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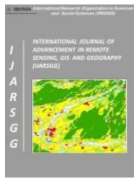

RESTORATION PRIORITISATION AT LANDSCAPE LEVEL CONSIDERING BIODIVERSITY, CARBON AND COMMUNITY CRITERIA WITH SPECIAL REFERENCE TO CDM/REDD+ – A GEOMATICS PERSPECTIVE

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ABSTRACT : A geomatics based method has been developed to prioritise the land for reforestation considering biodiversity conservation, carbon sequestration and community benefits. The reforestation sites were identified based on Kyoto Protocal norms using chronological satellite datasets. Surrounding landscape of such sites was then investigated for biodiversity (floral), carbon (tree and soil) and demographic patterns (community). The prioritised sites were those having highest carbon, biodiversity ratings and dominance of tribal population in their surroundings. Biodiversity was characterised using four basic data types i.e. vegetation type, terrain, field and social (disturbance due to road, railways and settlements) using SPLAM software package. Tree and soil carbon pools were estimated in sample plots distributed in homogeneous vegetation strata (HVS). Community demographic patterns were investigated using census linked village maps. The prioritised sites could potentially sequester 76729t of carbon, enough to compensate around 53% of carbon losses that have occurred since 1998. The species like *Shorea robusta* Roxb., *Schima wallichii* (DC.) Korth., *Tectona grandis* L., *Lagerstroemia parviflora* Roxb. and *Ficus rumphii* Bl. were found to be well distributed which together constituted 70% of the existing tree carbon pool of the region thus are potential species for future reforestation projects. The prioritised reforestation sites were surrounded by significant tribal population (57%) that could be effectively engaged in potential REDD+ carbon sink project.

KEY WORDS: Remote Sensing, Biodiversity, Carbon, REDD+, CDM, Reforestation

1. INTRODUCTION: The Afforestation/Reforestation (A/R) based *clean development mechanism* (CDM) projects under Kyoto protocol were criticised on account of promoting monoculture tree plantations, problems of additionality, leakage and permanence [(1),(2)]. Subsequently emphasis was given on deriving environmental, biodiversity and socio-cultural benefits in addition to carbon sequestration [(3),(4)]. In 13th meeting of conference of parties (COP) at Bali it was acknowledged that deforestation and degradation contribute significantly in global anthropogenic green house gas emissions. By avoiding the same, emission could be reduced and many co-benefits (i.e. biodiversity) could be derived. Thus, *Reduction in Emission by Avoided Deforestation and Degradation* (REDD) came into existence. The *REDD+* was an extension of REDD that included incentives for positive elements of conservation, sustainable management of forests and enhancement of forest carbon sink [(5),(6)].

Green India Mission (GIM) initiated by govt. of India is a critical component of India'a REDD+ strategy [(7),(8)]. It addressed the climate change issue through a) enhancing carbon sinks in managed forests and other ecosystems b) enhancing the resiliency and ability of vulnerable species/ecosystems to adapt to the changing climate and c) enabling adaptation of forest dependant local communities in the face of climatic variability. The option b is poised towards the biodiversity conservation. The GIM is targeted to carry out afforestation/eco-restoration of 20 million ha land in the next 10 years. This would result in green house gas (GHG) removals by India's forest reaching to 6.35% of country's total GHG emissions by the year 2020 (9). In many countries, restoration plantation is an important element of climate change mitigation plan. Brazil targets to enhance the forest plantation from 5.5 million hectare to 11 million hectare by 2020 (10). In other countries like China and Indonesia, afforestation/plantation has been a major landuse practice [(11),(12)].

With the possibility of extension of Kyoto Protocol to the second commitment period from 2013 to 2017/2020 (13) the A/R based CDM projects procedures need to be reviewed for their significance in biodiversity conservation. Kyoto protocol prescribed land definitions for carrying out A/R. i.e. *Aforestation could be carried out on the lands* *which were non-forest for last 50 years whereas, for Reforestation this limit was 31 December 1989. The forests are the areas having crown cover between 10 to 30%, land area between 0.05ha to 1.0 ha and tree height of 2 – 5 m.*

The protocol provided the flexibility to member countries to choose the definition of forest within these prescribed limits. Both *Afforestation* and *Reforestation* are treated equivalently for accounting purpose and their precise distinction was not important for implementation of protocol (14). It is therefore we have used A/R interchangeably in the present study.

Kyoto Protocol doesn't prescribe mechanism for biodiversity conservation (15). Similarly importance of involvement of tribal and natural forest dwellers in carbon mitigation activities though recognised lacks a transparent implementation approach. The addition of *plus* activities (REDD+) particularly *enhancement of forest carbon stock* that India had pushed for has raised concerns of potential negative impacts on biodiversity. India however has effective legislations like *Forest Conservation Act*, *Biological Diversity Act* and *Wildlife Protection Act* which provides enough safeguards against biodiversity loss (7).

We argue that such concerns are due to the fact, that methods for biodiversity accounting are neither widely applied nor integrated with carbon sink projects to establish trade-offs between carbon sequestration and biodiversity conservation. Pereria et al. (16) opine that the biodiversity matrices have not been established and there is so far no reliable metric for biodiversity estimation mainly because of lack of consensus about what to monitor. In Indian context (which is one of the biodiversity hotspot country) however, biodiversity matrices have been effectively used to characterise floral biodiversity at national level (17). Fewer efforts however were made to investigate biodiversity along with carbon sequestration patterns. The present research is an effort to fill this gap through development of a multi-criteria model for prioritising reforestation sites considering biodiversity conservation, carbon sequestration and community benefits.

