WATERSHED BASED ABOVE GROUND BIOMASS AND CARBON STOCK ESTIMATION USING REMOTELY SENSED DATA IN SRI LANKA

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Abstract: The need of mapping above ground biomass (AGB) is increasingly important to implement sustainable forest management, carbon accounting and model of forest productivity. Even in situ biomass measurement gives high accurate data, the replicability of the method over large area and estimating dynamic changes are neither feasible nor cost effective. Therefore several methods of biomass estimating have been developed using remote sensing techniques with enormous amount of complementary data provide by the diverse range of satellite launched in past which facilitated to have more reliable biomass estimation. But still having a finer spatial resolution biomass map over large area in frequent manner is challengeable. Nevertheless when it comes to carbon accounting both spatial and temporal resolution is important, therefore in this research present a methodology to estimate biomass in Sri Lanka with satisfactory spatial resolution together with reliable accuracy which can replicate in frequently basis. To accomplish earlier mentioned objective, Sri Lanka is subdivided into 34 watershed basin and developed a relationship between river discharge data and volume of forest, precipitation, slope and soil assuming that the volume of forest also one important factor which control the amount of water flow into river channel.

The relationship between radiance reflected from the Suspended Sediment Concentration (SSC) near river mouth and the river discharge has been established using the MODIS band 1 data and measured river gauging station data. GsMaP(Global Satellite Mapping of Precipitation) data is used for getting rainfall data. MODIS Normalized Difference Vegetation Index (NDVI) used to extract the rainforest in the country. The estimated mean above ground biomass is 159 t/ha and the mean carbon stock is 100TC/ha.

INTRODUCTION

The climate change is one of the most discussed topics in the world and the same time its consequence is experiencing by each one of us in different degree. The one of the significant fact that heightens the climate change is emission of greenhouse gases by deforestation and forest degradation. To monitor and control the CO_2 emission by forest cover change we have to periodically estimate the AGB. But with the lack of forest inventory data which have not periodically update, this task is going to be less precise and more unrealistic. Therefore the application of Remote Sensing data couple with some ground data can lead to overcome the problem. Fortunately nowadays use of Satellite images for different applications are popular and there are many freely available data sources and software. Therefore the replicability of any model depends on the temporal resolution of the satellite.

Therefore this effort is to find out a way to estimate the ABG and the carbon stocks from the application of Remote Sensing. When consider of watershed the amount of water flow in the river channel is depend on many parameters such as slope, soil condition, land use land cover type, size of the watershed, channel width and the length precipitation etc. At the same time the volume of the forest also can be a significant factor which controls the amount of the river flow. Therefore it is worth to look into this factor and make a model to estimate the volume of the forest when all other factors are known. The most difficult parameter to get is periodical river discharge of all the rivers. But with the new finding this also can be extracted from the remote sensing images with satisfying accuracy.

Therefore this research aims to estimate the ABG by considering the river discharge, slope, soil and the precipitation. Lately result is used to estimate the biomass carbon stocks.

BACKGROUND OF STUDY

Estimate Discharge from Reflectance Data

Recently there is one study conducted to estimate the river discharge by using the MODIS reflectance data (Oki et al, 2012). The measure of Suspended Sediment Concentration (SSC) which is, the mass of sediment entrained within a unit volume of water generally used for recognizing sediment transport (Bin he et al,2009;Oki at al,2012). Most researches attempting remote sensing of SSC have constructed empirical relationships between reflectance and in situ measurements collected simultaneously in the field (Curran and Novo, 1988;Nellis et al,1998;Woodruff et al,1999; Islam et al,2001; Schmugge et al, 2002;Miller and McKee,2004;Hellweger et al.,2006;Shi and Wang,2009, Oki et al, 2012).Addition to that Suspended sediment concentrations (SSC) normally exhibit a strong statistical relationship with such hydraulic flow parameters as discharge and velocity (Leopold and Maddock,1953;Maidment, 1993;Bin et al.,2009;Oki et al,2012).

Therefore the idea was, since there is an empirical relationship between SSC and the reflectance there also can be a relationship between the reflectance and the discharge. Then next thing needed to be considered is which wave length of the reflectance has most prominent relationship between the SSC and reflectance. Then the same data can be used to build a relationship between the discharge and the reflectance.

