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Potential for increasing carbon sink in Himachal Pradesh, India

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Abstract: In this study, the potential for increasing the tree cover and thereby the biomass and carbon as a mitigation option of three categories of wastelands, irrespective of their tenure, are considered. The area under wastelands in Himachal Pradesh, according to NRSA (2005), is estimated to be 2.83 Mha. Among the 28 categories of wastelands reported by NRSA, only 15 categories exist in Himachal Pradesh. In the present study, three land categories are considered for estimating the mitigation potential. They include: (i) Degraded forestland, (ii) Degraded community land and (iii) Degraded and abandoned private land. Choice of species or the mix of species to be planted on the three land categories considered for reforestation is discussed. Carbon pools considered in the present study are those, which account only for aboveground biomass, belowground biomass and soil organic carbon. This study estimates the mitigation potential at the state level considering land available under more than one category. It also provides a roadmap for future work in support of mitigation analysis and implementation.

Resumen: En esteestudio se considera el potencial para incrementar la coberturaarbórea, y así la biomasa y el carbono,como una opciónde mitigación en tres categoríasde tierras baldías, independiente de su régimen de propiedad. Se estima que el área de tierras baldías en Himachal Pradesh, de acuerdo con la NRSA (2005), es de 2.83 Mha. De las 28 categoríasde tierras baldías reportadas por la NRSA, sólo hay15 en Himachal Pradesh. En el presenteestudiose consideran trescategoríasde tierra para la estimación del potencial de mitigación. Éstas incluyen: (i) Bosque degradado, (ii) Tierra comunal degradada, y (iii) Tierra privada degradada y abandonada.Se discute la selección de especies ola mezcla de especies que debe plantarse en las trescategoríasde tierra consideradas para la reforestación. Los almacenes de carbono considerados en elpresenteestudioson los correspondientes ala biomasa aérea, la biomasa subterráneay el carbonoorgánicodel suelo. Esteestudio estima elpotencial de mitigación a nivel estatal considerando la tierra disponible en más de unacategoría yproporciona una guíaque apoyará el trabajo futuro en el análisis y la implementación de la mitigación.

Resumo: Neste estudo, analisa-seo potencial parao aumento da cobertura arbórea e, assim, de biomassa e de carbono como uma opção de mitigação de três categorias de terrenos baldios, independentemente do seu regime de posse. De acordo com o NRSA (2005), a área dos terrenos baldios em Himachal Pradesh, é estimada em 2,83 milhões de hectares. Entre as 28 categorias de terrenos baldios referenciados pelo NRSA, apenas 15 categorias existem em Himachal Pradesh. Neste estudo, para estimar o potencial de mitigação são consideradas três categorias de terra. Nestas incluem-se: (i) as florestas degradadas, (ii) as Terras comunitárias degradadas e (iii) as Terras privadas degradadas e abandonadas. Discute.se a escolha de espécies ou a mistura de espécies a serem plantadas nas três categoriasconsideradas para o reflorestamento. Os sumidouros de carbono considerados neste estudo contabilizam apenas a biomassa aérea e subterrânea e carbono orgânico do solo. Este estudo estima o potencial de mitigação ao nível estadual, considerando os solos disponíveis em mais de uma categoria. Ele também fornece um

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roteiro para o trabalho futuro para apoio na análise de mitigação e de implementação.

Key words: Afforestation, biomass, carbon pools, climate change, mean annual increment, mitigation potential, reforestation, wastelands.

Introduction

Forest ecosystems provide a wide range of provisioning, regulating, supporting and cultural services broadly termed the 'ecosystem services' (MEA 2003). Together with existing socio-economic processes such as population growth, forest fragmentation, deforestation, degradation and habitat loss, climate change could lead to significant changes in the delivery of such services (Ravindranath *et al.* 2006). The forest sector is, however, unique as regards to the climate change issue in several respects; (i) forests contribute significantly to global CO_2 flux thus providing significant opportunities to reduce the current or projected emissions, (ii) forests also provide a means to remove CO_2 accumulated from past emissions in the atmosphere, and sequester it in soil, vegetation and wood products, (iii) forest sector is closely linked to socio-economic systems, particularly the livelihoods of forest dwellers and rural communities, and (iv) future climate change, due to increased Greenhouse Gas (GHG) concentration in the atmosphere is likely to have adverse impacts on forest structure, composition, biodiversity, biomass and geographic distribution of plant species, all of which in turn would affect the environment and socio-economic systems (Krischbaum *et al.* 1995).

The forest and landuse sector has received significant attention globally in addressing the climate change problem. However, as evidenced by the Fourth Assessment Report (IPCC 2007) of the Intergovernmental Panel on Climate Change, mitigation potential assessment in the landuse change and forest sector has been limited by availability of information at the global-level, and by the lack of disaggregation of mitigation potential at the national and sub-national level. This is particularly true for India since very few forest mitigation assessment studies have been published (Ravindranath *et al.* 2001; Ravindranath & Sathaye 2002; Ravindranath *et al.* 2007). Further, these mitigation potential assessments except Ravindranath *et al.* (2006) provide technical potential estimates rather than economic or market potential. Another limitation of such national level mitigation potential estimates is that only a few values for biomass or soil carbon sequestration rates are used, not taking into consideration regional variations in species distribution, growth rates and carbon sequestration rates. Such estimates are further useful in the present scenario when the potential of reducing emissions from deforestation and degradation or REDD is recognized in global climate negotiations as a mitigation option.

