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From the Director

The SAARC Forestry Centre (SFC) has the pleasure in bringing out the annual SAARC Forestry Journal 2014. We would like to thank all the authors and co-authors for their efforts and contribution of articles in this issue. We congratulate all the authors whose articles have been selected and published. However, sincerely apologize for the rest of the articles which have not selected in this issue due to various reasons.

We strongly believe that through the publication of such science based forestry journal would contribute to sustainable forest resource management, biodiversity and water resource conservation in the SAARC Member States that would, in turn, help in addressing the issues of Climate Change, poverty and disasters related problems.

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Sangay
DIRECTOR

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Carbon Flux Assessments in Forest Ecosystems Using Landsat and Terrestrial Sample Based Inventory Data

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Abstract

Satellite observation of forest cover at local, regional and global scale is helpful for wall-to-wall forest mapping and forest biophysical properties estimation and contributes to understand the terrestrial carbon flux and climate change. The objective of this study is to quantify the changes of above-ground carbon stocks in forest ecosystems of a test site during the last decade (2001-2010). The study area is located at south-eastern Bangladesh. Forest coverage and standing forest biomass in the area is rapidly changing because of the extreme human intervention. Landsat images of 2001 and 2010 were utilized to estimate the decadal forest cover change. Forest survey was conducted to measure tree diameter and height by laying sample plots and the measurement was later converted to above-ground forest biomass and carbon stocks using allometric relations and ratios. Carbon stock of the study area was estimated by forest stratification on Landsat imagery. Spatial extent of forest strata and quantitative information on carbon storage were obtained from Landsat and ground-based survey data, respectively. The study estimated that 125 thousands ton of carbon was lost from the study area (300 sq. km) within the last decade (2001-2010), which is about one-third in compare to the previous decade (1992-2001). The method applied in this investigation is useful for local level studies if adequate ground samples are available.

Keywords: Forest biomass, carbon, forest inventory, Landsat

I. Background

The experimental results of Manua Loa has reported a rapid increase in the mixing ratio of CO_2 concentration in the atmosphere rising from 315 ppm in 1960 to around 390 ppm in 2010 (Tans 2010). Since the industrial revolutions CO_2 concentrations in our atmosphere increased in faster rate and are now 30% greater than pre-industrial time (Reay and Grace 2007). The rapid increase in CO_2 emissions observed during the last 250 years is assumed to continue for several forthcoming decades and likely to create many adverse impacts in our living system. Since the beginning of the industrial revolution land use change particularly loss of forest coverage plays a vital role in terrestrial carbon flux.

The area of global forest cover is just over 4 billion hectares, 31% of total land area (FAO 2010). The total carbon storage of global forest ecosystem is estimated to be 638 Gt for 2005, which is more than the amount of carbon in the entire atmosphere (FAO 2005). This huge amount of carbon stocks can be declined by the process of deforestation and forest degradation but can be increased by afforestation, reforestation and forest amelioration activities.

The net change in global forest area in the period of 2001-2010 is estimated to be -5.2 million hectares per year (an area about the size of Costa Rica), down from -8.3 million hectares per year in the period of 1990-2000 (FAO 2010). Estimation and monitoring of carbon flux due to forest cover change in local, regional and global scale is useful to understand the role of forest in global terrestrial carbon cycle.

Global estimation and modeling of above-ground forest biomass and carbon storage are still challenging tasks due to the unavailability of suitable method that can assess forest biomass using remotely sensed imagery over a large area with an acceptable accuracy. Local level studies utilizing both remote sensing and ground-based survey data can be an effective way to estimate the carbon flux in forest ecosystem due to deforestation, degradation and forest amelioration activities.

The aim of this study is to estimate above-ground carbon storage in study the area and quantify the changes in carbon stocks associated with the changes in forest coverage over the last decade (2001-2010).

II. Materials and methods

II. 1 Description of the study area and forests

The study area is located at Southern Chittagong of South-eastern Bangladesh. The size of the area is approximately 300 sq. km (20km x 15km) and it covers 21°29´to 21°37´ N Latitude and 92°05´ to 92°13´ E longitude (Figure 1). The area belongs to sub-tropical monsoon climate. Monsoon starts in June and continues up to October and accounts for 80% of total rainfall.

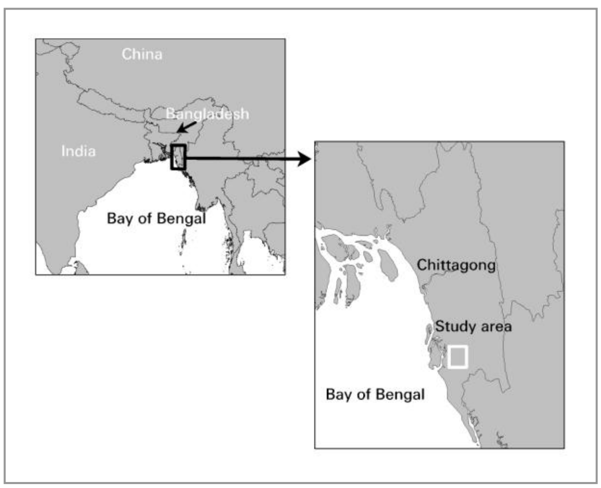

Figure 1. Location of the study area

The forests of the study area are classified as tropical wet evergreen and semi-evergreen forest (Champion *et al.* 1965, Figure 2). The evergreen stratum is dominated by *Dipterocarps* and a few semi-evergreen or deciduous species may present as well. In semi-evergreen forests, the presence of considerable amount of deciduous species in the top canopy is noticed. Because of extreme human intervention, virgin forests are almost absent. Existing vegetation mostly consists of secondary re-growth, which is in the process of succession to the climax evergreen type (Khan 1979).

Figure 2. Tropical wet ever-green and semi-evergreen forests in the study area (photograph was acquired during field sampling mission, 2002-2003)

II. 2 Landsat image processing

Orthorectified Landsat ETM+ and TM images of 2001 (7th February, 2001) and 2010 (24th February, 2010) (path/row: 136/045) were obtained from United States Geological Survey (USGS). The orthorectified data was atmospherically corrected using COST method (Chavez 1996), which is a modified dark object subtraction technique. The reflectance of a dark object was assumed as one percent (Chavez 1996, Moran *et al.* 1992). Firstly digital counts (DCs) of the image were converted to at-satellite radiance, and in the next step, at-satellite radiance was converted to surface reflectance by removing solar and atmospheric effects.

The images were re-projected to Lambert Conformal Conic projection. The geometric accuracy was checked in the ground with the objects identified both on Landsat scene and in the field (i.e corner of pond, bridge etc.). A linear distortion in the image of a few pixels was detected, which was corrected by linear shipment. The second image was rectified by image-to-image registration. The geometric distortion between the historical and recent images was less than a pixel (30m). The study area from the whole Landsat scene was clipped as subset.

Landsat image bands were visualized in 4 (red), 5 (green) and 3 (blue) and forest was appeared in brown to red, shrubs in yellow, bare soil in cyan, water in blue. Additional interpretation elements such as tone, texture, pattern etc. helped image interpretation as well. Approximately, one thousands pixels were chosen from each forest class as the training set. The entire scenes were then classified by supervised method using maximum likelihood algorithm. The identified forest classes were considered as forest strata.

II. 3 Forest sampling and measurements

Sample plots to measure trees were laid in eight different forest strata identified and classified based on the Landsat image. The size of the plots was variable depending on the type and condition of vegetation (Table 1). Sample plots were located in relative homogenous areas to reduce the chance of errors originated by the integration of remotely sensed information and terrestrial sample based forest inventory data. One hundred terrestrial sample plots were collected in two sampling missions; seventy samples were collected in the first trip (October 2002 to February 2003) and thirty samples were collected in the second trip (January 2004).