The simplest approach utilizes reflectance from a single band in the red portion of the spectrum, e.g., Landsat TM band 3 or MODIS for extracting SSC from remotely sensed images band (Shi and Wang, 2009; Miller and McKee, 2004; Islam et al,2001; Hellweger et al, 2006; Nellis et al, 1998; Woodruff et al, 1999; Pavelsk et al,2008). However, laboratory studies suggest robust reflectance-SSC relationships throughout the visible portion of the spectrum (Novo et al, 1991; Liedeke et al, 1995;Schiebe et al, 1992, Pavelsk et al.,2008), and many studies combine red reflectance with reflectance in one or more other visible bands in order to increase robustness when sediment color varies (Wu et al, 2007; Dekker et al, 2001; Han et al.,2006; Tassan, 1997; Lathrop et al, 1991; Aranuvachapun and Walling, 1988; Lathrop et al., 1991; Pavelsk et al.,2008). While the high sensitivity of the visible portion of the spectrum, especially red, to variations in SSC is well documented, portions of the near-infrared spectrum are also sensitive to SSC and have the advantage of being less influenced by bottom reflectance in shallow water environments than do shorter wavelengths (Tolk et al.,2000; Pavelsk et al,2008).

So all these factors encourage to use the MODIS red band to extract the reflectance from Remote Sensed images. And the main advantage of using MODIS is freely availability of the data and the daily coverage which permits to estimate the river discharge daily.

The studies conducted in the various river basins in the Asian region; Naka and Monbe rivers in Japan(Oki et al,2012) Serayu and Ciliwung rivers in Indonesia (Ramdhani et al,2012) and Mekong river basin (Subasinghe et al,2012) showed a good relationship between the river discharge and the reflectance. Therefore during this study also used the MODIS band 1 data to estimate the discharge in Sri Lankan river basins.

Biomass Mapping on Sri Lankan Forest

Sri Lanka has a total land area of 65,610 km^2 and an estimated population of 20.5 million (Department of Census and Statistics, 2010; E.Mattsson et al,2012).The country is divided into 3 climatic zone: dry zone, intermediate zone and wet zone respectively. Yearly average rainfall and the temperature are 28 ºC and less than 1750 mm for dry zone, 24- 26 ºC and 1750-2500 mm for intermediate zone and 24 ºC and more than 2500 mm for wet zone. Rain mainly bring from 2 monsoons; southwest monsoon season is from mid-May to September, the northeast monsoon season from November to March and also inter-monsoon convectional rains. Meanwhile country is divided into 3 zones according to the elevation; low-country, mid-country and up-country. Low country elevation range is 0-300m above sea level and 300-1000m for the mid country and above 1000m for up country (Agriculture Department, 2012). The highest point elevation is 2,524m at Piduruthalagala.

The south central part of the island is the most important geographic determinant of inland water resources. The radial drainage pattern carries surface water dividing the entire island into 103 river basins (Silva,1996).According to the HWSD(Harmonized World Soil Database) the country is divided into 23 soil groups.

Types of forest and forest area change in Sri Lanka

Eight national categories of natural forests, defined according to elevation and rainfall, have been used historically for inventory purposes. Lowland rainforest, sub-montane forest, moist monsoon forest and montane forest are found in the wet zone and the dry zone is home to most dry monsoon forests, riverine dry forest, mangroves, and sparse forest (E.Mattsson et al,2012).

Until the turn of the 19th century about 80% of Sri Lanka was covered by primary forests. The forest cover was reduced to 44% in 1956, 30% in 1996 and is presently close to 25% (FAO, 2010a; GOSL,2000; S Lindstrom et al 2012). Principal drivers of forest loss have been conversion of forests to agriculture and development schemes, logging activities due to high demand for round wood from industries and households, encroachment from, e.g., shifting cultivation, shrimp farming, unsustainable tourism industry and lack of demarcated forest areas. Identified underlying drivers of deforestation are, e.g., lack of a national land use policy and planning among ministries, poverty as a consequence of shortage of lands, lack of decentralized forest management and private sector involvement to use alternative wood resources (Bandaratillake,2003; Chokkalingam and Vanniarachchy, 2011; White, 2006; S Lindstrom et al 2012).The recently ended war between the government and the Liberation Tigers of Tamil Eelam (LTTE) also contributed to deforestation by increasing the demand for timber construction and displacing settlements (White, 2006; Suthakar and Bui, 2008; E.Mattsson et al,2012).