The state of Himachal Pradesh is almost wholly mountainous with a deeply dissected topography, complex geological structure and rich temperate flora in the sub-tropical latitudes. Physiographically, the state can be divided into five zones: (i) wet sub-temperate zone, (ii) humid sub-temperate zone, (iii) dry temperate-alpine high land, (iv) humid sub-tropical zone, and (v) sub-humid sub-tropical zone. Climatically, Himachal Pradesh can be divided into three zones (i) outer Himalaya with an average annual rainfall of 150 to 175 cm, (ii) inner Himalaya with an average annual rainfall of 75 to 100 cm and (iii) alpine zone which remains under snow for five to six months each year. The climate varies between hot and humid in the valley areas to freezing cold in the home of perpetual snow. Climate change will manifest most in Himachal Pradesh in the form of warming, rainfall variability and floods with significant impact on food production, water and forests with impacts likely to adversely affect large percentage of population depending on natural resources.

Current land use

According to the estimates made for Himachal Pradesh (Table 1), out of 5.5 Mha of geographic area, croplands and forestland account for 1.9 Mha and wastelands account for 2.84 Mha and the rest is under infrastructure, settlements, etc.. Wastelands account for 51.5 % of the total geographic area of Himachal Pradesh state.

State of forests

According to the latest remote sensing assess-

Table 1. Area under different land categories.

Category	Area (Mha)
Total geographic area	5.56
Forests	1.10
Land not available for cultivation	1.13
Permanent pastures and other grazing lands	1.50
Land under misc. tree crops and groves	0.07
Culturable wasteland	0.13
Fallow land incl. current fallow	0.07
Net sown area	0.54

Source: Land Use Statistics, Ministry of Agriculture, Government of India, 2006.

ment by the Forest Survey of India (FSI 2007), the total area under forests in Himachal Pradesh is 14,668 sq. km (Table 2). This is 26.35 % of the geographic area as against the National Forest Policy (1988) requirement of 2/3rd of the area to be under forest/tree cover for hilly states. Of the total area under forests, 34.5 % is under open forest with 10 - 40 % tree crown cover. When the changes in the area under different tree crown classes is considered, the area under dense forest has declined while the area under open forest has increased (by 82 %) over the period 1997 to 2005 (FSI 2007). This indicates that the forests in Himachal Pradesh are under pressure and undergoing degradation.

Forests in the state are subjected to degradation, due to anthropogenic pressure. Degraded or open forests are subjected to unsustainable harvesting of timber and non-timber products and heavy infestation of weeds. This has led to thinning of forest cover, loss of biodiversity, reduced biomass productivity, changes in plant community structure and composition, disturbed nutrient cycle and reduced organic carbon in soil (Himachal Pradesh Development Report 2005). As a consequence, these forests have limited capacity to regenerate by natural means under the prevailing landuse.

Rate of afforestation

Forest plantations have been raised in Himachal Pradesh under different schemes and projects such as the pasture and grazing improvement scheme, afforestation of blank areas, compensatory afforestation, river valley projects and projects such as the Integrated Wasteland Development Project (Phase I and II) or the Kandi, Swan, Changar and other projects. The cumulative area afforested over the period 1990 - 1991 to 2005 - 2006 is 3,65,583 ha at the rate of 22,849 ha per year (http://www.hpforest.nic.in). However, it is evident from Fig. 1 that the area afforested has reduced steadily over the years, post-2000. The area affo-rested during 2003 - 04 was the lowest at 13,414 ha over a 16 year period (1990 - 2006).

The area under wastelands in Himachal Pradesh according to NRSA (2005) is estimated to be 2.83 Mha. Among the 28 categories of wastelands reported by NRSA, only 15 categories exist in Himachal Pradesh. Of these, maximum area is reported under snow covered and/or glacial area followed by steep sloping areas, degraded forest-scrub dominated and degraded pastures or grazing land. The snow covered areas (43 % of the total wasteland area) are practically not fit for afforestation.

At the current rate of afforestation for the year 2006 of 19,150 ha annually, about 148 years are required to afforest or reforest all the potential wastelands. If the survival rate of plantations is considered, the time period required would be even longer. Thus, large parts of wasteland or degraded lands are unlikely to be afforested under the normal afforestation programmes in the coming decades and would remain in degraded state in the foreseeable future.

Himachal Pradesh like the other states of India is also carrying out afforestation programmes under different schemes and now gaining momentum under the National Action Plan for Climate Change is the Greening Mission. Given this and the policy to increase forest tree cover to 2/3rd of the total geographic area, there is a need to look at the potential for increasing the forest area and thereby the biomass and carbon stocks. In this study, the potential of three categories of wastelands, irrespective of their tenure are considered for increasing the tree cover and thereby the biomass and carbon as a mitigation option.

Approach and methods

Land categories

In the present study, three land categories are considered for estimating the mitigation potential. These are lands classified as degraded by the Forest Department and/or revenue department while the private lands by their very nature of being long fallow lands with no tree cover are considered degraded. They include:

(i) Degraded forestland: This land category is owned and controlled by the State Forest Depart-

Table 2. District-wise area under forest in Himachal Pradesh for 2007 (sq. km.).

District	Geographic area	Very dense	Moderately dense	Open forest	Total
Bilaspur	1167	24	171	167	362
Chamba	6522	853	773	810	2436
Hamirpur	1118	39	92	114	245
Kangra	5739	310	1221	531	2062
Kinnaur	6401	82	263	257	602
Kullu	5503	586	789	583	1958
Lahaul & Spiti	13841	15	32	146	193
Mandi	3950	373	735	565	1673
Shimla	5131	739	1037	608	2384
Sirmaur	2825	130	568	685	1383
Solan	1936	55	404	390	849
Una	1540	18	298	205	521
Total	55673	3224	6383	5061	14668

Source: FSI 2007.

