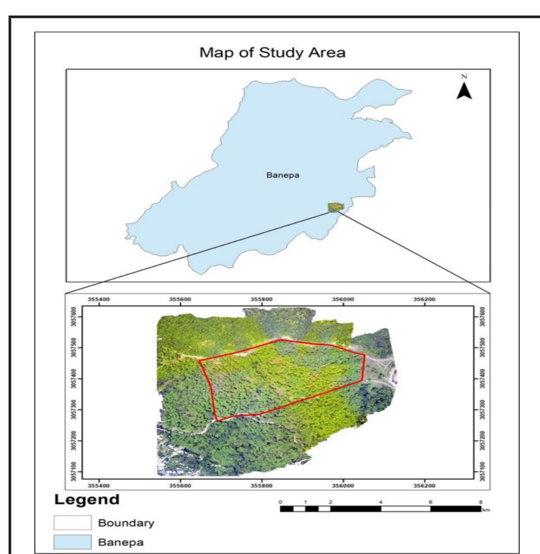

Figure 1 Study area map

2.2 Research method

The methodology consists of three major steps to fulfill the objectives of the study. The first step is field measurement while others are remote sensing and statistical analysis. Field Measurement part was carried out by Differential Global Positioning System (DGPS) survey and biometric data collection. DGPS survey was done to establish control points and biometric data collection was done to collect different tree parameters such as: measurement of DBH, tree height, etc. while the Remote Sensing part includes capturing digital images using UAV, processing the images to generate the orthophoto and mosaicking. Statistical Analysis includes developing the Non-linear regression model between CPA and Carbon Estimation followed by giving input of different parameters in allometric equation to estimate AGB.

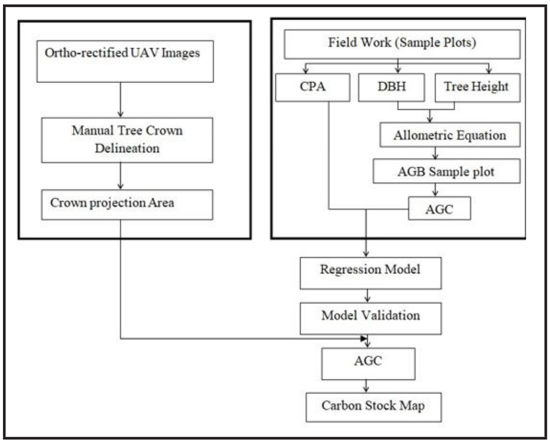

Figure 2 Methodological flowchart

2.2.1 Pre-field work

First, planning was done on how our study will be carried out. Planning includes general framework of the project such as: Establishment of Ground Control Points (GCP), survey method to establish GCP, Flight mission planning, GCP marker to be used during flight mission, Biometric Data collection and so on. Possible plots were identified in Google Earth Pro such that it covers the whole study area, and the coordinates of sample plot centers were noted.

2.2.2 DGPS survey

The ground control points were established using the Static DGPS survey. The established ground control points are required for accurate geo-referencing of the Orthomosaic. A total of 13 ground control points were established.

2.2.3 Biometric data collection

For the data collection of different tree parameters such as: DBH, CPA and height, field works were carried out. According to the study conducted by (Ruiz et al., 2014) ,if the plot size is increased above 500m^2, no significant difference in result could be found. Bigger plot sizes don't fundamentally increase the accuracy of models, yet they increment the expense of fieldwork. So, circular plots of area 500 m^2 (radius 12.62m) were used to collect the biometric parameters of the trees. The radius of the plots was measured by measuring tape.

The diameter at breast height (DBH) was measured using measuring tape at 1.3m above ground as usually DBH is measured at mentioned height above ground (Brown, 2002) . The tree height was measured using the Remote Elevation Measurement (REM) function of the total station. The tree having DBH equal to or greater than 10cm was considered because the trees that have DBH less than 10cm cannot contribute a role significantly in assessing aboveground biomass (Brown, 2002). Measurement of DBH, CPA, and tree height of 113 trees from 10 sample plots was done.