Table 1. Vegetation characteristics and distribution of ground samples (adapted from Rahman *et al.* 2008, Rahman and Sumantyo 2013)

Origin	Vegetation type	Number of plots	Plot size (m^2)	Vegetation structure and characteristics	
				Structural attributes	Dominant species
Natural vegetation	Primary forest	16	30×30	• Natural origin, multi-storied, a number of matured trees in the upper canopy; shrubs and sometimes bamboo in lower canopy, rich in biodiversity	*Diptercarpus turbinatus*, *D. alatus*, *Syzigium grande*, *S. wallichi* etc.
	Secondary forest	10	10×10	• The class is in the succession stage and resulted from earlier disturbance; • The trees are younger in age and smaller in size than the primary forest	*Diptercarpus turbinatus*, *D. alatus*, *Syzigium grande*, etc.
	Bamboo	10	5×5	• Dominated by bamboo, sometimes scattered trees are noticed in the upper canopy	*Melocanna baccifera*, *Bambusa tulda* etc.
	Shrubs	11	5×5	• Shrubs intermixed with seedling and sapling of tree species, bamboo and grasses • Vegetation in this formation is usually 1-2 m in height	Mixed species
Plantation	Indigenous species	11 8	10×10 15×15	• Monoculture with various indigenous species; the branching patterns of different species are different • The stocking levels are different: well-stocked to disturbed plantations	*Dipterocarpus turbinatus*, *Sysygium grande*, *Artorcarpus chaplasha*, *Hopea odorate*
	Teak	9 3	10×10 15×15	• Teak has identically larger leaves; no other tree species, undergrowth or ground vegetation is seen in this plantation	*Tectona grandis* or coppice
	Acacia	10	10×10	• A thick layer of green canopy is noticed	*Acacia auriculformis* and *A. mangium*

				• The heights of the plantations are variable mainly because of the difference in age class	
	Rubber	12	10×10	• Managed and cultivated ecosystem; the undergrowth is very sparse due to intense weeding operation • Generally, the plantations have wider spacing in compare to the other vegetation classes	*Hevea brasilensis*
Total		100			

Tree exceeding 5 cm diameter at breast height (*dbh*) inside the sample plots was measured by diameter tape. Height measurement of 3-5 dominant trees inside the plot was done by Suunto Clinometer and height of the remaining trees was estimated from those measurements. Smaller vegetation (lower than 5 cm diameter) was measured by laying sub-samples (2m×2m) laid at the center of the sample plot. The estimation of sub-sample was normalized to the standard sampling unit.

II. 4 Carbon stock estimation

Tree volume was computed from the measured data using local volume equations. Bangladesh Forest Research Institute (BFRI) developed local volume tables for a number of commercially important species (Latif and Islam 1984a, Latif and Islam 1984b, Latif *et al.* 1986, Latif *et al.* 1995). Tree volume for the remaining tree species was estimated by a generic volume function (Latif *et al.* 1986). Volume was then converted to above-ground tree biomass applying volume-to biomass conversion ratio (FAO 1997, Anon 2006).

Bamboo biomass was estimated from the conversion ratio developed by Forestal (1966). The ratios are available for different diameter classes. Above-ground forest carbon was estimated from biomass by multiplying the conversion ratio (0.5). Individual tree carbon was summed to compute plot carbon and later normalized to one ha standard unit to harmonize the estimation. Finally, carbon stocks for the entire study area was estimated based on Landsat area estimation and carbon stocks computed from the sample based forest inventory data.\

III. Results and Discussions

Above-ground carbon storage in various forest strata is computed by synthesizing the data of seventy sample plots collected in the first sampling mission (Table 2). The coverage of natural vegetation contains a large variability of carbon storage. Primary forest holds the largest amount of carbon in unit area (more than 130 ton/ha) and shrub contains the lowest level of carbon (less than 1 ton/ha). Secondary forest or plantation with indigenous species contains a moderate amount of carbon (more than 80 ton/ha). Bamboo or Teak plantation also has over 60 ton/ha of carbon storage. Among the plantations, Acacia or Rubber contains the lowest level of carbon (slightly higher than 30 ton/ha).

The forest coverage in historical and recent time is presented in Figure 3 and 4, respectively. Primary forest was declined from 3.95 thousands ha to 3.48 thousands ha during the period of investigation.

The net loss of primary forest was 0.48 thousand ha (Table 3). Total secondary forest of 1.03 thousands ha was lost during the study period. Non-forest area was increased from 11.04 thousands ha to 16.26 thousands ha. Plantations of indigenous species increased from 2.55 thousands ha to 2.73 thousands ha. There is a considerable change in the extent of Rubber plantation. This may be the result of classification errors. In the historical image, rubber plant was leafless (7th February, 2001) and it appears similar to scrubby re-growth. On the other hand, on recent image (24th February, 2010) rubber appears with newly flush leave on Landsat scene and was accurately classified.

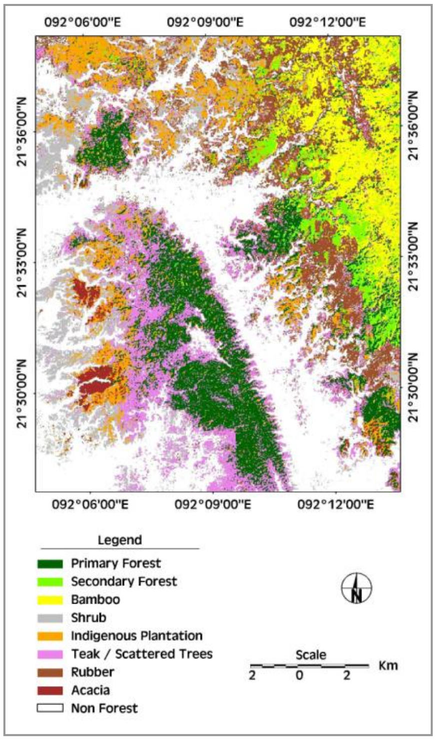

Figure 3. Forest cover map of Southern Chittagong, 2001

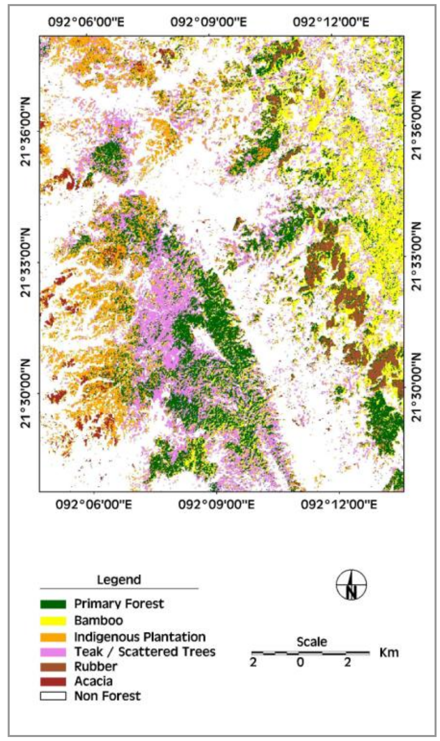

Figure 4. Forest cover map of Southern Chittagong, 2010

Table 2. Above-ground carbon storage in various forest strata estimated from terrestrial sample based inventory data (Rahman 2008)

Forest type		Mean carbon content (ton/ha)	Standard deviation	95% confidence level	
				Upper limit	Lower Limit
Natural vegetation	Primary forest	134,37	52,18	637 613	423 923
	Secondary forest	86,84	16,18	101 975	77 420
	Bamboo	62,70	15,21	189 499	132 186
	Shrub	0,87	0,45	3 637	1 654
Plantation	Indigenous species	83,73	54,10	279 353	148 505
	Teak	60,81	26,09	288 285	167 147
	Acacia	30,62	7,04	12 449	8 488
	Rubber	30,95	22,89	139 112	46 920

Table 3. Changes in the above-ground carbon storage in the forests of Southern Chittagong (2001-2010)