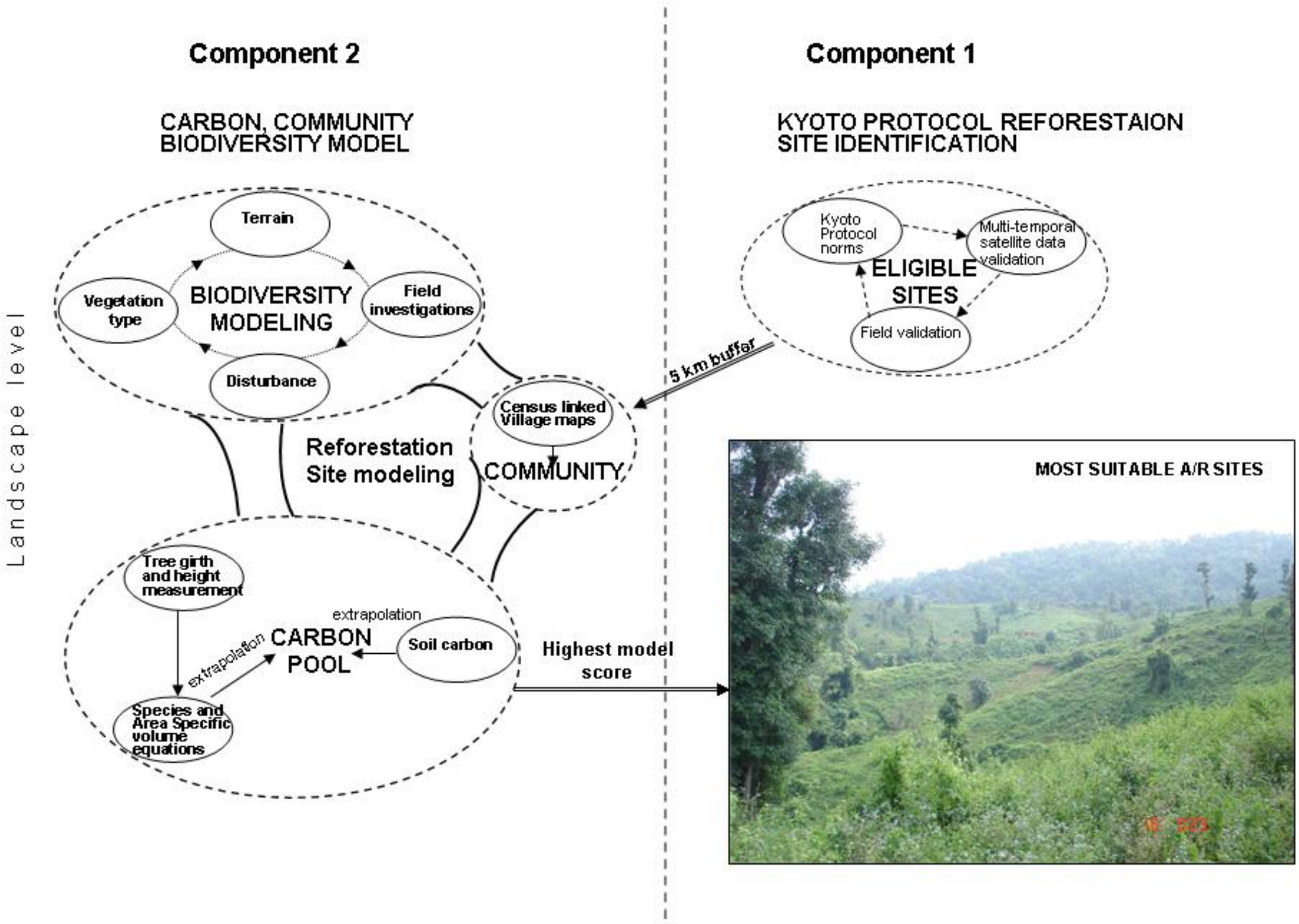

Fig. I. Approach for identification of most suitable Afforestation/Reforestation site based on Kyoto protocol norms and biodiversity, carbon and community parameters

Remote sensing coupled with field investigations is found to be useful in wasteland delineation and thus could be effectively used to fullfill Kyoto Protocol requirements (18). Joseph et al. (19) studied REDD+ projects monitoring, reporting and verification (MRV) status for 20 different projects in different parts of the world and found remote sensing and Geographical Information System (GIS) as promising available MRV tools. The technology has successfully been used in biodiversity characterisation (20), biomass/carbon pool estimation [(21),(22)] and restoration (23) at landscape level. Fewer studies however are known for coupled biomass and biodiversity investigations with special reference to CDM/REDD+ activities. Richards and Penfil (24) have provided guidelines on social and biodiversity impact assessment for REDD+ projects.

In the present research GIS based multi-criteria model has been developed considering carbon, biodiversity and community parameters for identification of most appropriate regions for reforestation. The study has been carried out in Kamrup district of state of Assam, India located between 25.46^{O}N to 26.49^{O}N latitude and 90.48^{O}E to 91.50^{O}E longitude, having geographical area of 4345 km^2, out of which 1433 km^2 is covered by forests (25). The region is one among the biodiversity hotspots of the world and has significant tribal population associated with forests. The tribal population has exhibited increasing trends from 1984 to 2001 (26). There is a reported loss of 29 km^2 of forest cover from 1998 to 2008-09 [(27),(25)]. Thus potential CDM/REDD+ project could compensate lost carbon through A/R by engaging tribal population and ensuring equitable profit sharing.