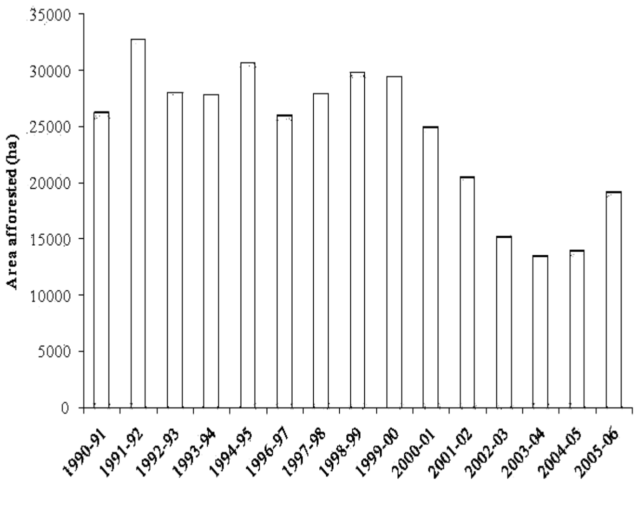

Fig. 1. Area afforested in Himachal Pradesh under various schemes during 1990 - 1991 to 2005 - 2006.

ment. However, the communities have right of access to some of the identified forest products. According to the laws, felling of trees in these lands is banned as governed by the forest conservation policy, laws and regulations (Indian Forest Act of 1927, Forest Conservation Act of 1980, Minor Forest Produce Act, Timber for Dwelling Rights Act). Conversion of this land for non-forestry purposes such as agriculture or infrastructure development is banned. These lands are devoid of any significant vegetation cover for the last several decades and are subjected to unsustainable biomass extraction (such as fuelwood and grass) over decades leading to loss of vegetation and continued degradation caused by soil erosion on the sloping topography (about 15 - 25 degrees).

(ii) Degraded community land: This category includes protected forests declared under 1952 notification; and village common land managed by communities through the Panchayat Raj Institution system or other village level institutions, in harmony with the provisions of the Participatory Forest Management rules. Conversion of this land for non-forestry purposes such as agriculture or infrastructure is banned. These lands have been continuously subjected to extensive grazing over decades, leading to loss of vegetation cover, suppression of regeneration and periodic fires. All such interventions have led to degradation of vegetation and soil erosion on the sloping topography (about 15 - 25 degrees).

(iii) Degraded and abandoned private land: These lands are owned and managed by individual farmers, often inherited. These lands have been left fallow due to lack of resources or their unsuitability for crop production. These lands were once grasslands or forests on sloping hills, and were subjected to land conversion many decades ago (as per the information from Participatory Rural Appraisal), for which no records exist. Cropping was practiced in the past. These lands were abandoned and left fallow due to low crop productivity caused by land degradation. These lands have very shallow soils subjected to continuous soil erosion and unsustainable grazing and harvesting of grass, further leading to degradation.

Species choice and species mix for different land categories

Choice of species or the mix of species to be planted on the three land categories considered for reforestation was based on the following approach: (i) Separate stand models were developed for degraded forestland, community land and private land categories, (ii) The three land categories were further divided into high, medium and low altitude strata, (iii) Multiple species included under each stand model, considering the land category and altitude, (iv) The species choice for the different land categories was based on consultations with gram panchayat members in the case of degraded forest and community lands and individual farmers in the case of degraded and abandoned private lands. The mix of species considered for the different land categories and the density of planting is provided in Table 3.

Carbon pools considered

Reporting of changes in the stocks of five C-pools; AGB, BGB, litter, dead wood and Soil Organic Carbon (SOC) is desirable. However, in the present study, aboveground biomass (AGB), belowground biomass (BGB) and SOC pools are selected for estimating carbon stock changes, since litter and dead wood are likely to be insignificant carbon pools given the lands considered for reforestation are in a highly degraded state. Further, the rate of increase in these pools will be marginal during the initial years and local communities will collect all the litter available in the form of fallen dry twigs for use as fuelwood during the subsequent years. In the case of dead wood, the likelihood of occurrence is very less in a growing forest for it takes 100 - 120 years for forests in Himachal Pradesh to reach maturity and for trees to senesce and die. Therefore, it is chosen to account only for aboveground biomass, belowground biomass and soil organic carbon pools in the present study.

Model used and data sources

Mitigation potential was calculated pool-wise using the Tool for Afforestation and Reforestation Approved Methodologies (TARAM) model developed by the World Bank. The input data required for the model include; (i) species or group of species to be planted; decisions taken in consultation with gram panchayats and/or individual farmers depending on the land category, (ii) wood density of species; obtained from literature, (iii) Biomass Expansion Factor (BEF); IPCC default value of 1.2 for tropical forests used, (iv) Root to shoot ratio; IPCC default value of 0.24 used, existing vegetation if any and its volume in m^3 ha^{-1} yr^{-1} - baseline status - based on field studies, (v) area to be planted under different strata, (vi) A/R plan (phasing of planting); decision based on financial resources and seedlings available in a year, (vii) growth rate or mean annual increment of species to be planted under different strata in t ha^{-1} $year^{-1}$; literature survey undertaken and values obtained from studies conducted in the region compiled. The IPCC defaults used are conservative in nature and largely for tropical forests as the regions considered for this analysis are largely tropical in nature although Himachal Pradesh has some regions with temperate conditions too.