Forest type		2001		2010		Change in total C (ton)
		Area (ha)	Total carbon (ton)	Area (ha)	Total C (ton)	
Natural vegetation	Primary forest	3 950	530 762	3 475	466 936	-63 826
	Secondary forest	1 034	89 706	0	0	-89 706
	Bamboo	2 566	160 826	3 456	216 691	55 866
	Shrubs	3 023	2 630	0	0	-2 630
Plantation	Indigenous spp.	2 554	213 930	2 726	228 248	14 318
	Teak / Scattered Trees	3 746	227 733	4 246	258 199	30 466
	Acacia	341	10 472	416	12 738	2 266
	Rubber	3 006	93 036	673	20 829	-72 206
	Non- forest	11 035	-	16 262	-	-
	Total	31 254	1 329 094	31 254	1 203 641	-125 453

Positive value in the last column indicates carbon sequestration and negative value means carbon release

The accuracy of Landsat image classification was analyzed for the historical image (Table 4). The overall classification accuracy was 86%. The class representing bamboo, shrubs and Acacia show higher producer's accuracy (more than 90%). Bamboo has the highest percentage of user's accuracy (97%). The lowest producer's accuracy was obtained for Teak plantation (74%). The lowest user's accuracy was obtained for secondary forest (55%). In this study, error analysis was performed with the training pixel sets, which indicates how well the classification procedure has categorized a representative subset of pixels used in the training process (Lillesand *et al.* 2008). Accuracy results to estimate the above-ground carbon storage was analyzed form thirty samples collected during the second sampling mission. Result shows the *RMSE* value was 47 and mean bias was 32 ton/ha. The standard error of bias was 6.47 (Table 5).

Table 4. Summary of error matrix computed for Landsat ETM+ image classification (2001) (Rahman 2008)

Broad land cover category	Forest / Land cover type	Producer's accuracy (%)	User's accuracy (%)
Natural vegetation	Primary forest	84	87
	Secondary forest	83	55
	Bamboo	96	97
	Shrubs	93	87
Plantation	Indigenous species	76	88
	Teak	74	74
	Acacia	91	87
	Rubber	85	81
Others	Soil	86	86
	Settlements	89	93
	Water	96	95

Overall accuracy: 86%

Table 5. Statistics representing validation tests for the estimate of above-ground carbon storage (Rahman 2008)

Parameters	Validation results
RMSE	47,13
Mean bias	31,76
Standard error of bias	6,47

The result reveals that primary forest losses a considerable amount of above-ground carbon storage (63.8 thousands ton, Table 3). Secondary forest also experiences with a high amount carbon loss (89.7 thousands ton). Bamboo holds 55.9 thousands ton of higher carbon in compare to the historical time. This increase is the result of the expansion of bamboo areas from 2.57 thousands ha to 3.46 thousands ha. The total amount of carbon loss from the study area was estimated to be 125.5 thousands ton in the last decade (2001-2010), while in previous decade (1992-2001) the loss was estimated to be 400.3 thousands ton (Rahman 2008). Therefore, the rate of carbon loss was reduced to approximately one-third in the last decade in compare to the previous decade.

In this study, above-ground carbon storage in the forests of study area was estimated by optimal stratification. Forest type identified on Landsat imagery was the optimal stratification criterion in the estimation. There is a limitation of such estimation. The amount of carbon stocks was estimated a fixed amount for the entire pixels belonging to a particular class. In real world, this is unrealistic since there is often variation in forest stocking in every class because of the variation in site quality and occurrence of previous disturbances.

On the other hand, carbon stocks computed by other methods (i.e. regression or *k*-nearest neighbor) are variable depending on the reflectance value of an image-pixel regardless the pixel belongs to same or a different vegetation types. As a result, stratification technique can only estimate the amount of terrestrial carbon flux due to deforestation or land cover change but unable to estimate the changes in carbon stock due to forest degradation or forest amelioration. The main advantage of stratification procedure is the simpler computation technique and the method does not depend on the robustness of the relationship between spectral reflectance properties and the amount of above-ground carbon stocks in forest ecosystems though the association between these two variables is often low. The success of estimation using this technique depends on the classification accuracy of remote sensing image as well.

IV. Conclusion

Based on experimental result, it was concluded in the present study (i) forest was considerably lost in the study area during the last decade (2001-2010); the net loss of primary and secondary forest was 0.48 and 1.03 thousands ha, respectively and (ii) 125 thousands ton of carbon was released from the study area during the period of investigation (2001-2010) and it was about one-third in compare to the previous decade (1992-2001).

The vast tract of deforested land has also widened the scope of forest plantation. Large-scale forest plantation with fast-growing species will sequestrate a huge amount of carbon. The rate of carbon sequestration will depend upon the growth rate of species in a given site quality. Fast-growing young plantation will have a high rate of carbon sequestration in compare to mature forest where growth is almost stagnant. The success of carbon sequestration and raising forest plantation in the study region still remains a challenging task for Bangladesh Forest Department since forest is highly vulnerable to the extreme human interference.

Acknowledgements

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Resource Poor Community Forests takes up Fuel Wood Plantations

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Abstract

Community Forests (CFs) initiated by the Department of Forests and Park Services in line with the decentralization policy started in the late 1990s. Most of the community forests established before the enactment of Forest and Nature Conservation Rules, 2000 were on degraded state reserved forest lands in the vicinity of rural settlements.

"Sustainable Rural Biomass Energy (SRBE) Project jointly executed by Department of Renewable Energy (DRE), Ministry of Economic Affairs and Department of Forest and Park Services, Ministry of Agriculture and Forests, aims to, among others - reduce GHG emissions through use of more efficient fuel wood technologies resulting in reduction in the annual biomass/fuel wood consumption and sustainable forest biomass generation.

One of the components under the project deals with fuel wood plantation in the Community Forests. The main objective of establishing fuel wood plantation in Community Forests is to contribute to the overall project goal of reducing greenhouse gas emissions through creation of carbon sinks.

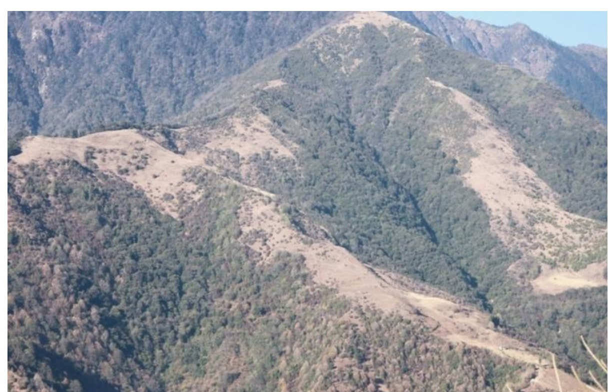
Since rural communities depend heavily on forest resources for fuel wood and other forest products, plantations raised through this project will contribute towards meeting future demands for forest resources, such as fire wood, timber, fodder and non-wood forest products. The project is expected to rehabilitate barren and degraded community forest areas, as well as contribute in alleviating poverty by fulfilling the demands of local communities.

I. Background

In 1979 when the Fourth King Jigme Singye Wangchuck proclaimed the importance of people's participation in natural resource management, the community forestry establishments in Bhutan were enhanced through endorsement of Forest and Nature Conservation Act in 1995 which lead to first community forests being approved and handed over to Dozam Community in 1996[1], Mongar Dzongkhag. Numerous policy developments commenced and subsequently the new regulations enabled the establishment of community forests. Most of the community forests established prior to Forest and Nature Conservation Rules, 2000 were on degraded Government reserved forest lands in the vicinity of rural settlements. This gives opportunity for the community forest management group members to establish plantation on their degraded community forests with donor supports.