According to the FAO (2005) annual forest change rate is –1.3 (Mattsson et al,2012) from 1992-1996 and which is -1.6 in Draft IPCC Good Practice Guidance for LULUCF from 1990 to 2000.Relevant to that report Sri Lanka in 3rd place in Asian countries and only seconded to the Yemen and Nepal by having high deforestation rate.

Biomass mapping in Sri Lankan forest

There are few literature can be found about estimating the forest biomass in Sri Lanka. One of those studies estimated the AGB of Sri Lankan five dry zone forests using past forest inventory data from 1961. Estimated above-ground biomass ranged from a minimum of 75.7 Mg ha^{-1}in the Kumbukkan forest to a maximum of 129.6 Mg ha^{-1} in the Kantalai forest. The total aboveground carbon stocks ranged from 37.8 Mg ha^{-1} in the Kumbukkan forest to a maximum of 64.8 Mg ha-1 in the Kantalai forest. The average above-ground biomass for dry zone forests was 92.62 Mg ha-1. When compared with the wet zone estimates (eg.Sinharaja 336.8 Mg ha-1) the dry zone forests have lower above-ground biomass due to high disturbances, low tree density and other factors such as slow growth pattern of most of the tree species (Kumarathunge et al, 2010).According to the IPCC Good Practice Guidance for LULUCF average above ground volume was 34 m^3/ ha and AGB was 59 t/ha in 2000. And there is no allometric relationship could be found for the Sri Lankan contest (E Mattsson et al,2012) and researches usually use allometric model developed for the tropical forest.

Biomass Carbon stock estimation in Sri Lankan forest

The latest Sri Lankan national forest inventory data available for year 1992-1996.Because of the lack of the inventory data, it is difficult to have a baseline to calculate the deforestation carbon emission in the country. The research conducted to find out REDD+ readiness implications for Sri Lanka in terms of reducing deforestation by Eskil Mattsson and the team, estimate that baseline deforestation emissions in Sri Lanka amounted to 17 MtCO2 yr^{-1} in the 1992-1996 period, but concluded that it is challenging for Sri Lanka to produce a robust and accurate reference level due to the lack of nationally based inventories. And they have projected the forest cover area and estimate the forest cover for year 2005 and estimated the above and below ground carbon stocks for year 1992, 1996, 2005 and the 2010. The result of that study is going to be used for validating the model result of this study.

METHODOLOGY

Established the relationship between Reflectance and Discharge

World watershed map download from HydroSHEDS from USGS used to extract the watersheds in Sri Lanka. Watersheds smaller than 100km^2 merged to the neighboring watershed and create a watershed map which include 34 main river basins. The Kelani river basin is selected to establish the relationship between the discharge and the reflectance since daily river discharge (Q m^3/s) data available at Hanwella gauging station (lat/long 06^0 54' 35" E , 80^0 04' 58" N) from October 2009 to September 2010. Atmospherically corrected MODIS band 1 250m data downloaded from NASA website for the same period of time and among them 33 cloud free images used to analysis. Reflectance value extracted at the river mouth because of the river is not visible at the gauging station due to the coarser resolution of the data. The relationship between the discharge and the reflectance is showed in the figure 1 and this equation is used to estimate the discharge at the river mouth of the rest of the watersheds.

Formation of Equation to Estimate the Forest Volume

The main assumption of this research is volume of the forest also one of contributing factor which control the flow of the river. The other factors considered are soil, precipitation and slope. So to form a relationship needed to have all the layers for all 34 watersheds in a same resolution and projection which were 250m and lat/long projection. Slope map is created from the SRTM 90m freely available data and GsMaP(Global Satellite Mapping of Precipitation) sponsored by JST-CREST and is promoted by the JAXA Precipitation Measuring Mission (PMM) Science Team, and distributed by the Earth Observation Research Center, Japan Aerospace Exploration Agency used to extract the precipitation data. The resolution of a pixel is 10km x 10km and used daily average data. Soil data extracted from the Harmonized World Soil Database (HWSD) which has resolution of about 1km.Most importantly soil data layer consists attribute for Available water storage capacity (AWC) in mm/m of the soil unit. So the value of this field is used to form the equation.

