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FOREST CARBON STOCK MEASUREMENT TO MANAGEMENT: PERSPECTIVE REDD+ IN BANGLADESH

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ABSTRACT

Quantification of the organic carbon stock of any forest area is impossible without estimating organic carbon storage of the forest. Presently, very scanty information is available about the organic carbon storage for forest areas of developing country like Bangladesh and thereby, a clear picture of organic carbon storage in the forests are yet to develop and the present study proposes a model of estimation of organic carbon of forest area based on their yield classes, as carbon content varies with the age of the species. Therefore, development of an allometric equation considering variables like yield class, species, age, site and exposures to hazard are necessary to estimate the carbon content of the species. Technological interventions *i.e.* applying remote sensing and GIS in measuring and managing carbon stock may facilitate in upcoming important event of forestry sector i.e. REDD+ and its MRV tasks to withstand the proper appraisal of carbon stock for present and future.

Key words: Carbon, Allometric equation, GIS application, REDD+ in Bangladesh.

Introduction

Climate change is one of the most vulnerable environmental concerns of the 21st century for Bangladesh. Forest plays an important role in carbon sequestration than any other terrestrial ecosystem and constitutes an important defence against climate change (Matthews *et al.,* 2000). IPCC estimates that the terrestrial biosphere could mitigate between (10-20%) of the world's fossil fuel emissions by 2050 (IPCC, 2000). It can be assumed that Bangladesh is playing a great role in mitigating global warming through a huge pool of existing plantations and natural forest. It also possess large amount of degraded forest lands and waste lands which can be reforested. However, severe poverty and lack of appropriate technology in the country are the barriers for establishing the carbon sinks in the forests through afforestation or reforestation. Bangladesh can participate in the carbon trading effectively, but the country is lacking research on the quantification of carbon credits by reforestation and afforestation (Shin *et al.,* 2008). Quantifying sequestered carbon of different species is important to realize the potential of emission mitigation by the forestry sector therefore, an attempt has been made in the present paper to draw a precise and easy accommodative method of measurement of carbon particularly paving the REDD+ road map for the country.

Model for measuring carbon

The following empirical organic carbon model is used to measure carbon sequestered for any species in woodland

TOC = (TrC + LiC +SoC) x A................................Model 1

where, TOC = Total organic carbon, TrC = Tree carbon stock, LiC = Litter carbon stock, SoC = Soil organic carbon stock up to 1 metre depth, A = Area.

The following models were developed to estimate TrCF, SoCF and LiCF:

Tr C = (AYC x Cm) = [{YCs + E_{jkl}} x Cm].........Model 1a

where, AYC = Adjusted yield class, C m = Carbon stock from Willis-Price (W-P) carbon model (Price, 2001, pers. comm.), YCs = Yield classes of Pyatt (1977) and expert advice, E_{jkl}= Adjustment effects of j = altitude, k = slope, l = exposure to wind.

LiC = AYC x Lics..Model 1b

where, Lics = Litter carbon stock with respect to yield classes (extracted from Dewar and Cannell, 1992).

SoC = $(SLOC)_{OABC}$ x (TLOCS / MOCTL)..........Model 1c

where, SLOC = Total organic carbon stock in soil layers (O, A, B, C) of soil classes in the study area, O = 0 to 3 cm depth, A = 4 to 14 cm depth, B = 15 to 30 cm depth, C = 31 to 100 cm depth, TLOCS = Tree and litter carbon stock per hectare for a given species and yield class, MOCTL = Mean of tree and litter carbon stock per hectare for all yield classes concerned.

Finally, Model 1 stands in the following way for any species in woodland:

The yield class, species, age, site and exposures to hazard are necessary to estimate the carbon content of the tree species and technological interventions *i.e*. applying remote sensing and GIS in measuring and managing carbon stock .

$TOC = [\{(YCs + E_{jkl}) \times Cm\} + (AYC \times Lics) + (SLOC)_{OABC} \times (TLOCS / MOCTL)\}] \times A$

Material and Methods

A. Estimation of tree carbon

Tree organic carbon was estimated with respect to yield class of the species (with maximum annual mean increment using *W-P* model) which was treated as a stock of the organic carbon with particular adjusted yield class (AYC) in woodland. Tree organic carbon stock per hectare was drawn from *W-P* carbon model for a yield class. GIS simulated model selected the sites of particular adjusted yield class and calculated the area of the sites and then multiplied tree carbon stock per hectare from *W-P* model, to get total tree organic carbon stock for any area.