2. MATERIALS AND METHOD: The methodology could be divided in two components. First component included identification of potential reforestation sites based on Kyoto Protocol norms, and second component included investigation of biodiversity, carbon pool and community patterns in surroundings of such sites for prioritisation of best suitable sites (fig. I). The different datasets used in the research have been listed in table I.

Data	**Sensor/Source**	**Period**	**Spatial Resolution /Scale/level**	**Purpose**
LANDSAT	Multi Spectral Scanner (MSS); Thematic Mapper (TM); Enhanced Thematic Mapper (ETM+) sensors (downloaded from Global Land cover Facility (GLCF) via http://glcf.umiacs.umd.edu/)	MSS-February 1977; TM-December 1987; ETM+ -December 1999 & February 2000	MSS-57m; TM-28.5m; ETM+-28.5m	Chronological forest investigations to rule out the possibility of temporary unstocking of ‘eligible’ lands
Indian Remote Sensing satellite (IRS)	Linear Imaging Self Scanner (LISS III)	December 2008	23.5m;	Recent time investigation of forest resources
Geo Eye and Ikonos	GeoEye sensor	Chronological data available on Google earth website (till 2010)	Upto sub-meter (varying from place to place)	Fine tuning the ‘eligible’ site extents derived from LANDSAT and LISS-III datasets
Digital Elevation Model (DEM)	ASTER Global Digital Elevation Model (GDEM)	2009	30m contour interval	Stratification of forested landscape for preparation of Homogeneous Vegetation Strata (HVS)
Soil	National Bureau of Soil Sciences (NBSS), India Maps (Sen *et al*. 1999)	1999	1:500000	Preparation of HVS
Biodiversity/ biomass	Field investigations	2009-2010	0.1 ha plot	Characterisation of biodiversity; estimation of carbon pool

Demography	Census of India, Survey of India (SOI) maps	2001	Village level	Determining the status of tribal population around the ‘eligible’ sites’
Topographic maps	SOI	1953-86	1:50000 scale	Field navigation
Land use - Land cover (LULC)vector map	National Remote Sensing Center (NRSC), India	2005	1:50000 scale	Classification scheme template and acquiring primary information about the land use-land cover; Used as a master layer for chronological LULC estimation
Forest administrative boundaries	Forest department, Kamrup district, Assam, India	2010	1:50000scale	Confirming the administrative status of ‘eligible’ lands’
Species and area specific volume equations	Forest Survey of India (FSI)	1996	Tree	Estimating the tree volume
Species and area specific values of specific gravity	Indira Gandhi National Forest Academy, India	1996	Tree	Estimating the tree biomass

Table I. Datasets used in the study

2.1 LANDUSE-LANDCOVER CLASSIFICATION: The Landuse-Landcover (LULC) classification scheme was adopted from National Remote Sensing Centre (NRSC) – Natural Resources-Census classification scheme. The vector LULC map of Kamrup district (2005-06), acquired from NRSC was used as a reference (Table I). The LULC maps of 1987-88 and 2008 were prepared using Landsat-TM and LISS-III satellite datasets respectively. The major LULC classes were moist deciduous forest-dense (*Mdf-d*), moist deciduous forest-open (*Mdf-o*), sal (Shorea robusta Roxb.) mixed moist deciduous forests (*Sal-mmd*) and scrub forests (*Sf*), current jhum (shifting cultivation), abandoned jhum, grassland, orchards, agriculture, barren, water, wetland and settlement.

2.2 IDENTIFICATION OF KYOTO ELIGIBLE LANDS: The classified maps of 1987-88 and 2008 were used to identify *eligible lands* for reforestation inside the administrative limits of forest department of Kamrup district. As per the Kyoto protocol norms the eligible lands were the lands devoid of *forests* since 1989. The adopted definition of forest in India in context with UNFCCC/Kyoto protocol. is- *forests are the areas having crown cover of 15%, land area of 0.05ha and tree height of 2m*. The *Sf* were primarily investigated to identify the eligible lands as these lands were not falling in the category of forests. Other lands that could satisfy the Kyoto protocol norms were *abandoned jhum*, *grassland* and *barren area*. *Abandoned jhum* were not considered owing to possibility of natural regeneration whereas, *grassland* ecosystem owing to their ecological significance were not considered as eligible lands. *Barren lands* were the areas with exposed rocks with little soil, thus had littile possibility of reforestation, hence these classes were also not considered as eligible.

The eligible lands were validated through 1999-2000, 2005 and 2009 using Landsat ETM, IRS LISS III and other high resolution satellite datasets made available through Google Earth to rule out the possibility of temporary unstocking (Table I).

2.3 BIODIVERSITY CHARACTERISATION: Biodiversity was characterised based on four basic data types i.e. vegetation type, terrain, field and social (disturbance due to road, railways and settlements). Vegetation types were extracted from LULC map, terrain was investigated based on Aster Global Digital Elevation Model (GDEM) data (released by NASA and METI (Ministry of Economy, Trade and Industry, Japan) in 2009; Aster GDEM is a product of METI and NASA). Field data was collected through 39 stratified random sample plots (0.1 ha each) distributed in homogeneous vegetation strata (HVS). The HVS were prepared in GIS by overlaying elevation, soil and vegetation type. The elevation was reclassified in three classes i.e. a) <40m, b) 41 to 100m c) above 100m. The minimum mappable unit (MMU) for HVS was fixed to 56.25 ha (28). The sample size was 0.002% of the total forest area (29). The sample plots were distributed in proportion to area of HVS. The enumerations related to tree girth (cm) and height (m) were made in sample plots for all the trees above 20 cm girth. The herbs identification and frequency estimation were carried out in four corners and centre of the plot in 1m × 1m quadrates, whereas shrubs were identified in 10m × 10m area in the centre of the plot and their average girth was noted. The social datasets were derived through SOI maps and satellite images (LISS-III).