Land available for mitigation and activities selected for mitigation assessment

As already discussed, the land categories considered for mitigation assessment include degraded forest lands, community lands and private lands that have been abandoned and fallow for more than a decade. Multiple approaches were used to identify the set of project activities including species to be planted (Table 3) and total area to be dedicated under the project activity for different land categories.

(i) Restoration forestry model: In this model, reforestation of degraded undemarcated forest land is proposed with a tree density of 1,100 plants ha^{-1}. The species to be planted under this model include largely native species. This model aims to protect the watersheds and regeneration of native flora, supplemented with planting of native tree species on degraded sloping high altitude lands in selected gram panchayats. This is also projected to lead to conservation of biodiversity. Regenerated forests are expected to provide non-timber forest products to local communities and improve their livelihood opportunities. This model is proposed to cover 3,177 ha.

(ii) Community forestry model: This model is proposed for reforestation of degraded community land (common land). The species included in this model are largely native species. The reforestation activity will lead to protection of watersheds, improvement in biomass required to meet the community needs such as small timber, fuelwood (woody litter), fodder collection for livestock and harvest of non-timber forest products. This model is

Table 3. Species included in the reforestation models for the three land categories.

Altitude	Growth rate	Species mix	Density		
			Restoration forestry for degraded forestlands	Community forestry for degraded community lands	Farm forestry for degraded and abandoned private lands
High (1400-800 m)	Fast growing	*Alnus nitida,Juglans regia, Populus ciliata,Quercus leucotrichophora,Salix alba,Toona ciliata*	550	660	
	Slow growing	*Ailanthus excels,Prunus armenica,Robinia pseudoacacia, Aesculus indica,Cedrus deodara,Pinus wallichiana*	550	440	
Medium (1100-1400 m)	Fast growing	*Populus ciliata,Salix alba, Tectona grandis, Albizzia procera,Juglans regia, Dendrocalamus strictus, Grevellia robusta,Quercus leucotrichophora,Morus alba,Pinus roxburghii,Toona ciliata,Robinia pseudoacacia,Bombax ceiba,Ulmus laevigata*	550	660	
	Slow growing	*Ailanthus excelsa,Melia azadirachta,Syzygium cuminii,Bauhinia variegata,Sapindus mukorossii,Mangifera indica,Aegle marmelos,Hicoria carya,Prunus armenica,Pinus wallichiana,Grewia optiva,Cedrus deodara, Robinia pseudoacacia*	550	440	
Low (600-1100 m)	Fast growing	*Acacia nilotica,Albizzia procera,Bombax ceiba,Dendrocalamus strictus,Dalbergia sissoo, Emblica officinalis,Morus alba,Pongamia pinnata,Populus spp, Salix alba,Tectona grandis, Toona ciliata*	550	660	
	Slow growing	*Acacia catechu,Aegle marmelos,Azadirchta indica,Bauhinia variegata,Butea monosperma,Cassia siamia,Grewia optiva,Mangifera indica,Melia azadirchta,Olea glandulifera,Syzygium cuminii,Terminalia arjuna,Terminalia bellerica,Terminalia chebula*	550	440	
		Total		1100	

expected to cover about 293 ha and the density of planting in this model is also 1,100 trees per hectare.

(iii) Farm forestry model: This model covering an area of 533 ha includes reforestation of abandoned or long-term fallow private land with tree species largely providing fruits and fodder to the land owners. The density of planting is 1,100 trees per hectare. Land owners will also derive fuelwood from fallen woody litter. This will provide employment to the land owners apart from protecting the abandoned hilly land.

Baseline scenario development

Under the Climate Convention, "the baseline for project activity is the scenario that reasonably represents anthropogenic emissions by sources of GHGs and removal by sinks that would occur in the absence of the proposed project activity". The first step in determining a project's mitigation potential is development of a 'without-project' baseline scenario against which changes in carbon stocks occurring in a project area over different time periods say 5, 10 and 20 years can be compared.

Table 4. Average above and belowground biomass (dry tonnes) and soil organic carbon under baseline condition in different land categories.

Baseline stratum	Altitude	Aboveground biomass (t ha^{-1})	Average aboveground biomass (t ha^{-1})	Belowground biomass (t ha^{-1})	Total biomass (AGB+BGB) (t ha^{-1})	Soil organic carbon# (t C ha^{-1})
Degraded forestland	High	1.80 (0.00-7.30) SE 0.79	1.55	0.43	2.24	26.98 (7.40-56.48) SE 1.51
	Medium	1.60 (0.01-3.95) SE 0.69		0.38	1.98	
	Low	1.24 (0.00-5.57) SE 0.52		0.30	1.54	
Degraded community land	High	2.73 (0.00-5.65) SE 1.15	1.49	0.65	3.38	30.21 (22.20-45.01) SE 3.01
	Medium	1.00 (0.00-4.05) SE 0.55		0.24	1.24	
	Low	0.75 (0.00-2.74) SE 0.51		0.18	0.93	
Degraded and abandoned private land	High	0.79 (0.00-2.96) SE 0.56	1.76	0.19	0.98	27.74 (13.39-49.88) SE 1.14
	Medium	1.59 (0.00-3.61) SE 0.38		0.38	1.97	
	Low	2.89 (0.00-3.94) SE 0.69		0.69	3.59	

#Figures in parenthesis indicate soil organic carbon range; SE is standard error.