For the simplicity, assumed that all variables have linear relationship with the discharge. And weight for the each variable needed to be determined. In statistically could assume that variance is inversely proportional to importance and in another way the less variance in the study, the more weight it should contribute. Thus weight can be directly calculated for the slope, precipitation and water storing capacity of soil. But there should be approximate weight for the volume of the forest. In this case Normalized Difference Vegetation Index (NDVI) used to estimate the weight. Since mixed dipterocarp rain forests are the dominant forest type of per humid parts of Southeast and South Asia (Whitmore, 1984) yearly average NDVI value for rainforest which was 0.715 extracted from the figure 2 (A Huete et al,2011). So used this value to extract the rainforest in Sri Lanka and then calculated the weight factor.

The equation used to estimate the Volume of forest is as below.

$$D = \sum_{i=0}^{n} (w_1 S + w_2 P + w_3 L + w_4 V) \quad - eq(1)$$

Where; D is Discharge(m3/sec),S is Water Storage Capacity of Soil (mm/m),P is Daily average precipitation (mm), L is Slope gradient, V is Volume of forest (m3/ha), w1-w4 are respective weight factors.

Estimation of AGB, BGB and Carbon stocks

The above ground biomass estimates from the below equation based on Brown and Lugo (1992).

Above ground biomass density (t/ha) = VOB*WD*BEF

Where WD is the volume-weighted average wood density and BEF is biomass expansion factor. The volume of forest estimate from eq(1) used as the VOB (Volume of Bole).

Biomass expansion factor is defined as: the ratio of total aboveground oven-dry biomass density of trees with a minimum dbh of 10 cm or more to the oven-dry biomass density of the inventoried volume. Analysis of data shows that BEFs are significantly related to the corresponding biomass of the inventoried volume according to the following equations (Brown and Lugo 1992).

BEF= Exp{3.213-0.506*ln(BV)} for BV<190 t/ha and BEF=1.74 for BV>=190t/ha
Where,
(Sample size = 56 ,adjusted r^2=0.76)
BV (t/ha)= VOB*WD

Since different categories of forests not taking to the account, mean value for WD (0.57) is used based on the wood densities research by Reyes et al (1992) which is the mean value for Asian region among 428 no of spices.

From the estimated AGB, Below Ground Biomass(BGB) can be computed. Ratios of BGB to AGB is 0.265 according to the standard value for tropical forest (IPCC,2006).

Carbon stock is estimated assuming that carbon accounts for 50% of dry biomass based on Brown and Lugo (1982) ,IPCC (1997) and E Mattsson et al (2012).

The detail flow of the methodology is depicted in the figure 3.