The biological richness (BR) index (as a surrogate to biodiversity characterisation) was estimated using equation 2 in SPLAM software package [(30),(20),(31),(32)].

$$BR = \sum_{i=1}^{n} DI_i \times Wt_{i1} + TC_i \times Wt_{i2} + SR_i \times Wt_{i3} + BV_i \times Wt_{i4} + EU_i \times Wt_{i5} \quad \text{eq. 1}$$

Where, DI = disturbance index, TC = terrain complexity, SR = species richness, BV = biological value, EU = ecosystem uniqueness, Wt = weight. The DI was derived through integration of fragmentation, patchiness, porosity, interspersion, juxtaposition and other elements of disturbance i.e. road network and settlements. Fragmentation is the number of patches of forest and non-forest/unit area. Patchiness is the number of polygons in a given mask (33). Porosity is the number of patches of particular vegetation type in a given mask, estimated for the dominant forest types and unique ecosystems of the area. Lower porosity indicates homogeneity and low fragmented habitats and vice versa (33). Interspersion is the count of dissimilar neighbours with respect to the central pixel. It is the measurement of spatial intermixing of vegetation types (29). Interspersion represents landscape diversity and dispersal ability of the species. Juxtaposition is the measure of the proximity of habitat types. Proximity is obtained by determining proportion of edge shared by central path with the adjacent patches [(35)-(37)] . Juxtaposition is a unique index that represents preference of one habitat over the other from biodiversity point of view. The juxtaposition weights between different vegetation types were decided based on number of common species. Higher weights were assigned to the forests having higher number of common species and vice versa (38).

The TC was derived using digital elevation model (DEM) in SPLAM. The SR was estimated based on forest type-wise Shannon Weiner index. The Shannon Weiner index provided a clue to rank the forest types based on diversity value that was estimated considering IVI (Importance Value Index). The IVI in turn was estimated by integrating relative frequency, relative density and relative basal area of the species occurred in a particular forest. The forest type-wise BV was estimated based on the integrated total important value (TIV) of each species related to grazing, medicine, timber, charcoal, fuel value and its ecological significance. Such values were rescaled from 1 to 10. The forests with higher TIV were considered biologically more important. The EU was estimated based on forest type-wise endemism (38). The higher EU weight was assigned to the forests having high endemism. The BR was classified in very high, high, moderate, low and non-forest classes using Jenk's natural break method in ARC-GIS software (39).

2.4 CARBON POOL ESTIMATION: The tree and soil carbon pools were estimated. The tree girth and height were used to estimate tree volume using species and area specific volume equations [(40), Table II]. The species for which specific volume equations were not available, generalised area specific volume equations were used. Such equations covered full species distribution for volume estimation.

The tree carbon (C_t) was estimated using eq. 2.

$$C_t = (V \times SG) \times 0.47 \quad \text{eq.2} \quad [(41),(42)].$$

Where V = species and area specific volume of tree and SG = species and area specific values of specific gravity (43). The V×SG provided tree biomass and when multiplied with 0.47 provided carbon amount. Several studies have confirmed that carbon in biomass varies between 45% and 50% in a variety of ecosystems and thus 47% carbon in unit biomass was considered in the present research (41). The area specific averaged specific gravity was used in case of unavailability of species specific values. The forest type-wise average tree carbon (estimated by averaging plot-wise tree carbon pool for a particular forest type) was multiplied by area of respective forest type to know the forest type-wise tree carbon pool (22).

Species name	Type of volume equation	a	b	c	d	Equation type	Specific Gravity
Shorea robusta Roxb.	$V = a+bD+cD^2$	0.16019	2.81861	16.19328	………	Local	0.7
Schima wallichii (DC.) Korth.	$V = a+bD+cD^2+dD^3$	0.11079	1.81103	11.4132	0.38528	General	0.645
Tectona grandis L.	$V = a+bD+cD^2+dD^3$	0.19112	3.25372	17.9194	1.66117	Local	0.541
Lagerstroemia parviflora Roxb.	$V = a+bD+cD^2+dD^3$	-1.25621	24.09227	135.3059	258.267	Local	0.648
Ficus rumphii Bl.	$V = a+bD+cD^2+dD^3$	0.11079	1.81103	11.4132	0.38528	General	0.385

V = Volume (m^3) under bark
D = Diameter at breast height (1.37m) over bark in meter (unless otherwise specified)
H = Height of tree in meter
a,b,c,d are statistical constants

Table II. Volume equations and Specific gravity of prominent Species found in the research area [(40), (43)]

The soil organic carbon (SOC) density was estimated using eq. 3 (44).

$$\text{SOC density (mg/ha)} = \text{SOC\%}/100 \times \text{corrected bulk density} \times \text{layer depth (m)} \times 10^4 \ (\text{m}^2/\text{ha}) \quad \text{eq.3}$$

Three soil samples (up-to 15cm depth) were collected in each plot at equal distance across the plot cross section to estimate the SOC% at plot level. The bulk densities were adopted from Kumar et al. (45). The plot-wise soil carbon pool was extrapolated to the forest types. The total forest type-wise carbon was estimated by adding up tree and soil carbon pools.