Adjusted yield class (reckoning method)

The following criteria were considered to calculate the adjusted yield class:

Species

The species selected for the study was Sitka spruce (*Picea sitchensis)*.

Soil

Yield classes were chosen with respect to soil class. The method of selecting yield class of Pyatt (1977) was followed. Moreover, local expert advice (Stevens, 2001) was also taken for ranking the soil types supporting vegetation. The following table illustrating the selection of yield class with respect to soil class for the study area for selected species was constructed:

Altitude

Effect of altitude (elevation) on yield of a species were estimated using the method prescribed by Busby (1973). This study considered three altitude classes:

Lower altitude = below 150 m	(+) 2 m^3
Middle altitude =150 to 600 m	Unchanged
Upper altitude = above 600 m	(-) 2 m^3

If an area was within the limit of lower altitude then the area was awarded an addition of 2 m^3 (jumping to the next yield class) and if in the upper altitude then the site yield was reduced by 2 m^3 (one step down to the next yield class). However, sites in the middle altitude yield class remain the same.

Slope

Contributions of slope to yield of a species were estimated with the method prescribed by Busby (1974). Here three slope classes were considered for estimating the yield class presented.

The classes are:

Lower slope = 0^0 to 20^0	(+) 2 m^3
Middle slope = 20^0 to 45^0	Unchanged
Upper slope = above 45^0	(-) 2 m^3

The areas that are in the middle slope yield class remain the same and in the lower slope class the sites were awarded with an addition of 2 m^3 (*i.e.* add another yield class because sites are sheltered). Moreover, the sites that were in upper slope, had 2 m^3 deducted from the original yield class (i.e. subtract one yield class).

Exposure to hazard (wind)

The upland of Wales is a wind prone area. Exposure to wind is considered using DAMS score developed by the Forestry Commission. Pyatt (1977) pointed out those areas over 22 DAMS score were unsuitable for *P. sitchensis* as it would be likely to blow down. Hence, the sites that were over 22 DAMS score had 2 m^3 deducted from the original yield class (i.e. subtract one yield class) for *P. sitchensis*. The yield class for sites below DAMS score 22.00 remain the same.

DAMS score: below 22	Unchanged
DAMS score: over 22	(-) 2 m^3

Table 1 : Yield class selection for P. sitchensis with respect to soil class.

Soil Classes	Local expert rating for plant support	Yield class Pyatt (1977)	Selected yield class
Brown Earths	14	16+	20
Brown Alluvial	14		
Alluvial Gley	13	16+	18
Cambic Stagno Gley	12		
Sandy Gley	11		
Brown Podzolic	10	14+	16
Humic Brown Podzolic	9		
Earthy eutro-amorphous Peat	8	12+	14
Humic Gley	7		
Ferric Stagnopodzols	6	12	12
Ironpan Stagnopodzols	5		
Cambic Stagnohumic Gley	4	10	10
Raw Oligo-amorphous Peat	3		
Sand Parendzinas	2	8	8
Humic Rankers	1		

Eventually,

Adjusted Yield Class (AYC) = Selected (soil) yield class altitude slope exposure to wind.

B. Litter carbon

Litter carbon is also an essential part of carbon measurement for woodland. This study considered the litter as comprising foliage, fine roots, branches and woody roots. Data regarding litter carbon were extracted from Dewar and Cannell (1992).