Bhutan Sustainable Rural Biomass Energy (SRBE) Project initiated by the Department of Renewable Energy (DRE), Ministry of Economic Affairs in 2008 has been approved in August 2012 for implementation. It is a three year project funded by Global Environment Facility (GEF) and co-financed by UNDP and Royal Government of Bhutan. The project is jointly implemented by the DRE, Social Forestry and Extension Division (SFED) under Department of Forests and Park Services of Ministry of Agriculture and Forests and Gross National Happiness Commission (GNHC).
The goal of the Project is to reduce GHG emissions from rural households and industrial sectors of Bhutan through sustainable production and utilization of biomass-based energy in the country, and the promotion of sustainable biomass energy technologies, using market approaches. It also aims to promote the sustainable production of fuel wood in community forests. The scope of the project entails (i) Strengthening policies and regulatory framework for sustainable production, conversion and utilization of biomass energy resources; (ii) promotion and dissemination of about 20,000 efficient cooking stoves in the country and demonstration of a biomass based power plant technology in some promising wood industry in Bhutan; and (iii) capacity building and knowledge management in biomass energy technologies[2].

Under the project, a small budget of USD 64,000 has been allocated for fuel wood plantation in the Community Forests (CFs) within 2013-2014 fiscal year. The main objective of establishing fuel wood plantation in Community Forests is to contribute to the overall project goal of reducing the green house gas emission through creating net carbon sink by planting tree seedlings. The planted seedlings will absorb and utilize carbon dioxide from the atmosphere for photosynthesis and hence will remove carbon dioxide from the atmosphere. It was also envisaged that cook stove installation and fuel wood plantation areas coincides simultaneously.


Khaling CF potential for establishing plantation

Since the rural communities depend heavily on the nearby forest for fuel wood and other forest products, the plantations raised through this project will be

[1] Rai, T.B., Dorji, K., Droelkar, K.T., Wangchuk, T. (2014). Descriptive Analysis Progress Report, Community and Private Forest Development in Bhutan. Social Forestry and Extension Division, Department of Forests and Park Services, Ministry of Agriculture and Forests.
[2] Department of Renewable Energy. Bhutan Sustainable Rural Biomass Energy Project Document. Thimphu: 2012.

managed for meeting the future forest product requirements. It will not only help in rehabilitating the barren and degraded forest areas thereby ensuring a carbon sink, but also will help in alleviating poverty by fulfilling the demand of forest products from the planted forests.

Project Activities

II. Site Assessment:

Potential sites for plantation have been jointly identified and assessed by the team comprising of representatives from Social Forestry & Extension Division (SFED), Dzongkhag Forestry Sectors, Geog Forest Extension Officers (GFEO) and Community Forest Management Group (CFMG) members. Visual identification was made and CFMG members were consulted. Technical feasibilities whether or not to fund for the proposed plantation site were decided on the spot. Agreement between the CFMG members and/or Dzongkhag Forestry Sector/SFED was drawn mentioning that CFMG members shall contribute labor where the Project shall fund for the materials like seedlings, fencing posts, nails, barbed wire, transportation costs, etc. GPS mapping of plantation area was done wherever feasible. Few plantation areas were drawn with sketch map. When the proposed area is agreed to be brought under plantation, the Dzongkhag Forestry Sector estimates the costs for plantation and submit to SFED. The Plantation Section under SFED verifies the cost estimates and facilitates in obtaining the Technical Sanction from the Head of the Department of Forests and Park Services.

Identification and site assessment in 2012: In 2012 four Dzongkhags were visited and found seven CFs potentials for taking up fuel wood plantations. The details are provided in the Table 1.

Table 1: CFs identified in 2012 for fuel wood plantation

Sl. No.	Dzongkhag	Geog	Name of CF	Area in Ha
1	Trashigang	Lumang	Phenden Dongdey Nagtshel CF	8
		Khaling	Khaling CF	8
2	Trashi Yangtse	Jamkhar	Rebuktongphu CF	7
		Ramjar	Namtongphu CF	7
3	Sarpang	Doban	Lhayul CF	7.5
4	Tsirang	Rangthangling	Dajay CF	2
		Dunglagang	Norbugang CF	4
			Total Ha.	**43.5**

Establishment of plantations also depends on the community forest management group members' enthusiasm and interest. Tashi Yangtse Dzongkhag (in red font) was not able to take up the plantations due to non availability of the plantation cost estimates.

III. Identification and site assessment in 2013:

In 2013 seven districts were visited and found 42 CFs potential for plantations (Table 2). Some CFs identified even two plots within one CF, which is also feasible. However, due to shortage of fund only 34 CFs were able to support for establishing plantations. Community Forests with red fonts were not able to establish fuel wood plantation due to fund shortage from the donor agency.

Table 2: CFs identified in 2013 for fuel wood plantation

Sl. No.	Dzongkhag	Geog	Name of CF	Area in Ha
1	Tashigang	Radhi	Sharmidung CF	6.00
2		Samkhar	Pam CF	5.00
3		Udzorong	Drothphu CF	8.00
4	S/Jongkhar	Serthi	Khandophung Gayjung CF	4.00
5		Serthi	Suskar Kuenphen Norbuling CF	3.00
6	Sarpang	Gelephu	Raidangra CF	8.00
7		Gakidling	Rilangthang CF	8.00
8		Samtenling	Dungkarling CF	8.00
9		Chudzom	Lhayul CF (Malabunchori)	8.00
10		Chudzom	Lhayul CF	8.00
11		Jigmecholing	Lungsigang CF	10.00
12	Pemagatshel	Khar	Kharwar Jungzhi Sungchop	2.00
13		Nanong	Pangthang Kulung CF	4.00
14		Dungmin	Dongdongma CF	2.00
15		Chongshing	Mandi Yerjay CF	1.00
16		Chimong	Chimong Doendrupling CF	1.00
17		Shumar	Dagore Phendey CF	2.00
18		Shumar	Shali Peldrup CF	1.00
19		Shumar	Rangjung CF	1.00
20		Shumar	Gamung Gongphel Dondey	0.40
21		Zobel	Pangthangdaza Sokpotsho	2.00
22		Zobel	Tshelingore CF	1.00
23		Dechenling	Namdaling CF	1.20
24	Punakha	Talo	Norbuling CF Area 1	2.30
25		Talo	Norbuling CF Area 2	2.50
26		Lingmukha	Yargay CF	1.00
27		Lingmukha	Wongbaab CF	2.00
28		Lingmukha	Lumsum CF	2.00
29		Barp	Peljorling CF	1.50
30		Talo	Parikha Norbuling CF	10.00
31	Lhuntse	Gangzur	Nganey CF	2.00
32	Tsirang	Shemjong	Tashiding CF	8.80

33		Tsirangtoe	Zomnya CF	0.96
34		Tsirangtoe	Gongpheling CF	0.84
35		Tsirangtoe	Youngdrag Chen CF	0.64
36		Tsirangtoe	Chithuen CF	2.60
37		Phuentenchu	Phuen Thog Chen CF	1.33
38		Tsholingkhar	Jangchubling CF	0.93
39		Tsholingkhar	Lhasoelthang CF (Plot I)	1.50
40		Tsholingkhar	Lhasoelthang CF (Plot II)	1.13
41		Tsholingkhar	Norbuling CF	2.75
42		Tsholingkhar	Phendheling CF (Plot I)	0.85
43		Tsholingkhar	Phendheling CF (Plot II)	0.69
44		Mendrelgang	Reserboo CF	0.97
45		Mendrelgang	Chirphen CF	1.38
			Total Ha.	**143.27**

IV. Plantation Establishment:

The Dzongkhag Forestry Sector needs to draw an agreement with the Community Forest Management Group and submit the plantation cost estimates to SFED based on "Norms and Standards for Nursery and Plantation, 2008". The Plantation Section under SFED verifies the plantation estimate and facilitates in seeking approval on the "Technical Sanction" from the Head of the Department. Upon approval of the Technical Sanction, the SRBE Focal Officer in consultation with Ministry's Finance Division sends the fund to respective Dzongkhag or Geogs.