2.5 COMMUNITY DEMOGRAPHIC INVESTIGATIONS: The population patterns were investigated from census linked village population maps acquired form Survey of India (SOI). These maps provided information about tribal (along with scheduled cast and others) population present in revenue as well as forest villages. Since the information was linked in GIS it was straightforward to estimate the area weighted population.

2.6 BIODIVERSITY, CARBON COMMUNITY MODEL: The surroundings (5 km) of eligible lands were investigated for biodiversity, carbon pool and community (demography) patterns (fig.I). The overlapping boundaries of surrounding areas were dissolved, that resulted in formation of three unique clusters.
Clusters were prioritised for reforestation using following equation (eq. 4).

$$C_n = \sum_{j=1}^{n} w_j r_{j,k}\ , \quad r \in m, m = 1,2...10 \quad \text{eq. 4}$$

$$\sum_{j=1}^{n} w_j = 100$$

w_j is weight assigned to theme $_j$, $r_{j,k}$ is the rank assigned to class $_k$ of $_j$th theme, C_n is the score of cluster n. BR, carbon pool (tree and soil) and weighted community population were taken as inputs in the model. The maximum score (C_n) was the basis of cluster prioritisation.

The carbon, BR and census linked village population maps were clipped with cluster boundaries in order to derive carbon, biodiversity and population maps at the level of clusters. The village population in a particular cluster was considered to be in proportion to the area of village present inside that cluster.

The theme weights were eigen vectors derived through iterative pair-wise comparison of themes (46). Final eigen vector was the one, having no significant difference in eigen values (up to fourth decimal place) from previous iteration. In pair wise comparison of themes higher importance was given to BR.
The class-wise ranks were assigned in the scale of 1 to 10. The higher ranks were assigned to higher values of BR and carbon and vice versa. The scheduled tribe (ST) population was assigned higher class rank followed by schedule caste (SC) and others population.

3. RESULTS AND DISCUSSION: The major forests in Kamrup are moist deciduous forest-dense (*Mdf-d*), moist deciduous forest-open (*Mdf-o*), sal (*Shorea robusta* Roxb.) mixed moist deciduous forests (*Sal-mmd*) and scrub forests (*Sf*). The *Mdf-d* is predominant in south-central and eastern parts, whereas in western parts it is intermittently mixed with *Mdf-o*. Sal-mmd are generally found at lower elevations as distinct patches. Sf depicts the disturbance in the forested landscapes caused primarily due to anthropogenic pressure. *Mdf-d* is the most dominant forest type and covers around 25% of the total LULC of the region. Encroachment of forests by agriculture was visible at many places. Some of these areas maintained the encroached status for a long time (beyond 20 years). Other landuse are current jhum (shifting cultivation), abandoned jhum, grassland, orchards, agriculture, barren, water, wetland and settlement. Such landuses were not found important considering the eligibility criteria of Kyoto protocol, however they were important for biodiversity characterisation at landscape level.