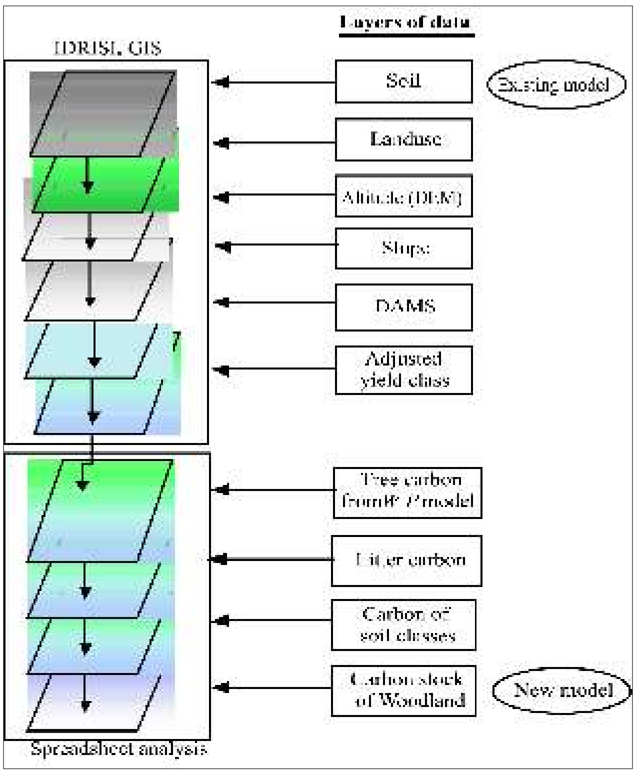

Fig. 1 : Viewing GIS procedure to construct a carbon management model for woodland (Al-Amin, 2011).

C. Soil Carbon

A systematic approach was adopted to perceive and analyse the soil information from different sources for the study area. Soils were grouped according to Avery (1980) and the Soil Survey of England and Wales (1983). The conifer plantations within the study area have fifteen distinct soil classes. The carbon stock of the soil classes was estimated up to 1 metre depth in the various layers (horizons) i.e. O (0–3 cm), A (3–14 cm), B (14–30 cm), C (30–100 cm).

The calculation procedure for organic carbon for each horizon is the following:

Organic carbon presence = C1%

Depth of horizon = (Final depth – initial depth) cm = D1 cm

Bulk density = B1 gm/ cm^3

OC1 (Organic carbon gm/cm^3) = (C1 / 100) x B1

OC2 (Organic carbon gm/m^2/horizon) = OC1 x D1 x 10000

OC3 (Organic carbon tonne/ha/horizon) = (OC2 x 10000) / 1000000

Therefore, total organic carbon stock up to 1 metre depth of soil for any soil type = Addition of carbon stocks of all horizons of that soil type.

Application of GIS for measuring carbon

Figure 1 portrays the spatial datasets used to

Table 2 : Two soil classes with *Picea sitchensis* of SNP.

a	b	c	d	e = a+b+c+d
Humic ranker 8	Altitude (400 m) 0	Slope (lower) 2 cum	DAMS (17) 0	AYC 10
Brown earth 20	Altitude (100) 2 cum	Slope (upper) (-) 2 cum	DAMS (24) (-) 2 cum	AYC 18