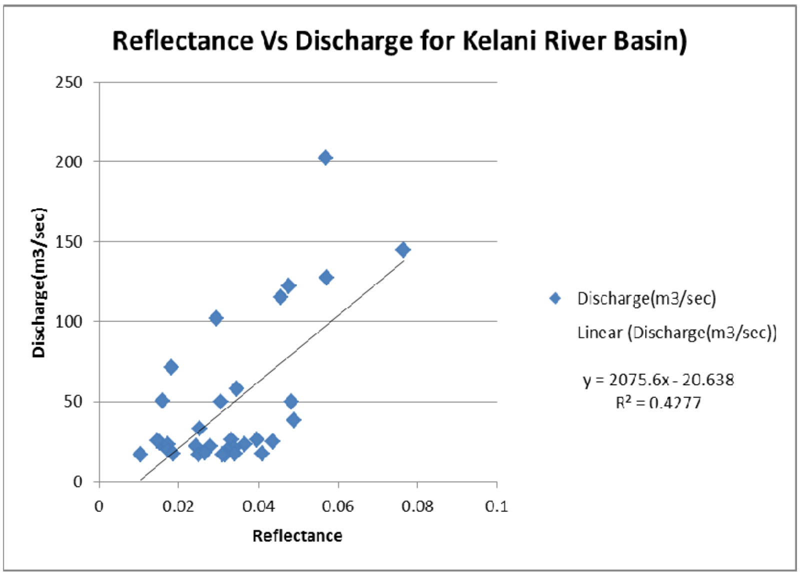

Figure 1: Relationship between reflectance and discharge for Kelani River basin

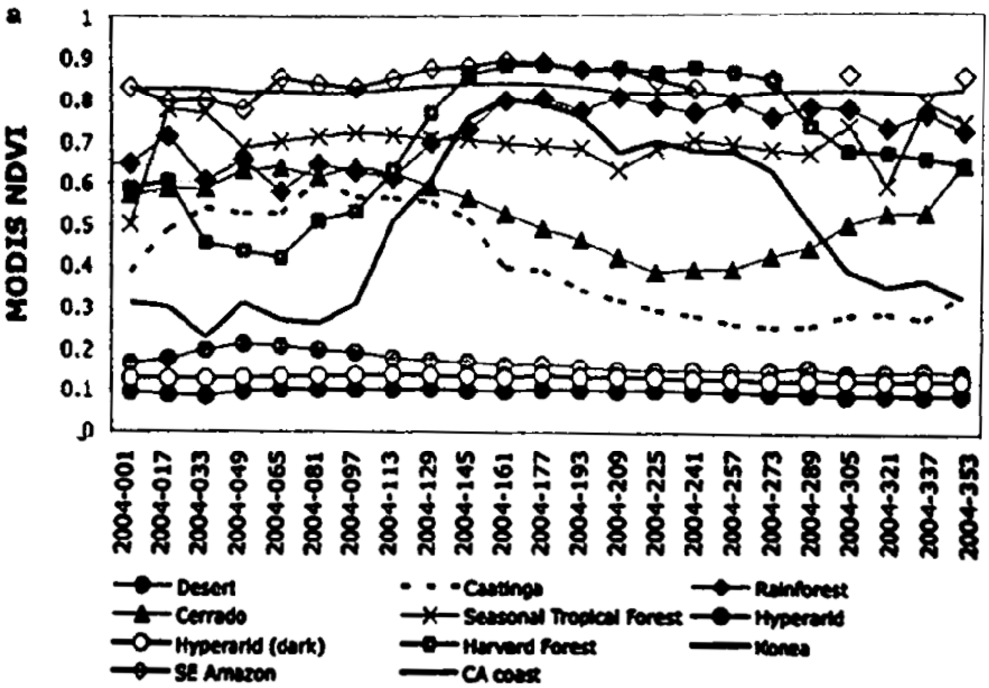

Figure 2: Representative MODIS VI seasonal profiles of major land cover types at 1-km resolution (MOD12A2), depicting dynamic ranges and values (Huete et al,2011)