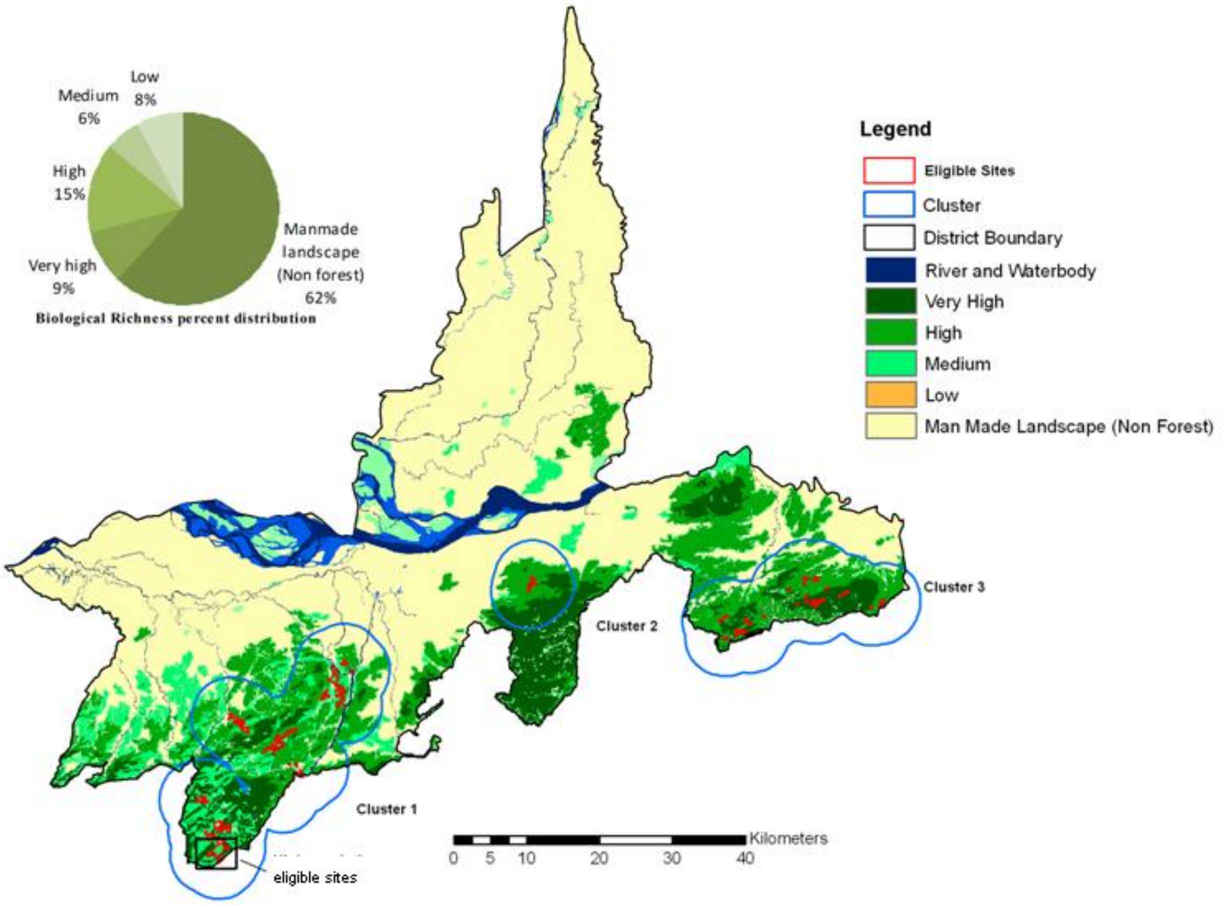

Fig.II Biological Richness (BR) map of Kamrup district (2008), Assam, overlaid with eligible sites and cluster boundaries

Total 28 eligible lands were identified in the study area. No eligible land was found to be temporarily unstocked. During the ground validation, some of the sites were found to be encroached with agriculture (Fig. I). As per the prevailing norms in Indian context the lower limit of canopy/density cover for open/degraded forest is 10% and for scrub forest it is <10% whereas, as per the UNFCCC norms adopted by Indian government, the minimum prescribed canopy cover to qualify for forest is 15%. It is therefore other forest types (*Mdf-o* and *Sal-mmd*) were investigated objectively to delineate the patches with canopy cover between 10% to 15%. Such patches were validated through ground truth and high resolution google earth images.

The biodiversity investigation revealed very high BR (9%) in south-central, western and eastern parts. Such areas were dominated by *Mdf-d*, which are unique ecosystems with high EU, SR and BV (Fig. II, Table III). Low biodiversity (8%) was mainly confined to *Sf* present in western parts (Fig.II). Juxtaposition investigation revealed high species intermixing in *Mdf-d and Mdf-o,* and *Sal mmd* and *Mdf-o* and consequently higher weights were assigned to these combinations.

	Ecosystem Uniqueness	Species Richness	Biological Value	Average tree carbon (t/ha)	SOC average density (Mg/ha)	Dominant speceis
Mdf – (d)	5	9	8	62.28	18.76	*Schima wallichii* (D.C.) Korth., *Tetrameles nudiflora* R. Br. ,*Albizia lebbeck* (L.) Benth.
Sal-mmd	3	4	5	41.05	15.13	*Shorea robusta* Roxb., *Ficus rumphii* Bl., *Adina cordifolia* Benth. & HK.,*Tectona grandis* L.
Mdf – (o)	2	5	7	46.71	20	*Artocarpus heterophyllus* Lamk., *Holarrhena pubescens* (Buch.-Ham.) Wall. ex. G. Don, *Tectona grandis* L., *Bambusa tulda* Roxb.
Scrub Forest	2	6	4	22.07	12.2	*Shorea robusta* Roxb., *Sterculia villosa* Roxb., *Tectona grandis* L.

Table III. Ecosystem Uniqueness (ER), Species Richness (SR) and Biological Value (BV) of different land use in Kamrup district

The plot-wise tree carbon varied between 5.81t/ha (*Mdf-o*) to 158.58 t/ha (*Mdf-d*), whereas forest type-wise tree carbon pool varied between 22.07 t/ha (*Sf*) to 62.28 t/ha (*Mdf-d*) (Table III). The SOC density at plot-level varied between 8.1 Mg/ha (*Sal mmd*) to 38.7 Mg/ha (*Mdf-o*), whereas the forest type-wise SOC varied between 12.2 (Mg/ha) for *Sf* to 20 (Mg/ha) for *Mdf-o* (Table III, Fig. III). The *Mdf-d* forests constitute around 87% of tree and 82% of soil organic carbon (Fig. III).

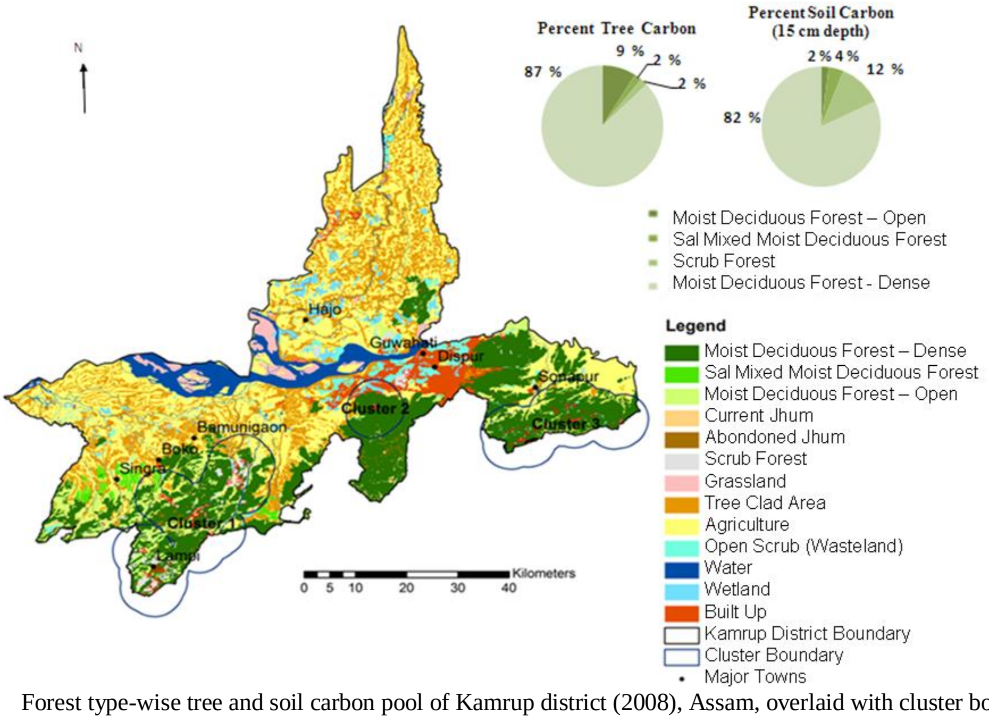

Fig. III Forest type-wise tree and soil carbon pool of Kamrup district (2008), Assam, overlaid with cluster boundary