2.2.4 UAV flight planning

Map Pilot Pro was used to plan the photogrammetric flight for the DJI Phantom 3 aircraft. The flight planning took major parameters like flight height, overlap and flight speed into consideration that had direct impact on the quality of imageries that the aircraft would capture (Dandois et al., 2015). The flight mission parameters used is tabulated below:

Table 1 Flight Planning Parameters

Application Name	Map pilot
Type of mission	Singe grid
The geometry of flight mission	Polygonal
Flying height	70m
Resulting resolution	3cm/pixel
Forward Overlap	90%
Side overlap	70%

2.2.5 Ground control point (GCPs)

We selected the spots for GCPs such that there was enough open space in the sense they are visible in UAV images. The ground control points were used for geo-referencing of the orthomosaic. As, the number and distribution of GCPs influence image orientation (Hashem, 2019) so, the GCPs were established such that they cover the area of our study and will be sufficient for geo-referencing.

2.2.6 DGPS data processing

GCPs were established using the Static DGPS survey. Here, established GCPs were computed using the reference station at National Trig point of Nepal. The rover stations at GCP were kept at least 1 hour at a single station. The collected raw data were processed using GNSS Solution by Spectra Precision.

2.2.7 UAV image processing

The software used for image processing was Pix4D Mapper. It was used to generate 3D dense point cloud and orthophoto from UAV images. This software used SfM and stereomatching algorithms for 3D feature reconstructions. SfM represents the process to obtain a 3D structure of a scene of an object from a series of digital images. SfM uses a sequence of overlapping images to produce a sparse 3D model of a scene (Curtis, 2008). Initially, the software executed the keypoints extraction, keypoint matching and camera calibration. In the second stage, point cloud densification was done. The point cloud was used to develop the orthophoto.

2.2.8 Manual tree crown delineation

After obtaining Orthomosaic from image processing, Manual Tree Crown Delineation was done to obtain the CPA of individual trees of the whole study area using Quantum GIS (QGIS).

2.2.9 Data analysis

Different Statistical methods such as coefficient of correlation, regression analysis was done to statistically analyze the obtained data.

2.2.9.1 Estimation of aboveground biomass

The most common method of AGB estimation is by using an allometric equation in a non-destructive way. Various researchers have developed allometric equation based on a destructive method to estimate biomass and carbon in the different forest ecosystem and different tree species (Curtis, 2008). The generic allometric equation developed by (Chave *et al*., 2014) was considered a suitable equation to estimate above-ground biomass of the forest area. A study conducted by (Shrestha et al., 2014) also used the same allometric equation for aboveground tree biomass estimation.

The equation used is:

$$AGB = 0.0559 \times (\rho D^2 H) \quad \ldots\ldots\ldots\ldots i$$

Where,

AGB= estimated above ground biomass (kg),

D= diameter at breast height (cm),

H= tree height (m),

ρ= wood density (gm/cm³) = 0.357 (for Pinus Wallichiana) (Lu & Sinclair, 2006)

2.2.9.2 Estimation of carbon stock

The estimated biomass can be converted to carbon stock by using a factor value. Various factors have been defined but for our study biomass is multiplies by the factor of 0.47 to estimate the carbon stock (Mc Growdy *et.al*., 2004).

The carbon stock is calculated by using the equation below:

$$Carbon\ stock = 0.47 * AGB \text{................ii}$$

3. RESULTS

This research was performed in a well-formatted methodology to gain the potential outcomes identified during the desk study. All the results obtained during various stages of the research are briefed hereafter.