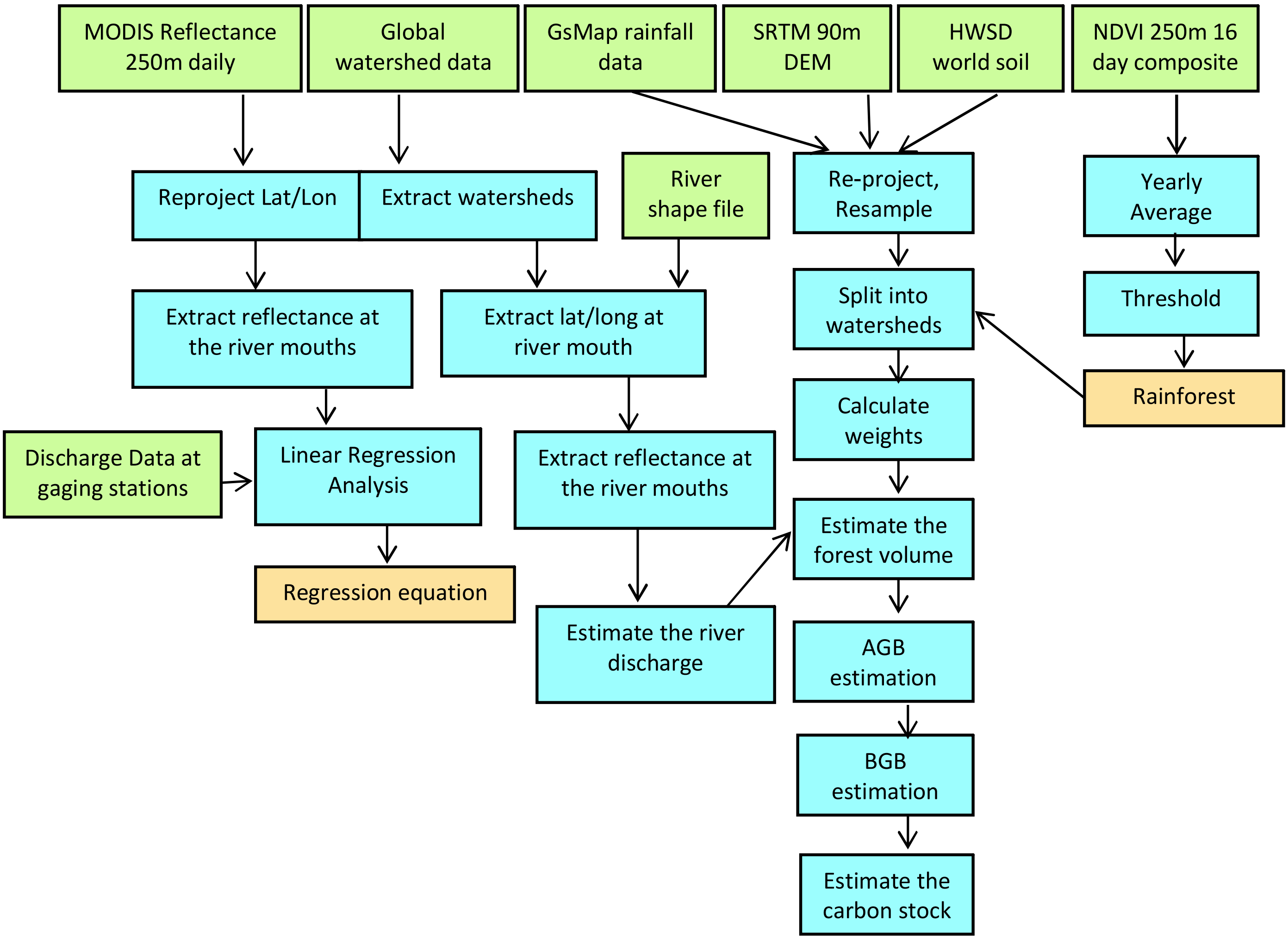

Figure 3: The detailed flow of methodology of estimating the AGB and carbon stocks

RESULTS & DISCUSSION

The AGB (t/ha) classified map shows in the figure 4 with the forest cover map of Sri Lanka year 1999. The area is equal to 3312 ha and relevant to 40 percent of the total area of the country. But according to projection of the E Mattsson et al (2012) closed-canopy forest (>70% crown area) area is 19% of the total area and according to the decline trend of forest area by 2010, this figure should go further low. Therefore the NDVI value used to extract the rainforest needed to be changed.

Table 1: Estimated biomass carbon stock for AGB and BGB

Carbon stock estimation 2010 (t/ha)			
	Minimum	Maximum	Mean
AGB	82.7	209.5	159.1
BGB	21.9	55.5	42.1
AGB+BGB	104.7	265	201

According to the Kumarathunge et al, (2010) the wet zone ABG approximately is 336.8 Mg ha^{-1} and some dry zone forest have minimum value as 37.8 Mg ha^{-1}.Therefore the minimum and the maximum value of ABG is underestimated in this approach.