Based on the biodiversity, carbon and community investigations in the surroundings of eligible lands (inside clusters), cluster one (having embedded eligible land area of 1232ha) score was maximum thus found most suitable for reforestation. Cluster two had slightly higher score than cluster three and thus was identified as second best alternative. The reforestation based restoration is one of the widely used restoration methods. Rodrigues et al. (47) have found reforestation as the main restoration method while studying restoration of high diversity forest in Brazilian Atlantic forest. Many studies have found that site level ecological restoration is influenced by the surrounding landscape [(48),(49),(23)]. The distance of the species (seed) pool from the focal site often determines the magnitude of the restoration efforts. Thus strategic restoration prioritisation at landscape level is important to maximise the biodiversity benefits [(50),(51)]. The eligible sites in the present research are surrounded by natural vegetation having high BV (owing to the presence of dominant species with high TIV). A strategic restoration initiative may provide economical gains and catalyse successional processes (52). Mixed plantations are more productive than monoculture plantations (53) thus ensure higher carbon sequestration. The study area is one of the biodiversity hotspots of the world having naturally occurring mixed vegetation formations thus ample opportunities of restoration using mixed species exists in the region.

The biodiversity characterisation approach adopted in the present research was found to be important in many ways i.e. a) satellite datasets could be used to derive vegetation type which is considered as 'patch'. Such patches were resulted due to activities in the surrounding (34). Thus the regular monitoring of vegetation in relation to socioeconomic dynamics at landscape scales was possible. b) The patch parameters reflecting ecological status were size, shape, association and isolation. Thus the alteration in patch resulted in variations in species frequency, adjacency, vulnerability and resiliency. Such information was found to be highly suitable for quantifying disturbance that existed within each patch, which in turn helped in assessing status of biodiversity (20). c) Species (trees, herb, shrubs, lianas, climbers) level information provided valuable information about EU, BV of major vegetation types. Such information was found to be useful in strategic restoration planning of eligible lands d) the BR could be directly compared with carbon owing to use of vegetation type for deriving both BR and carbon. The restoration is a time consuming process thus the regular monitoring of restoration sites and surrounding biodiversity provide very important clues to the stakeholders about the latest status of A/R based restoration efforts and potential disturbance that could later on have detrimental effects on CDM/REDD+ project. This helps in bringing in transparency and accountability in the biodiversity conservation process and facilitate stakeholders to forecast the dividends in the form of carbon credits that could accrue through the project.

Imai et al. (54) tested the robustness of the community composition of canopy tree species as a surrogate to estimate forest degradation and claimed that such methods would be most adequate to detect effects of management on biodiversity during a REDD+ project. This study was carried out in forest management units of privately managed timber production companies. On the contrary the natural forests of our study area are located in human dominated matrix thus subjected to anthropogenic disturbances. Landscape level approaches, that consider disturbance along with SR, EU and BV seems to be more appropriate for biodiversity characterisation in biodiversity hotspots regions like the present study area. Thus any change in the biodiversity patterns resulted due to species loss, loss of vegetation, disturbance is directly reflected in terms of changed BR value which is a very important biodiversity indicator.

The forest loss due to deforestation between 1998 to 2010 in Kamrup district was 2900 ha [(27),(25)]. In units of carbon the average loss was 145039 tons (considering the current average/ha tree carbon pool excluding scrub). In order to meet the baseline of 1998, 145039 t of additional carbon gains would be required, (the baseline of 1998 has been considered because for Kamrup district, continuous forest cover area statistics is available since 1998). This could be achieved by avoided deforestation/degradation, supplemented with reforestation. The potential average tree carbon gains through reforestation in the eligible lands of cluster one considering prevailing conditions are 76729 t (considering the average carbon pool in *Mdf-d*) which is around 53% of total carbon sequestration needs considering 1998 baseline. Hence intensive reforestation coupled with avoided deforestation and degradation could result in surplus carbon sequestration that could be claimed for carbon credits. In a hypothetical situation of complete protection to such areas, it is difficult to predict the timeline and carbon sequestration potential through natural restoration. Thus the assisted restoration with mixed local species is not only important for maintaining the biodiversity and connecting the forest fragments to develop potential corridors but also to predict the timeline in which carbon sequestration targets could be achieved. It has been observed that *Shorea robusta* Roxb., *Schima wallichii* (DC.) Korth., *Tectona grandis* L., *Lagerstroemia parviflora* Roxb. and *Ficus rumphii* Bl. shared around 70% of the total tree carbon pool present in all the trees encountered in all the sample plots. Such species have high TIV and were well distributed along the elevation gradient. These species were present in mixed as well as gregarious formations, hence could be supplemented for A/R activities (Fig. IV). It is interesting however to note that at comparatively higher elevation (150m and above) the carbon share of these species decreased to 12% and that of other species i.e. *Tetrameles nudiflora R.Br. Albizia lebbeck (L.)* Benth., *Salix tetrasperma* Roxb., *Duabanga grandiflora* (Roxb. Ex DC). Walp. *and Artocarpus chama* Roxb. increased to 54.22%. The elevation and carbon were found to be positively correlated with $r^2 = 0.24$. This was probably due to comparatively less disturbance at higher elevation.