3.1 Regression Model Development and Validation

3.1.1 Regression model development

Data collected from the field observations in six sample plots were now used as input parameters in the global allometric equation to estimate the AGB. Different equation models were evaluated against each other to get the most suitable one. Among the tested models, the Fourth Order Polynomial Equation was chosen to be the best as it had the highest correlation coefficient (R^2) among all. A detail comparison of the models is tabulated below:

Table 2 Model Comparison

Model	Equation	R^2
Linear	*Carbon (kg)=4.31016*CPA-8.3818*	0.6591
Logarithmic	*Carbon (kg)=98.973*ln CPA-211.3*	0.5571
Exponential	*Carbon (kg)=32.975*$e^{0.0387*CPA}$*	0.5578
Quadratic	*Carbon (kg)=0.1169*CPA^2-2.3297*CPA+72.49*	0.7105
3rd Order Polynomial	*Carbon (kg)=-0.0013*CPA^3+02237*CPA^2-5.05*CPA+93.24*	0.7111
4th Order Polynomial	*Carbon (kg)=-0.0005*CPA^4+0.0593*CPA^3-2.150*CPA^2+33.08*CPA-116.8*	0.7217

The following graph shows the scatter plot diagram of the data with the best-fitting fourth-order polynomial curve (dotted).

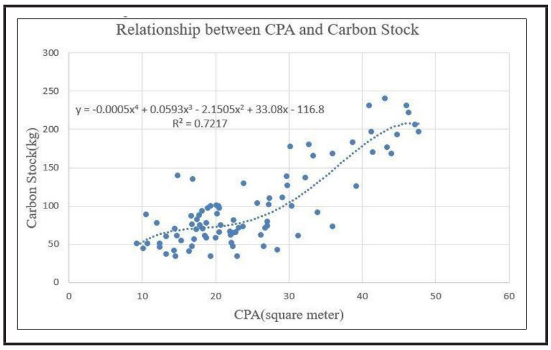

Figure 3 Scatter plot diagram of the chosen model

3.1.2 Model validation

The manually delineated CPA of the trees of the remaining 4 sample plots obtained from the image were used as input in the established regression equation to obtain carbon stock. The field measured DBH and tree height of the same sample plots were used in the allometric equation to estimate the value of carbon stock. This value was compared with the value obtained from regression equation.

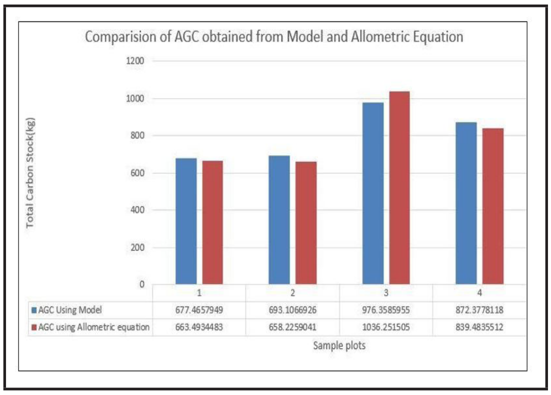

Figure 4 AGC Comparison Chart

3.1.3 Estimation of AGC and AGB of the study area

After the model validation was done the AGC of the whole study area was obtained by using the CPA delineated manually from the orthomosaic image. The total AGC obtained was 210.7480 tons. While the equation 2 resulted in the AGB of 448.4 tons.

3.1.4 Carbon stock mapping

A few numbers of trees that contributed more than 400 kg of carbon were present whereas most of the trees contributed to less than 100 kg of carbon.

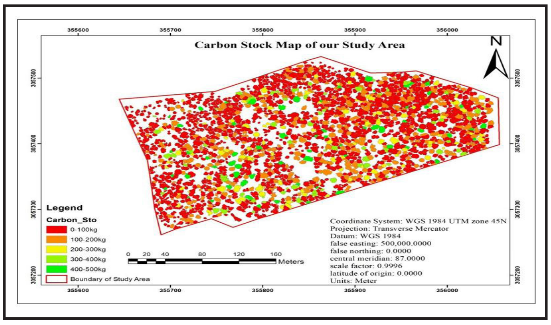

Figure 5 Carbon Stock Map

4. DISCUSSION

Almost all related studies tend to focus on evaluating the accuracy of each step involved in measuring biomass and carbon stock, but often overlook the careful consideration of error propagation in the results (Chave *et al.,* 2014). So, we must identify and assess the influence of various sources of error on biomass and carbon estimation.