Baseline scenario of degraded forest and community lands

These two land categories are owned by Government agencies and have similar tenurial condition. If these degraded lands were not re-forested, they are very likely to continue to degrade as evident from the biomass and soil organic carbon status of these lands and further conversion of these lands to non-forestry purposes in not possible given that national and state policies that ban conversion of these land categories, particularly croplands.

Baseline scenario of degraded private lands

In the case of degraded and abandoned private land, the only plausible option is for lands to continue to be abandoned and fallow, and subjected to further degradation as evident from these having been left fallow and abandoned for over 20 years because of the unsuitability of these lands for profitable cropping. Table 4 provides average above and belowground biomass (dry tonnes) and soil organic carbon stocks under baseline condition in the degraded forest, commu-

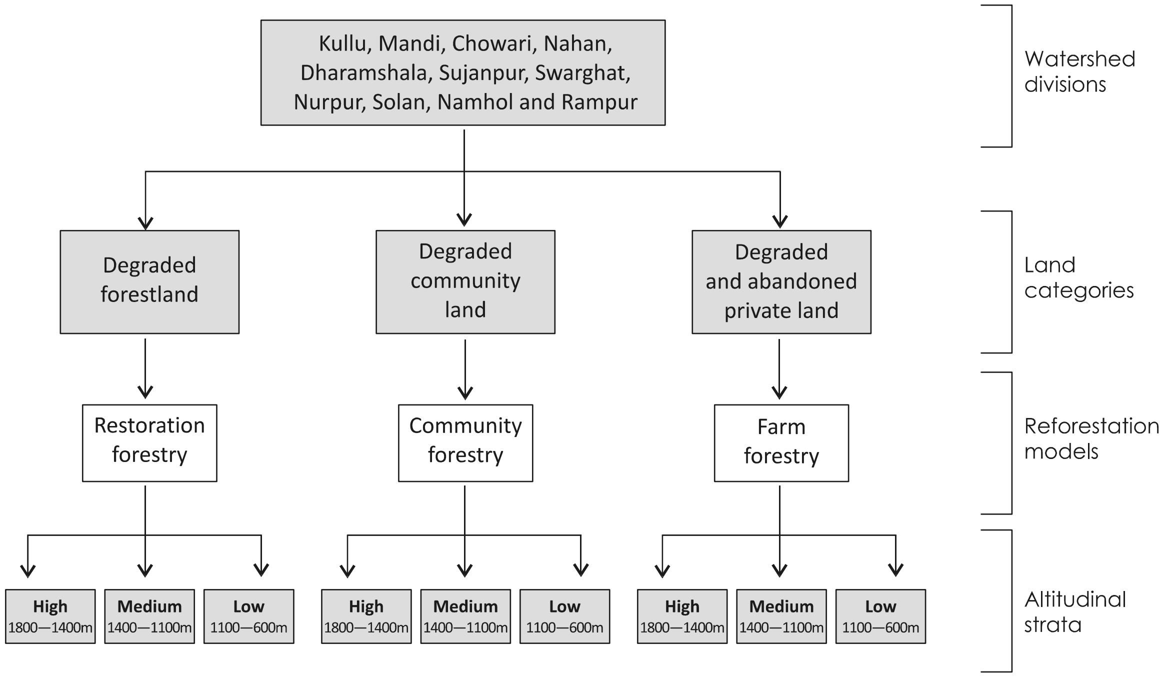

Fig. 2. Stratification adopted for the reforestation activities.

nity and private lands that was generated through field sampling.

Steps in estimating carbon stocks for project scenario

Stratification

The first step in development of a project scenario is stratification. The stratification procedure adopted in this study is discussed below:

Survey of the records of the project area as well as field visits and observations revealed that factors such as altitude, slope, soil depth and pre-existing vegetation conditions are critical in influencing the aboveground biomass, belowground biomass and soil carbon pools. The current landuse and the location of the three land categories with respect to habitation is likely to characterize carbon stocks and, therefore, the three land categories under baseline scenario form the primary basis for stratification under the project scenario. The second level of stratification takes into consideration the three reforestation models to be adopted on the three baseline land categories and the tertiary level stratification considers altitude as there are likely to be variations in: (i) soil status, (ii) species suitability, and (iii) biomass growth rates with varying altitude. The three altitude-based sub-strata are - high (1400 to 1800 m), medium (1100 to 1400 m) and low (600 to 1100 m). The three-stage final stratification adopted, based on a combination of pre-existing conditions, reforestation model and altitudinal sub-strata are presented in Fig. 2.

Approach for estimating changes in carbon stocks

The change in living biomass and soil organic carbon that would be achieved by the proposed plantation activities was estimated for the three reforestation models using the following approach:

Step 1: Area under each reforestation and/or stand model

The area to be brought under different reforestation models was estimated taking into consideration the total potential area available and the suitability of an area to the mix of species being considered at different altitudes. The total area to be brought under the three reforestation models is 3177 ha for reforestation forestry, 293 ha for community forestry on community lands and 533 ha for farm forestry on private lands.

Step 2: Density of the trees to be planted according to species and phasing

A phasing staggered over six years is considered (Table 5). Harvesting is not envisaged for a period of 20 years as the dominant species

Table 5. Phasing of plantations in degraded forest, community and private lands.