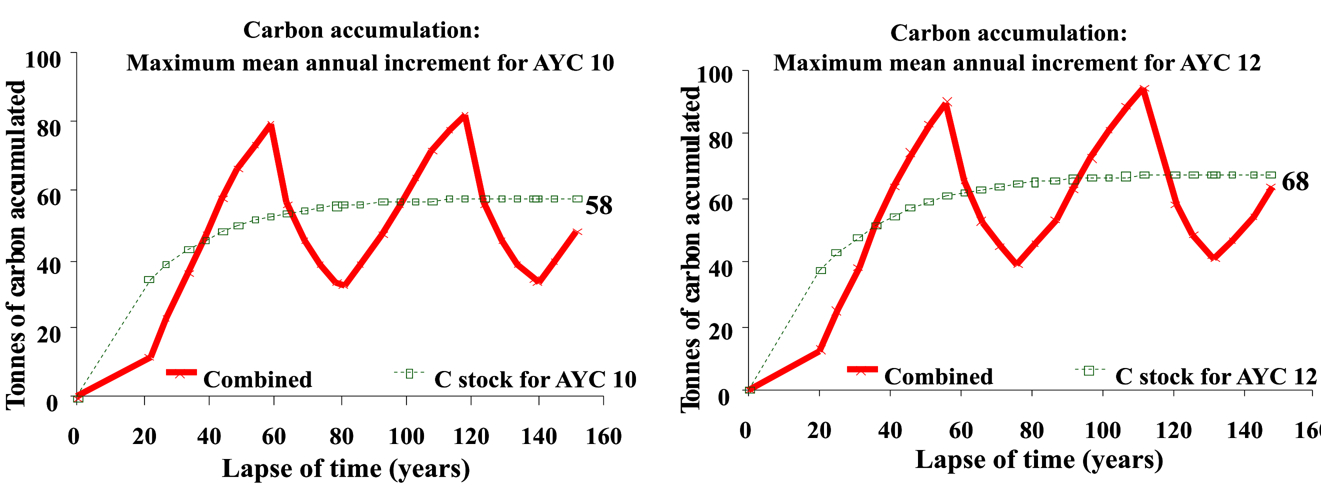

Fig. 2 : Carbon stock of adjusted yield class 10 and 12 of *Picea sitchensis* for maximum mean annual increment per hectare with *W-P* carbon model.

Table 3 : Litter organic carbon stock with respect to yield classes for *P. sitchensis* (extracted from Dewar and Cannell, 1992).

Yield class *P. sitchensis*	Litter organic carbon stock (tonnes / hectare)
YC 24	29
YC 22	29
YC 20	26
YC 18	25
YC 16	23
YC 14	21
YC 12	19
YC 10	17
YC 08	14
YC 06	11

construct the carbon sequestration model.

Result and Discussions

Worked example for testing the proposed model

Proposed model was tested with an experimental setting for estimating the organic carbon stock of the Snowdonia national park (SNP) of UK: as relevant data are available). The study considered plantation of *Picea sitchensis,* a conifer species in SNP. Considering soil class, altitude, slope and hazard class (DAMS) score following adjusted yield class was made to calculate the tree carbon applying Willis –Price carbon model. In Table 2 the results of two soil classes with *Picea sitchensis* of SNP.

Estimation of tree carbon: Willis-Price *(W-P) carbon model*

The carbon stock of adjusted yield classes with their maximum mean annual increment was calculated with the Willis–Price (*W-P)* carbon model. The model turned the adjusted yield class into mean carbon stock in tonne per hectare. The following Fig. 1 is an example of carbon stock per hectare for the study species according to yield class (the spacing of plantations is 2 metre and has line thinning)

Table 3 presents the litter organic carbon stocks with respect to yield classes for *P. sitchensis* (conifer).

The organic carbon contents in percentages, their bulk density for each horizon with respective soil classes of the study area were extracted from Rudeforth *et al*. (1984); Avery (1980) and the Soil Survey of England and Wales (1983). Where no information was found local expert advice (Stevens, 2001) was taken to fulfil the study. An example of organising and calculating the carbon stock for the humic gley (soil type of SNP) is presented in Table 4.

Assuming in equilibrium,

[carbon outflow] = [carbon input]

Again, [carbon outflow] = [carbon stock] [Residence time]

By rearrangement,

[carbon stock] = [carbon input] x [Residence time] (Price, 2001, pers. comm.)

From the above, carbon stock is proportional to carbon input for a given residence time. There is no estimate for the organic carbon input for any soil type

Table 4 : Showing how carbon stock was derived for the humic gley soil type of SNP.

Initial depth (cm) a	Final depth (cm) b	Org. C (%) c	Org. C (gm/gm) d = c / 100	Bulk density (gm/cm^3) e	Org. C (gm/cm^3) f = c x d	Org. C (gm / m^2 /horizon) g = f x (b-a) x 10000	Org. C (tonne / ha /horizon) h = (g x 10000) / 1000000
0	3	5.6	0.056	1.05	0.0588	1764	17.64
3	14	5.6	0.056	1.05	0.0588	6468	64.68
14	30	5.6	0.056	1.05	0.0588	9408	94.08
30	41	0.7	0.007	1.5	0.0105	1155	11.55
41	52	0.3	0.003	1.8	0.0054	594	5.94
52	100	0.2	0.002	1.45	0.0029	1392	13.92
	Total					20781	207.81

Table 5 : Showing how organic carbon stock was derived for the humic gley soil class of the SNP considering covered with the conifer species.