Errors and uncertainties from various sources such as inaccuracies in tree parameter measurements, error in allometric equations, and data processing errors can impact the final estimated biomass. A previous study identified four types of errors when assessing the biomass and carbon, which include errors in tree measurements, selection of allometric equations, selection of the sampling plot size, and the representation of the landscape at a larger scale (Chave et al., 2014).

4.1 Limitations

Some of the significant limitations are mentioned below which would serve as recommendations while conducting this type of research in the future. To establish control points and place the GCP markers inside the forest enough open space is required. In forests, it is a very challenging task to find enough open space to place the GCP markers. Because of the low accuracy of handheld GPS identification of the correct location of sample plot centers is challenging. During tree crown delineation it is difficult to delineate a tree crown where tree crowns of two or more trees overlap. The suppressed trees which are covered by dominant trees aren't considered.

4.2 RECOMMENDATION

To enhance the accuracy of the carbon stock estimation model, certain improvements should be made before developing the model in future. Some of the major recommendations are briefed below:

As an equation developed by (Chave *et al.,* 2014) was used due to the lack of local level allometric equations, the error can be reduced by using a local level allometric equations. Thus, it is highly recommended to develop allometric equations for the forests of Nepal to estimate carbon stock accurately.

The high speed of UAV produces motion blur, while the polygonal flight path can result in tilted images at the corner flight paths, which can affect the accuracy of orthomosaic resulting in degrading accuracy of CPA which is directly related to AGC as per the developed model. Therefore, it is suggested that a moderate speed be chosen as a parameter when flying UAV to achieve better results.

5. CONCLUSION

Assessing the productivity and sustainability of forest ecosystems requires an accurate estimation of AGB. The primary aim of this study was to create a carbon stock estimation model and compare the predictions against the one generated from allometric equation. To achieve this, CPA of the individual trees which was the main factor was manually delineated from the orthomosaic.

There exists a reasonable relationship between the CPA and the carbon stock. The obtained relationship has the coefficient of determination (R^2) of 0.7217. Hence, the total aboveground carbon and biomass obtained for our study area are 210.7480 tons and 448.4 tons respectively.

REFERENCES

Anderson, S. C., Kupfer, J. A., Wilson, R. R., & Cooper, R. J., (2000). Estimating forest crown area removed by selection cutting: A linked regression-GIS approach based on Stump Diameters. *Forest Ecology and Management*, *137*(1-3), 171–177. https://doi.org/10.1016/s0378-1127 (99)00325-4

Brown, S., (2002). Measuring carbon in forests: Current status and future challenges. *Environmental Pollution*, *116*(3), 363–372. https://doi.org/10.1016/s0269-7491 (01)00212-3

Brown, S., Sathaye, J., Melvin, C. M. G. R., & Kauppi, P. E. (1996). Mitigation Actions. In *Mitigation of carbon emissions to the atmosphere by forest management* (1st ed., Vol. 75, pp. 80–91). essay, Commonwealth Forestry Association.

Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M. S., Delitti, W. B. C., Duque, A., Eid, T., Fearnside, P. M., Goodman, R. C., Henry, M., Martínez-Yrízar, A., Mugasha, W. A., Muller-Landau, H. C., Mencuccini, M., Nelson, B. W., Ngomanda, A., Nogueira, E. M., Ortiz-Malavassi, E., Vieilledent, G., (2014). Improved allometric models to estimate the aboveground biomass of tropical trees. *Global Change Biology*, 20(10), 3177–3190. https://doi.org/10.1111/gcb.12629

Dandois, J., Olano, M., & Ellis, E. (2015). Optimal altitude, overlap, and weather conditions for Computer Vision UAV estimates of forest structure. *Remote Sensing,* 7(10), 13895–13920. https://doi.org/10.3390/rs71013895