Year	Degraded forestland				Degraded community land				Degraded private land			
	Low	Med	High	Total	Low	Med	High	Total	Low	Med	High	Total
2006-07	16	66	65	146	0	5	14	18	0	0	0	0
2007-08	20	67	8	95	81	6	16	103	5	0	0	5
2008-09	150	154	184	488	19	0	0	19	0	0	0	0
2009-10	368	396	347	1111	5	7	0	12	0	0	0	0
2010-11	231	191	419	840	5	9	47	62	218	193	58	469
2011-12	193	95	208	496	15	40	24	79	9	28	22	59
Total	976	970	1082	3177	125	67	101	293	232	221	80	533

included in the three reforestation models are long rotation timber or NTFP yielding species, with long gestation periods of more than 20 years. The density of trees to be planted on all the land categories is 1,100 plants ha^{-1}, with varying proportion of fast and slow growing species. As can be seen from Table 3, the species to be planted for the different altitudes are different, but predominantly native species.

Step 3: Dominant species in each stand model identified and growth rate data compiled

The stand models contain 6 species (restoration model) to 14 species (farm forestry model). The dominant species in each of the stand models was identified and extensive literature survey was conducted for obtaining Mean Annual Increment (MAI) or growth rate values. However, MAI values were not available for many of the species included in the stand models and therefore data available for some of the species (classified as fast, slow growing species under each stand model) was obtained separately.

If MAI was reported in terms of m^3 ha^{-1} year^{-1}, the same was converted to tonnes ha^{-1} year^{-1} using species-specific wood density values. In some cases, the reported biomass and the age of the stand was used to compute the MAI of a particular species. Since most studies report only the merchantable biomass, a biomass expansion factor was used to convert merchantable biomass to whole tree biomass using an IPCC default value of 1.2. A weighted average of the MAI of fast and slow growing species was estimated so as to make a conservative estimate of the MAI for a mixed species forest plantation. This MAI is lower than the maximum MAI reported for a species identified as the dominant species and for which MAI data are available. Per hectare mean annual increment for aboveground biomass was estimated separately for each stand model.

Step 4: Estimation of belowground biomass

The belowground or root biomass was estimated using the IPCC default factor of 0.24.

Step 5: Soil organic carbon increment

Irrespective of the land category and the project activity proposed on the three land categories, the increment in soil organic carbon is assumed to be 1.2 t C ha^{-1} year^{-1}. This is because the baseline soil organic carbon in the three land categories is low and comparable as evident from field sampling conducted in sample locations.

Step 6: Estimation of total carbon

The changes in living biomass carbon stocks and soil organic carbon of the three different land categories being planted with the three different models was computed independently and summed to obtain the total annual carbon stock for the total project area.

Carbon stock projections

The carbon stocks or mitigation potential of the three land categories considered was calculated carbon pool-wise using the TARAM model developed by the World Bank and data obtained from various sources, as discussed earlier.

Mean annual increment considered for projections

Irrespective of the stand model - reforestation or community forestry or farm forestry model, the mix of species for the different altitudinal strata is the same. The density of planting is, however, different in the farm forestry model, which is for private abandoned lands as opposed to the other two stand models which are for public lands - degraded

Table 6. Mean annual increment considered for carbon stock projections in different strata.

Stand model	Altitude range	Average MAI* (t ha^{-1} yr^{-1})
	High (1400 – 1800 m)	4.62
Restoration	Medium (1100 – 1400 m)	4.19
	Low (600 – 1100 m)	4.44
	High (1400 – 1800 m)	4.62
Community forestry	Medium (1100 – 1400 m)	4.19
	Low (600 – 1100 m)	4.44
	High (1400 – 1800 m)	5.20
Farm forestry	Medium (1100 – 1400 m)	4.45
	Low (600 – 1100 m)	4.91

***** MAI: Mean Annual Increment.

forest and community lands. The species in each of the stand models have further been stratified as fast and slow growing considering their growth rates. The same species and growth rate is considered for the different altitudes (Table 6), although in reality, the growth rates may vary with altitude, due to unavailability of literature reporting growth rates of any other species or for the same species at different altitudes.

Conservativeness was ensured for all the strata, by selecting weighted average MAI, which is lower than the maximum MAI reported for the species selected. Further, the MAI value considered for assessment is an average of MAI reported for different aged stands and lower than the maximum reported MAI for the chosen species. Only species with moderate MAI has been chosen to represent a stand model and not one with highest MAI.

Carbon accumulation rates per hectare

Planting on all the three land categories is carried out in a phased manner over a 6 year period on all the three altitudes. Carbon accumulation, therefore, steadily increases with number of years in all the land categories. There is a continuous increase in carbon stocks as all species considered for the three reforestation models have a long gestation period and involve no harvest. The increase per hectare is highest under farm forestry on degraded and abandoned private lands although the area is much less than that of degraded forest and community lands. This is because the increment in growth rate per ha considered for farm forestry is slightly higher than that considered for reforestation on degraded forest and community lands (Fig. 3). When the different carbon pools are considered, the increase in aboveground biomass is highest, followed by soil organic carbon and then belowground biomass carbon pool. The accumulation is slightly higher for farm forestry as a result of higher growth rates considered. SOC considered of course is a constant 1.2 t C ha^{-1} increase over a 20 year period for all the land categories and belowground biomass is 0.24 % of aboveground biomass.

Comparison of per hectare stock accumulation rates of private (degraded and abandoned private land) and public lands (degraded forest and community lands) indicates that the tonnes of CO_2-e accumulation are comparable till the 10th year and after the 10th year, the accumulation rate in the private lands is slightly higher than that of public hands, because of higher growth rates considered.