Patch name	Area (ha)	AYC	Soil type carbon stock (tonne)	Tree and litter carbon stock (tonne / hectare)	TLO_{CS}/ MOC_{TL}	Soil organic carbon stock (tonnes)
a	b	c	d	e (TLO_{CS})	f = e / 91.42*	g = b x d x f
Humic gley						
hglelsnd	5	18	207.81	123	1.35	1398
hgmelsnd	145.75	16	207.81	111	1.21	36777
hgmemsnd	34.25	14	207.81	99	1.08	7708
Total	185					45883

*Here 91.42 is the mean of tree and litter carbon stock per hectare considering all (12) AYCs

Table 6 : Estimated tree, soil and litter organic carbon using adjusted yield classes for the conifer plantations of Snowdonia National Park.

Adjusted yield class	Area (hectares)	Tree organic carbon (tonnes)	Soil organic carbon (tonnes)	Litter organic carbon (tonnes)	Total organic carbon (tonnes)
AYC 02	3.50	53	131	18	201
AYC 04	17.50	438	1077	140	1654
AYC 06	49.00	1862	5305	539	7706
AYC 08	411.00	20139	76586	5754	102479
AYC 10	1653.75	95918	392024	28114	516055
AYC 12	3964.50	269586	2011488	75326	2356400
AYC 14	2785.75	217289	548949	58501	824739
AYC 16	2102.50	185020	328339	48358	561716
AYC 18	2853.00	279594	483309	71325	834228
AYC 20	1125.25	121527	198195	29257	348978
AYC 22	103.75	12243	22462	3009	37714
AYC 24	17.75	2254	4933	515	7702
Total	15087.25	1,205,921	4,072,798	320,853	5,599,572

(with specific land use such as conifer), but the input should be proportional to tree and litter carbon stock (of that landuse). Considering these views, the soil carbon stock for a given species and yield class is estimated in the following way:

$$SO_C = SO_{CS} \times \frac{TLO_{CS}}{MOC_{TL}}$$

where, SO_C = Soil organic carbon stock per hectare, SO_{CS} = Soil type organic carbon stock per hectare, TLO_{CS} = Tree and litter carbon stock per hectare for a given species and yield class, MOC_{TL} = Mean of tree and litter organic carbon stocks per hectare which is derived from following equation:

$$MOC_{TL} = \frac{\text{Sum of tree and litter carbon stocks per hectare for all yield classes}}{\text{Total number of yield classes concerned}}$$

An worked example of organising and calculating the soil carbon stock for the humic gley (soil type) with conifer species for the study area is presented in Table 5.

Estimating total organic carbon for conifer plantations of SNP

Total organic carbon for conifer plantations in the study area was estimated by adding tree, litter and soil organic carbon stocks. Table 6 demonstrates the total organic carbon stock of the study area according to adjusted yield classes

GIS application

This study is presenting a model to estimate carbon content of woodland of the Snowdonia National Park (study area), considering the spatial datasets with the available information and expert advice. Nevertheless, the questions remain:

- how the sequestered carbon will be estimated for each species and yield class.
- how the land use change will be predicted if any forests will be converted into other land use in the future.
- how the available spatial database can provide the sound, quantitative information about carbon to see the differences between land use changes.

These questions state that a need exists to develop a theoretical framework and a model the forest manager would be required to use the available spatial datasets for woodland for its management and reorganisation.

Contributions of spatial data sets underpinning the models

This study focuses on the contributions of geographic information systems to provide the opportunity to assemble and analyse multiple layers of spatial data sets with tree, management and climate data sets. Spatial data sets such as soil, slope, altitude and exposure to hazard are incorporated for carbon estimation of a woodland, more particularly applying spreadsheet analysis (allometric models) on GIS platform may able to generate authentic measurement for estimating carbon and may able to predict for future.