Dhital, N. (2009). Reducing Emissions from Deforestation and Forest Degradation (REDD) in Nepal: Exploring the Possibilities. *Journal of Forest and Livelihood,* 8(1), 56–61. Retrieved from https://www.nepjol.info/index.php/JFL/article/view/1884

Gibbs, H. K., Brown, S., Niles, J. O., & Foley, J. A., (2007). Monitoring and estimating tropical forest carbon stocks: Making REDD a reality. *Environmental Research Letters,* 2(4), 045023. https://doi.org/10.1088/1748-9326/2/4/045023

Gschwantner, T., Schadauer, K., Vidal, C., Lanz, A., Tomppo, E., di Cosmo, L., Robert, N., Englert Duursma, D., & Lawrence, M., (2009). Common tree definitions for National Forest inventories in Europe. *Silva Fennica*, 43(2). https://doi.org/10.14214/sf.463

Hashem, M.A., (2019). *Estimation of aboveground biomass/carbon stock and carbon sequestration using UAV imagery at Kebun Raya Unmul Samarinda education forest, East Kalimantan, Indonesia.* Faculty of Geoinfromation Science and Earth Obsrevation of University of Twente. Retrieved from http://essay.utwente.nl/83721/1/hashem.pdf

Huynh, T., Lee, D. J., Applegate, G., & Lewis, T., (2021). Field methods for above and below ground biomass estimation in plantation forests. *Methods X*, 8, 101192. https://doi.org/10.1016/j.mex.2020.101192

Kachamba, D., Ørka, H., Gobakken, T., Eid, T., & Mwase, W., (2016). Biomass estimation using 3D data from unmanned aerial vehicle imagery in a tropical woodland. Remote Sensing, 8(11), 968. https://doi.org/10.3390/rs8110968

Koh, L. P., & Wich, S. A., (2012). Dawn of Drone Ecology: Low-cost autonomous aerial vehicles for conservation. *Tropical Conservation*

Science, 5(2), 121–132. https://doi.org/10.1177/194008291200500202

Lu, P., & Sinclair, R. W., (2006). Survival, growth and wood specific gravity of interspecific hybrids of pinus strobus and P. Wallichiana grown in Ontario. *Forest Ecology and Management,* 234(1-3), 97–106. https://doi.org/10.1016/j.foreco.2006.06.027

Nordh, N., (2004). Above-ground biomass assessments and first cutting cycle production in willow (Salix sp.) coppice: A comparison between destructive and non-destructive methods. *Biomass and Bioenergy,* 27(1), 1–8. https://doi.org/10.1016/ j.biombioe.2003.10.007

Oli, B. N., & Shrestha, K., (2009). Carbon Status in Forests of Nepal:An Overview. *Journal of Forest and Livelihood,*8(1), 62–66. Retrieved from https://www.nepjol.info/ index.php/JFL/article/view/1885

Ravindranath, N. H., & Ostwald, M., (2008). Carbon inventory methods handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects. https://doi.org/10.1007/978-1-4020-6547-7

Ruiz, L., Hermosilla, T., Mauro, F., & Godino, M., (2014). Analysis of the influence of plot size and LIDAR density on forest structure attribute estimates. *Forests,* 5(5), 936–951. https://doi.org/10.3390/f5050936

Saatchi, S. S., Harris, N. L., Brown, S., Lefsky, M., Mitchard, E. T., Salas, W., Zutta, B. R., Buermann, W., Lewis, S. L., Hagen, S., Petrova, S., White, L., Silman, M., & Morel, A., (2011). Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the National Academy of Sciences*, 108(24), 9899–9904. https://doi.org/10.1073/pnas.1019576108

Shrestha, S., Karky, B., & Karki, S., (2014). Case study report: REDD+ pilot project in community forests in three watersheds of Nepal. *Forests,* 5(10), 2425–2439. https://doi.org/10.3390/f5102425

Vashum, T. K., (2012). Methods to estimate above-ground biomass and carbon stock in natural forests - A Review. *Journal of Ecosystem & Ecography,* 02(04). https://doi.org/10.4172/2157-7625.1000116

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