CFMG members clearing bushes for establishing plantation

Plantation of any plant species plays a vital role in sustainable management of forest resources and maintaining ecological balance in perpetuity. Further, it is one of the viable measures to contribute towards fulfilling the Constitutional requirement of maintaining 60% forest cover for all times to come. The plantation in CFs were mainly focused on multi-purpose tree species *ficus*, *melia* etc where leaves can be used as fodder for their cattle, branches can be used as fuel wood for heating and cooking and the bole of the tree can be used for timber for house construction.

CFMG members supplied with free seedlings for plantation

With the financial support from SRBE Project and with technical facilitation from SFED, CFMG members of different CFs in different Dzongkhags and Geogs contributed labor during plantation establishment in their respective CFs. The total barren area inside community forests brought under plantation is 111.47 hectares (278.675 acres).

V. Capacity Building:

Capacity building is an ongoing process through which individuals, groups, organizations and societies enhance their ability to identify and meet development challenges. Capacity building describes a particular way of working with and supporting communities - to build skills and experience, increase opportunities and enhance involvement in the decisions that affect them. Capacity building involves in developing confidence, skills, structures and knowledge.

SRBE Project Team members visited Energy Park in AIT, Thailand

Capacity building within the SRBE Project was conducted at different levels. The exposure visits for SRBE Project staff in order to enhance their knowledge and experiences in biomass energy technologies. For instance, the SRBE Project implementing partners were taken for study visits in Thailand and Cambodia. The team visited Asian Institute of Technology (AIT) in Thailand and Group Energy Renewable, Environment and Solidarity (GERES), a French Non-Governmental International Agency in Cambodia. The purpose of the visit was to see the working Biomass Energy Technologies (BET) models like gasification and briquetting systems, furnaces and improved cook stoves, dissemination strategies of BETs and their testing methodologies to ascertain the system efficiencies.

The SRBE team comprising of five members visited the Energy Park where different Renewable Energy Technology models were installed and performance on various aspects were tested with the aim to get into the commercial industries. Given that AIT is fully resourced to conduct all types of tests related to use of renewable energy technologies, the SRBE team felt that AIT could be requested to conduct the combined efficiency tests on SRBE promoted stoves. As a part of this testing program, the relevant officials of the SRBE project could be fielded as hands-on-training at AIT in future.

In Cambodia with the logistical supports from GERES, the SRBE team visited improved cook stove industry initiated by the GERES and local government in Cambodia. The team also visited charcoal manufacturing kilns and community wood lot for supply of raw materials for charcoal making. GERES-Cambodia claims to have sold about two million improved cook stoves in Cambodia to date. The GERES improved cook stoves dissemination strategy consists of the following steps: 1) Diagnostic study, assessment, choice of pilot area, project component, 2) Development/validation of interests and production of the new equipment, 3) Preliminary

SRBE Project Team members visiting Charcoal production kiln in Cambodia dissemination, promotional activities, validation of distribution systems, and 4) large-scale dissemination, sector becoming self supporting. The program takes about five years to complete its cycle.

The other level is focused at the community level where Community Forest User Group members and the local Geog Forestry Extension Officers were imparted with training on different subjects related fuel wood, biomass energy and other hosts of different topics related to tree seedling nursery, plantation maintenance, wood harvesting, wood energy, etc.

CFMG members undergoing training

Community Forest Management Groups who already established fuel wood plantation were trained by the SRBE Project Focal Officer on sustainable wood energy, plantation and tree seedling nursery management, among others. The SRBE Focal Officer in SFED with the support from Dzongkhags trained numerous CFMG members in different Dzongkhags where the plantations were established. Most of CFMG members were invited for the training including the local GFEOs. The participants were also provided with meals and daily subsistence allowance in line with financial rules of our country. The financial supports were also provided by the SRBE Project.

In 2012-2013 financial year the training was conducted in Tashigang, Tsirang and Sarpang Dzongkhags. In 2013-2014 financial year the same training were conducted in Samdrup Jongkhar, Tashigang and Tsirang. Rest of the Dzongkhags who have established plantation will be covered in 2014-2015 financial year. The details of CFMG training are in Table 3.

Table 3: CFMG training details

Sl. No.	Year	Dzongkhag	Male	Female	Total
1	2012-2013	Tashigang	74	45	119
2		Tsirang	55	19	74
3		Sarpang	47	46	93
Total A			**176**	**110**	**286**
4	2013-2014	Tsirang	207	117	324
5		Samdrup Jongkhar	45	27	72
6		Tashigang	129	67	196
Total B			**381**	**211**	**592**
Grand Total (A+B)			**557**	**321**	**878**

In third quarter of the 2014-2015 financial year, two regional training workshops are planned. The first region will be in Tashigang and the second region will be in Punakha. The regional training workshop which will include participants from all Community Forests with fuel wood plantation and the concerned Geog Forest Extension Officer will be focused mostly on plantation maintenance and after-care. This is mainly guided by the "Norms and Standards for Nursery and Plantation, 2008" where the beneficiaries have to maintain the plantation at least for the next five years to ensure that plantations are thriving in the field. The training workshop will be hands-on training taken in the field to lay sample plots to measure seedlings survival percentage. Moreover, the beneficiaries will be inculcated the sense of ownership which will enhance in plantation maintenance. Therefore, this three days training workshop will be focusing on maintaining plantation journals, plantation maintenance includes survival survey, casualty refilling, weeding, watering and fence repairing works.

VI. Conclusion

The Sustainable Rural Biomass Energy (SRBE) Project is a three-year program contributing to the reduction of greenhouse gas emissions through the sustainable production and utilization of biomass through the promotion and dissemination of efficient cook stoves in the rural areas of Bhutan and implementation of demonstration biomass energy technologies in relevant industries. This will be achieved through supporting market mechanism, mainstreaming sustainable biomass energy in policy formulation and building capacities in the management of Community Forests and production and utilization of biomass energy technologies using wood as fuel.

Plantation of any plant species plays a vital role in sustainable management of forest resources and maintaining ecological balance in perpetuity. In less than two years in 2012, the SRBE Project supported in establishing more than 111.47 hectares (278.675 acres) of plantation inside barren areas of community forests in different Dzongkhags and Geogs. This small area brought under plantation also contributes towards fulfilling the Constitutional requirement of maintaining 60% forest cover for all times to come. Moreover, since rural communities depend heavily on nearby forest resources for fuel wood and other forest products, the plantations raised through this project will contribute towards meeting future demands for forest resources, such as timber, fodder, non-wood forest products, etc. The project through its small yet effective contribution rehabilitated significant areas of barren and degraded community forest areas. Once the plantations attain harvesting age and size, it will also help alleviate poverty by fulfilling the demands of local communities.

Capacity building for Community Forest Management Group members is a need base activity at regular intervals where the groups can be enhanced with ability to maintain their plantations established within their community forests. More than 878 Community Forest Management Group Members which includes 321 females were trained through capacity building support mechanism.

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Sustainable management of some of the Non Wood Forest Product species in Pemagatshel, one of the poor south-eastern districts of Bhutan: An Observation

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Abstract

The sustainable management of Non Wood Forest Product (NWFP) resources is a turning point for the improvement of forest resources and at abreast to socio-economic development of the rural community. It is not limited to this only but it benefits even the peri-urban and urban dwellers through economic trade activity of the NWFP resources. Sustainable management of NWFP resources enhance the natural regeneration capacity of the forest and underpin the biodiversity conservation of flora and fauna. It also helps to mitigate problems associated to watershed degradation, soil erosion, landslip and slide.