Implications in Bangladesh for carbon measurement to management

Bangladesh so far no allometric equations have been developed in but it has potential data sets for drawing better allometric equations for carbon measurement particularly for the following purposes:

- to make up yield classes applying species and site interactions;
- to generate tree carbon model with respect to yield class;
- to quantify soil carbon with respect to soil types and residence time;

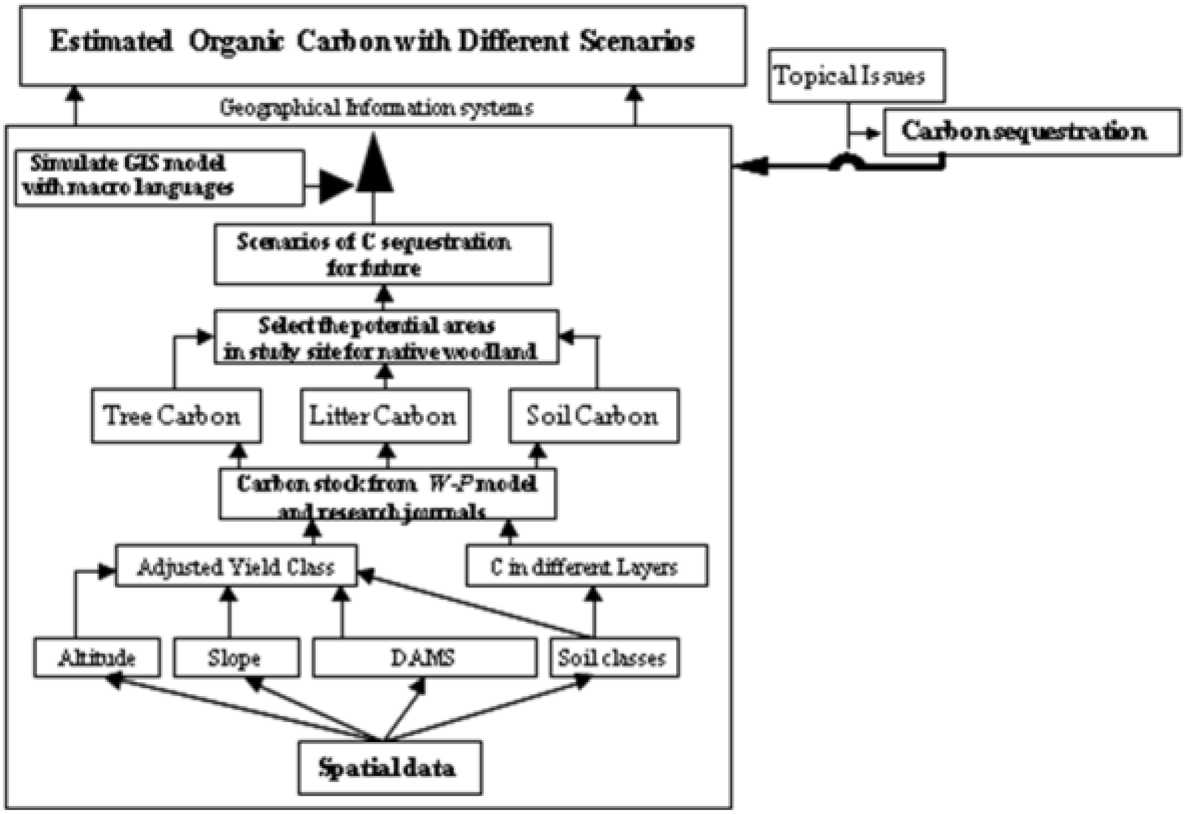

Fig. 3 : Flow of carbon management with technological interventions (applying GIS)

- to put a figure on litter carbon (as most of the trees are broadleaved);
- to weight and adjust yield classes with respect to vulnerability to climate induced hazard.

These data sets may provide the basis for drawing allometric models for estimating carbon for large area which can be put in the GIS platform to visualize different scenario. If a forest manager expresses carbon content as a total output of woodland then it:

- may be able to give a clear scenario of how much above and below ground organic carbon is retained, which may facilitate a lesser degree of uncertainty about the missing carbon sink and help the policy makers to prepare a national network for carbon.
- may be capable of accounting for the whole biomass of forest trees, soil resources and their interactions.
- may offer a chance to standardise the forest with globally accepted parameters of measurement.

Figure 3 illustrates the way spatial data were processed to locate the sites of adjusted yield classes for plantations and estimate carbon by applying GIS.

Conclusions

There is no doubt allometric equations are the most easy and authentic way to estimate biomass or volume of tree. However, variables like yield class, species, age, site and exposures to hazard are necessary to consider during generating allometric equations that will allow more precise estimation of the carbon content of the species and generating interactive maps to visualize not only the present scenarios but the sketching the future to pave the way REDD+ concerns.

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