Carbon stock accumulation under different reforestation options for the total area

Maximum area brought under reforestation among the three land categories considered is degraded forest land on which restoration forestry is the option considered. Over a 30 year period, the total stocks of carbon accumulated on degraded forest lands (cumulative stocks) through restoration forestry is highest at 1,187,745 tCO_2-e followed by farm forestry (199,328 tCO_2-e) and then community forestry option (110,454 tCO_2-e) for degraded community lands (Table 7 and Fig. 4). Fig. 5 illustrates the cumulative accumulation of carbon in the three carbon pools, pooling together stock accumulation as a result of implementation of the three reforestation options on the three de-

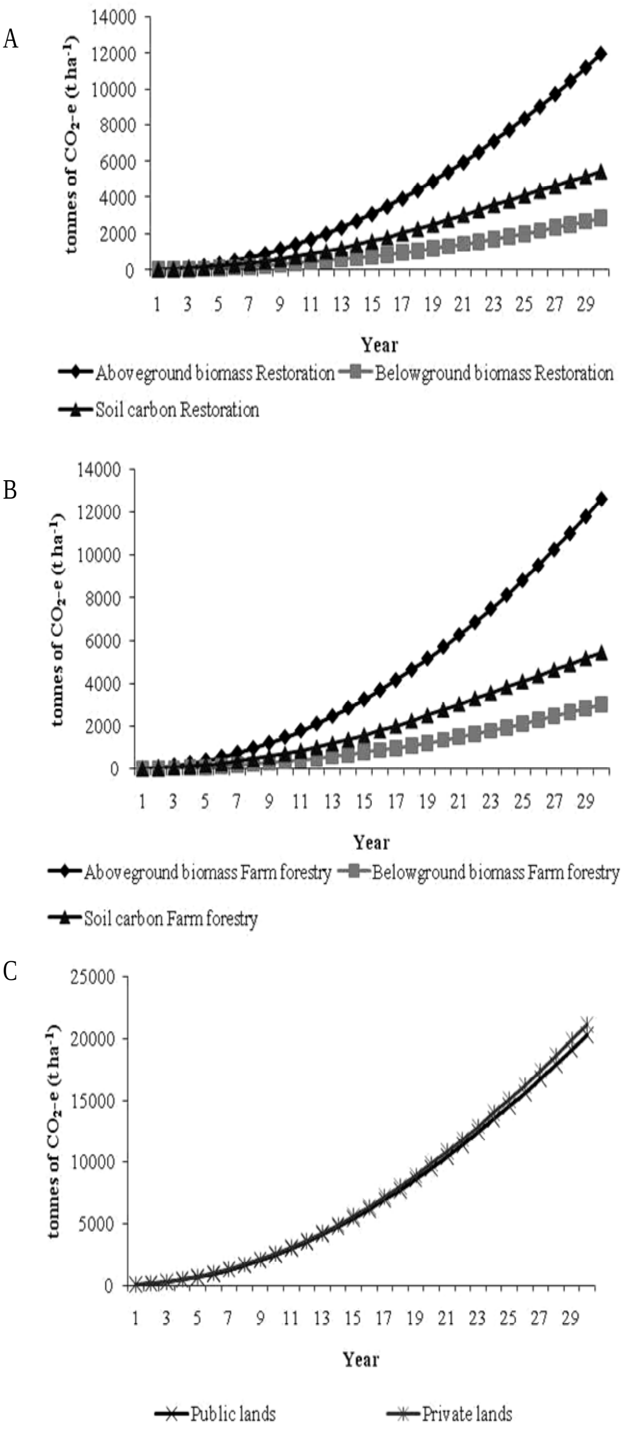

Fig. 3. Per hectare increase in carbon stocks. A. Stocks increase under restoration forestry; B. Stock increase under farm forestry; C. Total carbon stock increase on public and private lands.

graded land categories. The total aboveground biomass accumulation across the three reforestation options gradually increases with the number

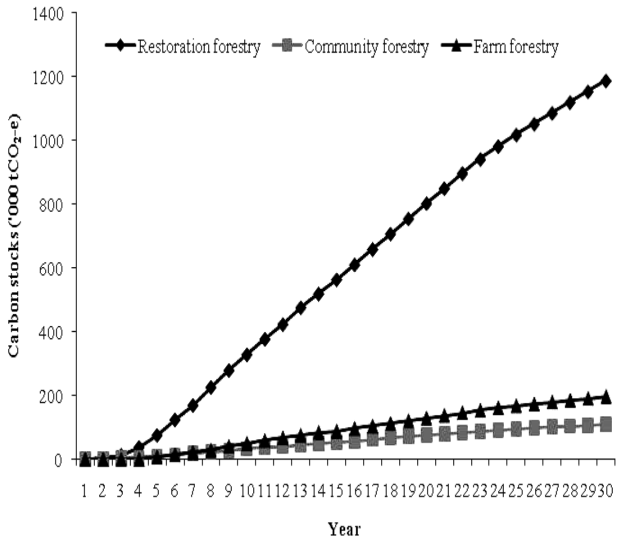

Fig. 4. Cumulative carbon stock accumulation in the three land categories under different reforestation options over a 30-year period.

of years and is highest for restoration forestry (732,405 t CO_2-e) and lowest for community forestry option (68,278) over a 30 year period. Belowground biomass accumulation is relative to aboveground biomass and, therefore, the same trend is seen. Soil organic carbon accumulation is assumed to at the rate of 1.2 t C ha^{-1} over a 20 year period, after which it is assumed to stabilize and this also is highest in the degraded forest lands wherein restoration forestry is considered follows a similar trend.