For sustainability of any natural resources, it is crucial to place in a policy, the national strategy, framework, management plans and guidelines and above all good governance is must to achieve the progress of sustainable development. Local knowledge on forest resources is an ideal tool for sustenance and conservation of the biodiversity resources in in-situ state. For instance, Pemagatshel is one of the poorest districts in Bhutan where the rural poor are engaged in sustainable management of such resources and generated themselves a self employment economic activity. A significant positive financial flow can be observed from the seasonal activity of the natural resources and aiding to a prominent numbers of local folks. Analysis of the collected data demonstrated a sustainable model of linear regression with an exponential growth. The trend is significantly positive in which, predicted $R^2 = 0.625$ and $y = 2916*\ln(x) + 516.20$. It has determined the sustainability of seven NWFP species that has been managed by the rural people of Pemagatshel district.

This observed field article wraps by pointing that, about 17% of the entire district populations have been receiving a considerable benefit through the sustainable management, utilization and trade of the available Non Wood Forest Product resources in outskirt habitation of the Government Reserved Forests areas.

Key words: *Benefit, biodiversity, collaboration, farmers group, livelihood, policy, self employment.*

I. Introduction

The Non Wood Forest Product (NWFP), definition by Food and Agriculture Organization (FAO, 2010) is "Goods derived from forests that are tangible and physical objects of biological origin other than wood". Similar definition is also applied in the Bhutanese context but it is limited within the scope of the Interim Framework for Management and Marketing of NWFP 2009 and the revised Interim Framework for Management and Marketing of NWFP in 2011. These two frameworks spelt for the own country's reference and categorized NWFP as asphalt; bamboos and canes (rattans); barks, fibres, roots, rhizomes or rootstock and leaves of trees and plants; decorative plants and flowers; edible fruits and nuts; entire plants including bulb, rhizome, tuber or root; fodder; fungus mushroom and other edible mushroom; green vegetables; gums and resin; honey; incense plants; lichens and mosses; medicinal and aromatic plants; oil seeds and nuts; that are usually from the Government Reserved Forest / Land (GRF). It is not limited only to GRF, but these cited NWFP also means for those which are from the Private Registered Land (PRL) or Community Forest Land (CFL).

For the developing countries like Bhutan, NWFP is an imperative natural commodity that can have a great economic benefit to the subsistence farmers in their rural livelihood. It can generate income and seasonal employment opportunity during lean agricultural farming season. For instance in Bhutan, the highlanders of 6 districts involved in collecting *Ophiocordyceps sinensis* from May to June. *O. sinensis* is a Chinese caterpillar (high medicinal value fungus) that can fetch premium price in the available market. Similarly, other NWFP like fibre of Daphne, spike of *Piper longum and Piper peepuloides*, fibre of Pouzolzia, entire creeper of *Rubia cordifolia* and entire parts of *Swertia chirayita* are also economically indispensable for rural livelihood of some rural communities in Bhutan.

NWFP can be considered as a subsidiary means to rural Bhutanese farmer that can improve the rural livelihood. Encouraging in establishment of NWFP enterprises may reduce wildlife trade and has minimum negative impacts on forest ecosystems than timber harvesting. Collectively it can provide social, economic and environmental benefits, particularly in context to managing community forest. The diversified products and income opportunities from forests can be obtained through sustainable management of NWFP comparatively in a shorter span than timber. Meanwhile NWFP harvest through management is the part and partial of most forest management systems in the globe for both commercial and subsistence purposes.

The sustainable management of NWFP will lead offering lots of avenues like markets (for edible mushrooms, ferns top and other types of green vegetable from forest) by establishing linkages with in-house schools, colleges and institutions. "La daam[3]" and "Ri daam[4]" are one of those age-old sets of customary which will be included in the by-laws of sustainable management practice of NWFP or Community Forest and that subsequently adds advantage upon the Protected Areas for natural regeneration and biodiversity conservation of the flora and fauna species. It is not limited within itself but also helps in reducing further acceleration of watershed degradation, soil erosion, landslip or

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[3] Customary restriction to go or enter the mountain or forest through pass as a traditional by-law that has been practicing in the community since generation

[4] Customary restriction to go or enter the water catchment area as a traditional by-law that has been practicing in the community since generation

landslide. The NWFP activity like construction of eco-friendly camp sites, bamboo gazebos or from locally available materials and then promoting eco-tourism will definitely supports the rural local economy contributing a fair percentage to the country's revenue. One of the good examples is the annual matsutake festival held in Ura, Bumthang (central district of the country) during matsutake mushrooms harvesting season. In this festival variety of wild edible mushrooms will be displayed by the local communities with different taste of cuisines prepared out of such mushroom. Among all, most popular mushroom display is *Tricholoma matsutake*. A good number of international and national tourists visit and enjoy the festivity. NWFP trade and its ecotourism activity clearly indicate that NWFP has potential to overcome some economic burdens of the local rural people. FAO (1995) also stated that in fragile ecosystems, integrated development activity of NWFP provides the prospects of earning higher rural incomes and conserve biodiversity. Thus sustainable management and utilization of NWFP resources is becoming a crucial issue that has to be tackled jointly through collaborative action of multi relevant stakeholders. Meanwhile, fundamental sustainable forest management that complements wood-based management provides a holistic sustainable approach for managing forest for NWFP resources.

The global action plan of Agenda 21 which was approved by the UN Conference on Environment and Development (1992) recognizes the function of NWFP in sustainable forest management. It stated that sustainable management of NWFP is important to regard local demand on the forest resources, to consider local knowledge of the forest resources, to involve nearby dwellers as stakeholders in managing and ensuring obligation on sustainable management of the natural resources and to employ local people in their own economic change by incorporating decisions on social, cultural and environmental values. It is a prudent resource use if communities are encouraged to involve in managing local resources equitably and sustainably (ibid).

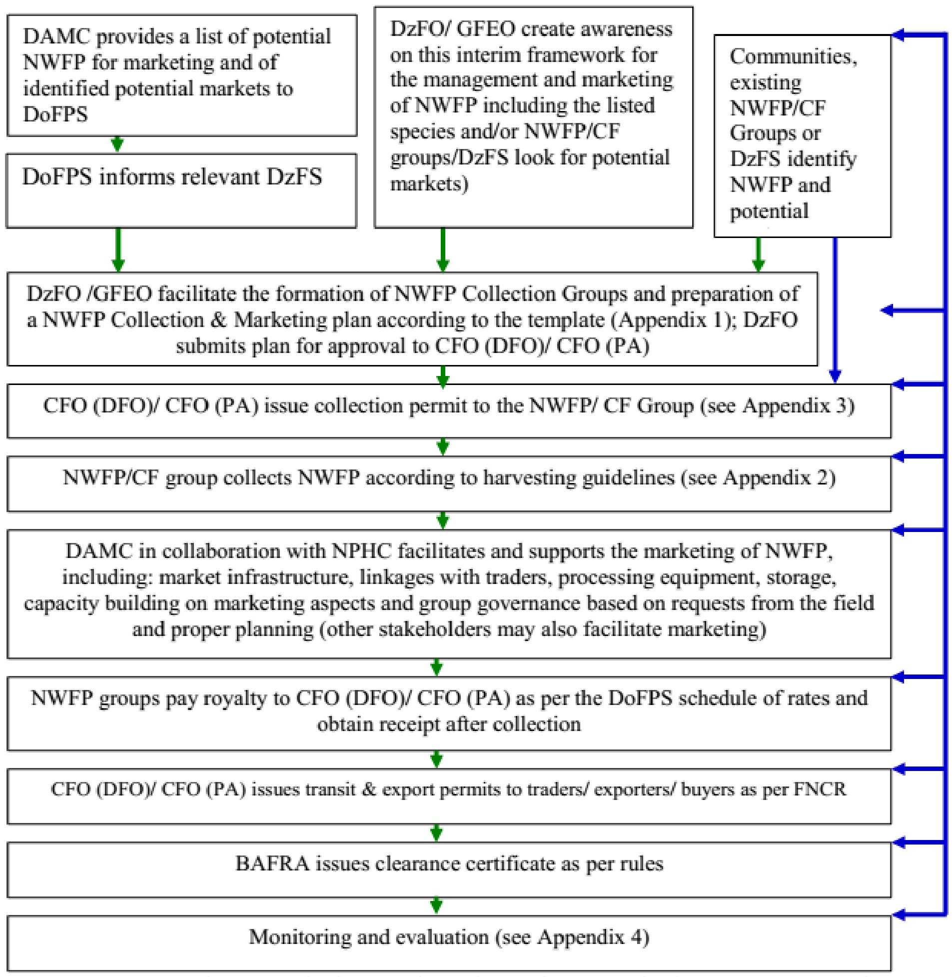
Entailing article is one of the observations in which relevant stakeholders engage in sustainable management of NWFP in south-eastern district of Bhutan for the rural income. Therefore, the **objectives** of this paper are to:

- Determine whether the managed NWFP resources by the rural people is sustainable
- Observe the off-farm income generation from managed NWFP
- Deduce production trend of NWFP and
- Find actual number of NWFP resources beneficiaries of that particular district

II. Policy pertaining to NWFP Development

In 1974, National Forest Policy (NFP) has been accorded as the country's first legislation and policy statements emphasizing protection rather than conservation and sustainable utilization of the forest resources. In-spite of this, the collection of NWFP has been considering by the department of forest on case by case basis. The allowed NWFP to harvest has not been monitored properly instead the permit holders have collected the resources like bamboos, canes (rattan), persea bark indiscriminately. In due course of time, the production of these resources have been declined to that extent that the number of particular persea species has gone declined these days in Bhutan, same status goes to some of the species of bamboos and canes. This situation has occurred just because that there was no appropriate management plan or harvesting guidelines in place for those species. Such practice of exploiting NWFP resources has continued until 2007. In 2006, the government and the Department of Forest have recognized the economic importance of NWFP for the reduction of poverty in the rural areas that has led in organizing the National Stakeholders Workshop for NWFP Programme Development in Bhutan. The resolution of that national workshop has resulted to produce a National Strategy for the Development of NWFP in 2008. This strategy gave access to place Interim Framework for Management and Marketing of NWFP in 2009.

According to the framework, NWFP resources are allowed to manage and utilize through permit, based on community management system (Fig. 1). The individual permit may be considered on a case by case basis, only if the community residing nearby NWFP resources sites given in writing that they don't want to manage the resources, otherwise individual permit will not be considered. With the introduction of Interim Framework for Management and Marketing of NWFP (2009) gave access to harvest 41 NWFP species. The framework is very dynamic due to which, it is revised in 2011 and added 29 more species totaling to 60 NWFP species that are allowed to harvest by the NWFP Farmer Group following the guidelines prescribed in the framework for Management and Marketing of the NWFP. The revised National Forest Policy (2011) also lets sustainable harvesting of NWFP through a management guideline or plan and even in July 2014, the final draft version of Forest and Nature Conservation Rules included a section that describe the sustainable management and utilization of NWFP resources. Because of all these friendly rules and



Note : BAFRA = Bhutan Agriculture and Food Regulatory Authority, CF = Community Forest, CFO (DFO) = Chief Forestry Officer (Divisional Forest Office), CFO (PA) = Chief Forestry Officer (Protected Area), DAMC = Department of Agriculture and Marketing Cooperative, DoFPS = Department of Forests and Park Services, DzFO = Dzongkhag Forestry Officer (Dzongkhag = District), DzFS = Dzongkhag Forestry Services, FNCR = Forest and Nature Conservation Rules, GFEO = Gewog Forestry Extension Officer (Gewog = Block), NPHC = National Post Harvesting Centre, NWFP = Non Wood Forest Product

Figure 1: An overview of the major steps and responsibilities of different while managing, harvesting and trade of NWFP

policies in place, there are more than 99 NWFP Farmer Groups formed as of date to management, utilize and trade varieties of NWFP through sustainable means.

III. An observed district's description

Pemagatshel Dzongkhag is a rural district in southeast part of Bhutan (Fig. 2). The Dzongkhag has total area coverage of 115,913.40 ha, out of which about 88% is covered by forest, 5% of the total land is managed under agricultural farm and the rest (about little bit more than 7%) is comprised of meadows, shrubs, water bodies and others. The Dzongkhag shares its border northwest with Mongar, to northeast Tashigang and to its southeast and southwest with Samdrupjongkhar Dzongkhags. It is positioned at an elevation of 600 to 3,000 m above sea level. It experience monthly maximum average temperature of 20.43 ºC and monthly minimum average temperature of 11.24 ºC with an annual mean temperature of 15.84 ºC. It receives total average annual rainfall of about 2060 mm (NSB, 2013).

Pemagatshel Dzongkhag comprised of eleven Gewogs, viz., Chhimoong, Chhoekhorling, Chongshig, Dechhenling, Dungmaed, Khar, Nanong, Norboogang, Shumar,Yurung and Zobel. It has 56 Chiwog[5] (s) and 157 villages. In total there are 5,254 households out of which 494 households fall in urban and 4,760 households in rural areas accordingly in 2011. The Dzongkhag has total projected population of 24,075 (Males = 11,912 and females = 12,163) and population density estimated to 23 persons per Km^2 (ADS, 2011).

It has temperate climatic condition, hot at lower altitude in summer and cold breeze in winter. The practice of shifting cultivation can be observed in most of the cultivated land. The staple crop of the place is maize. The cash crop like potatoes, oranges, varieties of vegetables and other subtropical fruits like, banana, guava, jackfruit, litchi, mango, papaya, passion, pear, pineapple, pomegranate, walnut and water-melon are also grown.

Therefore, the major sources of income for the people of Pemagatshel are agriculture, small scale of horticulture and livestock farming. While in lean farming season, NWFP provides off-farm income and also the gypsum mining and the gypsum power factory at Khothakpa under Shumar Gewog provide employment for unskilled laborers in the off season. Further, some of the farmers engage in weaving Bhutanese clothes which is also a source off-farm income.