It has been observed that the reducing size of households resulted in more number of households particularly in the biodiversity hotspot countries. This has taken a toll on resource use and biodiversity (55). In Kamrup district the number of households has increased from 2001 to 2011 by about 23%. More households demand more resources for food, timbre and fuel that put pressure on forest resources. The experiences gained through social forestry programs in India has made it clear that it is difficult to prevent forest degradation unless real and immediate benefits equitably accrue to forest dependent communities (56). The potential carbon sequestration on eligible lands could fetch significant carbon credits to local population thus reduce the load on natural forests and conserve the biodiversity.

Cluster one had highest carbon stock and tribal population as compared to other clusters. The overall biodiversity and land available for restoration (1232ha) was also highest for cluster one. Such land could be subjected to assisted restoration for enhancing the carbon sink. The tribal population could be effectively engaged for such restoration activities and benefits accruing through the potential REDD+ sink activity could be equitably shared.

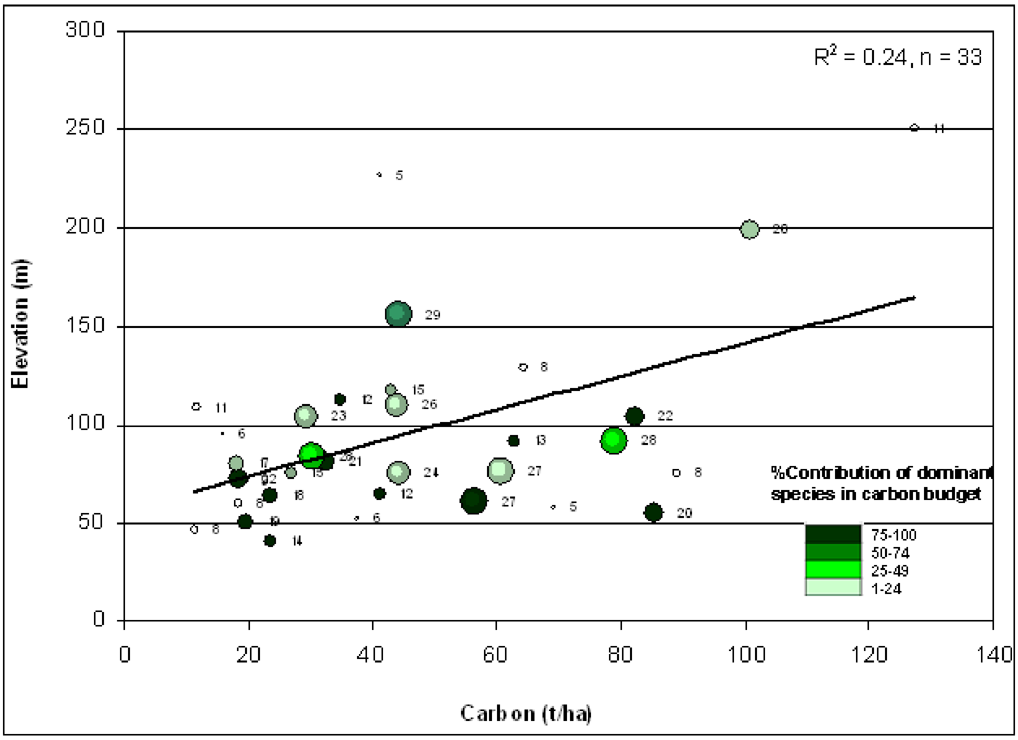

Fig. IV Carbon and species distribution patterns along the elevation gradient in Kamrup district, Assam (the numbers adjacent to bubbles depict species count in sample plot). The contribution of dominant species i.e. *Shorea robusta* Roxb., *Schima wallichii* (DC.) Korth., *Tectona grandis* L., *Lagerstroemia parviflora* Roxb. and *Ficus rumphii* Bl. in carbon budget has been listed

4. CONCLUSION: Carbon, community and biodiversity are three major aspects of forest management in recent times. Biodiversity conservation often conflicts with the community resource demands and hence participatory approaches for ecological and economical gains are important to ensure long term sustainability. Carbon pool enhancement needs to be coupled with protection and conservation of biodiversity; else they may become carbon source in the event of extreme climate change. Methodologies to realise carbon and non-carbon (mainly biodiversity) benefits out of REDD+ initiatives have not yet been fully realised. The present research is an attempt to fill this gap. Approval of a new REDD+ /CDM carbon sink project requires logical explanations related to site selection criteria and potential biodiversity and community benefits. The present method provides a transparent mechanism to gauge the carbon, biodiversity and community benefits through potential REDD+/CDM initiative. The carbon budget of the region is primarily controlled by a few species only. Increasing elevation results in complexity of terrain and thus the disturbance is comparatively lower, which possibly increases the carbon stock. As the carbon budget at higher elevation is controlled by different set of species it is extremely important to have provisioning of zonal biodiversity conservation rather than just concentrating on carbon sequestration through generalised approach. Comprehensive targeted studies are required to understand the species niche and their role in carbon sequestration along with associated demographic patterns in order to effectively plan the potential REDD+ carbon sink projects.

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