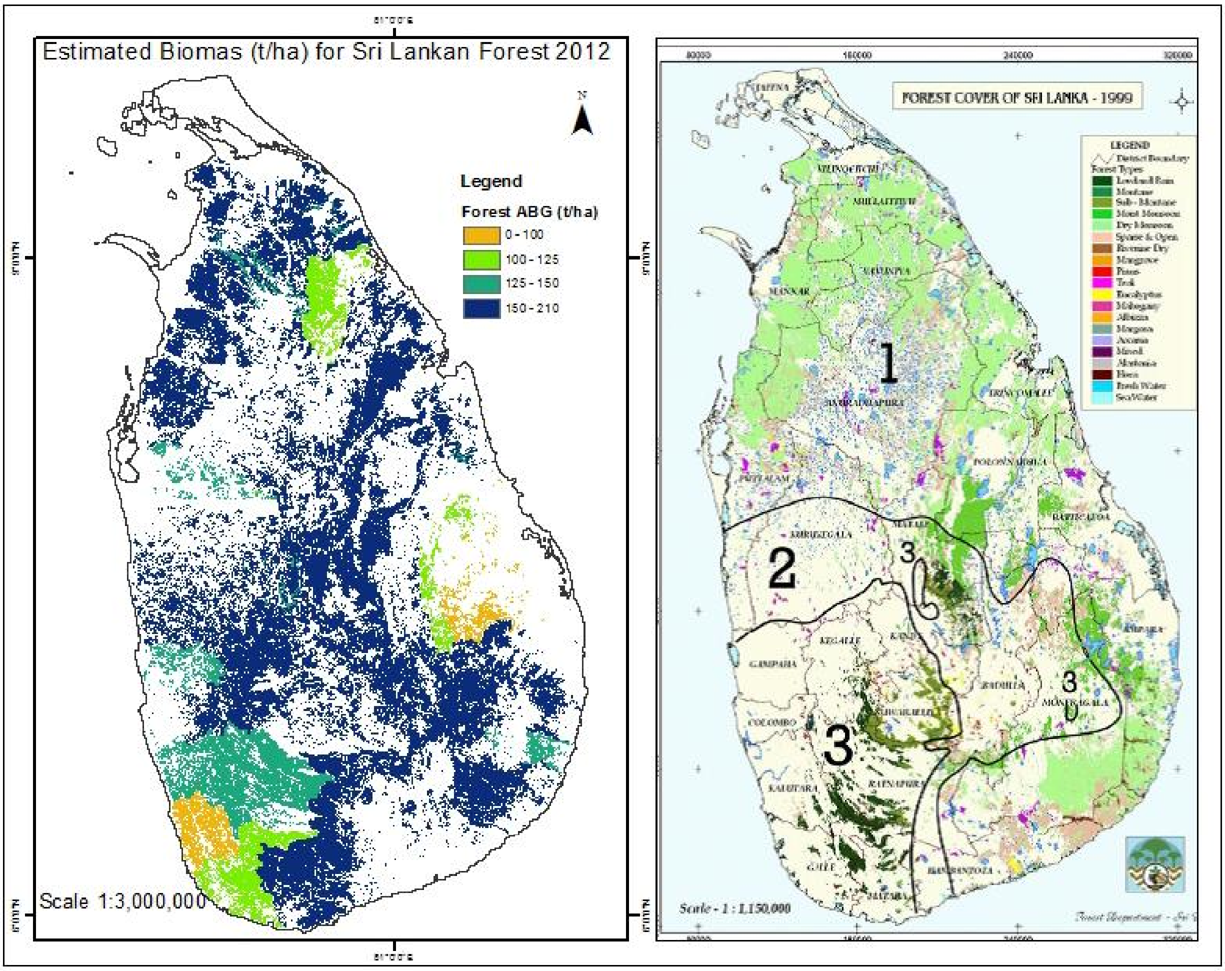

Figure 4: Estimated AGB(t/ha) compared with the Forest cover of Sri Lanka in 1999 (Mattsson et al,2012) Area(1)Dry Zone (2)Intermediate Zone (3)Wet Zone

Table 1: Comparison of the estimated biomass carbon stocks for Sri Lankan forest.

Tier 1 estimates - Sri Lanka			
Source	2010		
	MtC	tC/ha	Ha
FAO(2005)	N/A	N/A	N/A
FAO(2010)	61	33	1860
Total	333	100.6	3312
Tier 2 estimates 2010			
	MtC	TC/ ha	Ha
Total of all forest Mattsson et al.(2012)	204	120	1698

The different tiers is a set of guidelines for estimating GHG inventories at different level of quality; tier 1-simplest to use & globally available data, tier 2- nationally derived data which allow for more precise estimates where changes in carbon stock are calculated and tier 3-high resolution methods specific for each country and repeated through time (IPCC,2006). With respect to this definition the approach used in this study can be considered as Tier 1 approach. The estimated mean biomass carbon stock per hectare is closed to the higher resolution approach conducted by Mattsson et al.(2012).

CONCLUSIONS

The following conclusion can be drawn from this research.

- The volume of forest also one important factor which control the amount of water flow into river channel additional to the other factors like slope, soil and the rainfall.
- After further calibration of the methodology can be used to estimate the ABG and the carbon stocks of the regions since most data is open to public. And this can contribute to the society while estimating the GHG emission due to deforestation and can be considered to use for the REDD+ activities.

FUTURE WORK

- Need to find a better way to extract the rainforest from vegetation indices of the MODIS data.
- Use of land use land cover map of the study can be able to estimate the ABG and the carbon stocks for the each species which permits more detailed study
- Consider the other factors which effect to the river discharge such as evapotranspiration, width and the length of the river channel etc.

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