Conclusions

India has been implementing one of the world's largest afforestation programmes to meet its biomass requirement (fuelwood, timber and non-timber products) and for forest conservation purposes. India has also set a goal of covering about one-third of the geographic area under forests, compared to less than 20 % area currently under forests. This goal is still higher in the case of hilly states such as Himachal Pradesh wherein as per the National Forest Policy 1988, 2/3rd of the geographic area is to be under forest/tree cover. This study has attempted to overcome the limitations of existing studies or more the lack of such studies estimating the mitigation potential of different land categories.

In the year 2000, the total carbon emissions in Himachal Pradesh, with diesel and coal contributing the most - 39 % and 37 % was 660,000 t CO_2-e

Table 7. Stocks of carbon in different pools and total stock accumulation under different reforestation options over a 30-year period.

Year	Stocks of carbon in different pools ('000 tCO_2-e)			Total stocks ('000 tCO_2-e)		
	Aboveground biomass	Belowground biomass	Soil organic carbon	Restoration forestry	Community forestry	Farm forestry
1	1	0	1	2	0	0
5	52	12	30	78	9	7
10	239	57	118	330	33	51
15	405	97	206	564	54	90
20	577	139	294	803	76	131
25	751	180	352	1018	95	170
30	924	222	352	1188	110	199

A B C D

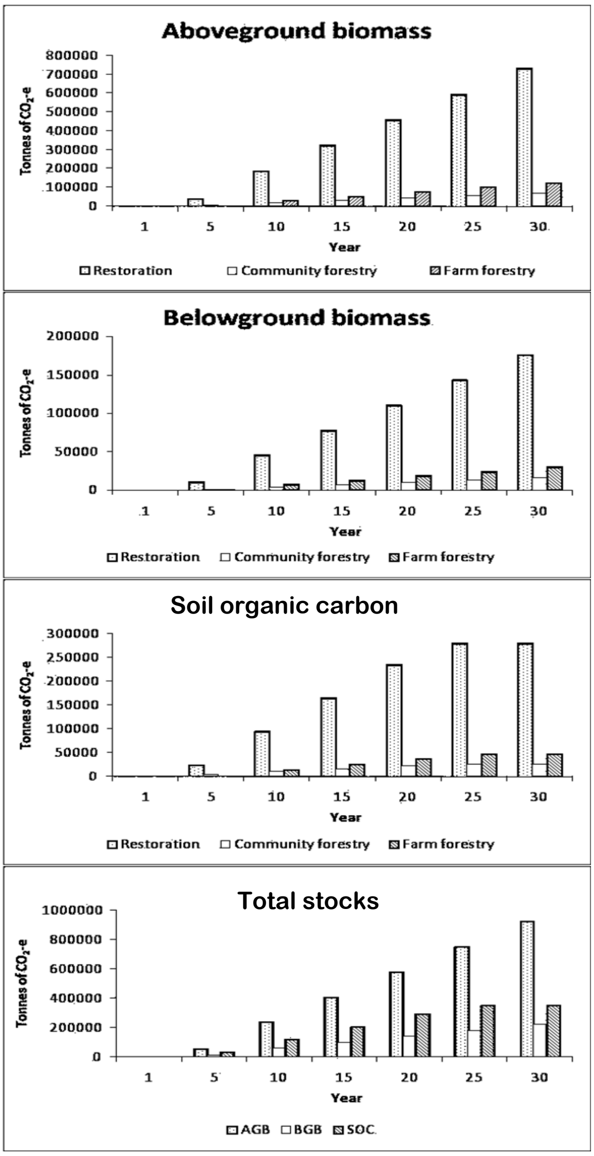

Fig. 5. Cumulative carbon stock accumulation in different carbon pools over a 30-year period.

(Ghoshal & Bhattacharya 2007). It is abundantly clear from this study that degraded lands available in the state could be effectively utilized and could contribute significantly to emissions removal, which would be further enhanced with the operationalization of the Greening India mission under the National Action Plan for Climate Change. The mitigation potential of degraded forest lands alone is 1,187,745 t CO_2-e and added to this is 110,454 and 199,328 t CO^2-e by reforestation of degraded community lands, and degraded and abandoned private lands, respectively. Given that a decade has gone by and the emissions are likely to be much higher, reforestation of degraded forest lands, community lands and private lands can definitely help offset a very significant amount of emissions given that the combined mitigation potential of reforestation of the three land categories is 1.5 $MtCO_2$-e over a 30 year period or 49,918 t CO_2-e $year^{-1}$.

What will further impact the mitigation potential estimates is the decisions regarding what lands are to be considered available for mitigation. In this analysis, only parts of degraded forest lands, community lands and private lands have been considered. If further analysis, taking into consideration the potential and feasibility of allocating land for different options such as biomass production, carbon sequestration, biofuel, and other landuses is conducted, a realistic estimate of the mitigation potential would be possible.

The uncertainty in the estimates of mitigation potential is mainly from use of one growth rate for a stratum that is to be reforested with a mix of species. This is because there is a lack of growth rate data available for many of the species considered, based on community choice. Generating reliable, disaggregated estimates of the carbon stock gain by mitigation option, considering varied growth rates, could reduce this uncertainty. However, this study offers a significant advance over previous studies for India, by making estimates of mitigation potential at the state level considering land available under more than one category. It also provides a roadmap for future work in support of mitigation analysis and implementation.

The estimates provided by this study indicate opportunities for claiming credits or incentives under the emerging REDD + mechanism. Such projects, although designed to limit harmful climate change could provide additional benefits, such as conservation of biodiversity, ensuring collateral benefits of emissions reductions and biodiversity conservation are achieved in the same places.

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