[5] Sub-block

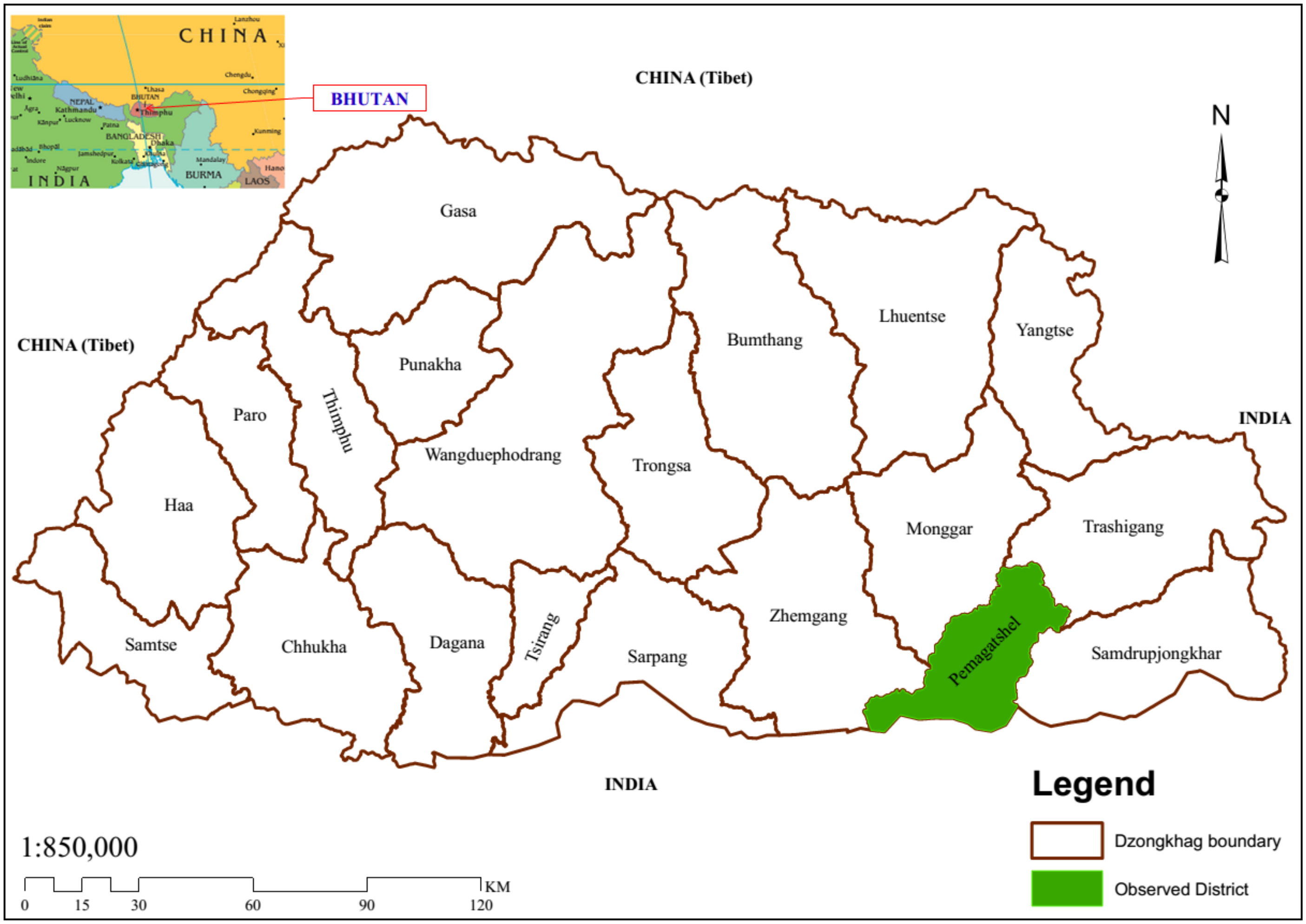


Figure 2: An Observation Area Map

IV. Methods

A series of primary data was collected from the observed district through semi-structured interview and key informant interview with the Dzongkhag Forest Officer. A team comprising from Department of Agriculture and Marketing Cooperative and Dzongkhag Forestry Sector including Gewog Forestry Extension Office under Ministry of Agriculture and Forests were involved for information recording at times of the entire auctioning process. A total of six (6) years data was gathered (2008-2013) for analysis and deducing overall findings and conclusion of the products harvested.

The number of available literatures, reports, documents and news articles were also reviewed extensively to ascertain the information appropriateness and present in this observed field article.

V. Data analysis

The collected data were compiled in Microsoft Office Excel (MS Excel) spreadsheet. For presentation and analysis, MS Excel spreadsheet table, frequency table like graph were used. Further, to determine year-wise production trend and its relationship, statistic tool like exponential linear regression was employed using same MS Excel spreadsheet.

VI. Result and discussion

a. Result

Figure 3: Rural poor farmer

Bhutan Poverty Analysis Report (2012) stated that five districts of Bhutan have been surveyed as the poorest districts in Bhutan. One of them is Pemagatshel and others are Dagana, Lhuentse, Samtse and Zhemgang districts. The national poverty line established at Nu.1,704.84 per person per month, which means households with per capita real consumptions below the poverty line are said to be poor whose consumption expenses is inadequate. With this calculation, it is deduced 12% of the total Bhutan population is categorized as poor. As compared to other poor districts, Pemagatshel has a significant numbers of rural populations recorded under the national poverty-line. Thus, to such section of the rural people, NWFP species are indispensable to comfort their livelihood. Till date the district has 14 NWFP Farmer Groups which are comprised of 465 rural households to manage, utilize and market the NWFP species that are available from the designated and allocated Government Reserved Forest (GRF) areas in the name of the group. From such nearby allocated GRF sites, the local people (only the members of the NWFP Farmer Group) harvest bark / fibre of Daphne spp.; spikes of *Piper longum, Piper pedicellatum and Piper peepuloides;* bark or fibre of Pouzolzia spp.; entire creeper of *Rubia cordifolia* and entire plant of *Swertia chirayata*. The people do manage these products by following the guidelines prescription prescribed in the NWFP management plan template prepared jointly by the community, GFEO and DzFS. As per the record, such NWFP Farmer Groups has benefitted to about 4,000 rural heads.

Table 1: Year-wise sale of NWFP species for income generation

Source: DzFS, Pemagatshel, 2014.

Year	NWFP Species	Quantity sold (Kg)	Average Rate (Nu.) / Kg	Average Total Amount (Nu.)
2008	Daphne spp.	0.00	0.00	0.00
	Piper longum	0.00	0.00	0.00
	Piper pedicellatum	0.00	0.00	0.00
	Piper peepuloides	0.00	0.00	0.00
	Pouzolzia spp.	0.00	0.00	0.00
	Rubia cordifolia	1427.00	20.00	28540.00
	Swertia chirayata	0.00	0.00	0.00
2009	Daphne spp.	0.00	0.00	0.00
	Piper longum	0.00	0.00	0.00
	Piper pedicellatum	0.00	0.00	0.00
	Piper peepuloides	0.00	0.00	0.00
	Pouzolzia spp.	739.00	30.00	22170.00
	Rubia cordifolia	0.00	0.00	0.00
	Swertia chirayata	168.00	30.00	5040.00
2010	Daphne spp.	0.00	0.00	0.00
	Piper longum	0.00	0.00	0.00
	Piper pedicellatum	0.00	0.00	0.00
	Piper peepuloides	0.00	0.00	0.00
	Pouzolzia spp.	960.00	25.00	24000.00
	Rubia cordifolia	1657.00	30.00	49710.00
	Swertia chirayata	5.00	40.00	200.00
2011	Daphne spp.	2300.00	40.00	92000.00
	Piper longum	380.00	99.47	37798.60
	Piper pedicellatum	810.50	50.00	40525.00
	Piper peepuloides	0.00	0.00	0.00
	Pouzolzia spp.	422.00	25.00	10550.00
	Rubia cordifolia	2103.00	39.57	83215.71
	Swertia chirayata	136.00	40.00	5440.00
2012	Daphne spp.	0.00	0.00	0.00
	Piper longum	1111.20	102.13	113486.86
	Piper pedicellatum	462.25	40.00	18490.00
	Piper peepuloides	2328.50	187.83	437362.16
	Pouzolzia spp.	1812.00	15.99	28973.88
	Rubia cordifolia	980.00	25.00	24500.00
	Swertia chirayata	32.00	40.00	1280.00
2013	Daphne spp.	1379.00	40.00	55160.00
	Piper longum	13.00	150.00	1950.00
	Piper pedicellatum	0.00	0.00	0.00
	Piper peepuloides	0.00	0.00	0.00
	Pouzolzia spp.	9.00	30.00	270.00
	Rubia cordifolia	2969.50	30.00	89085.00
	Swertia chirayata	84.00	40.00	3360.00

Table 1 in above page presents a year-wise income generation from the sale of different NWFP species, viz. Daphne spp., *Piper longum, Piper pedicellatum, Piper peepuloides,* Pouzolzia spp., *Rubia cordifolia* and *Swertia chirayata* by the rural farmers of Pemagatshel Dzongkhag. The data recorded started from 2008 and in which year farmers have earned Nu.28,540.00 from the sale of *Rubia cordifolia*. In 2009, the highest sale of Nu.22,170.00 received from Pouzolzia spp. And the lowest one from *Swertia chirayata* Nu.5,040.00. Likewise in 2010, sale of *Rubia cordifolia* fetched the highest with about Nu.49,000.00, second highest by Pouzolzia spp. with about Nu.24,000.00 and the lowest of Nu.200.00 from the sale of *Swertia chirayata.* In 2011, the highest income received from the sale of Daphne spp. with about Nu.92,000.00 followed by *Rubia cordifolia* with about Nu.83,000.00 and the last being by *Swertia chirayata* with about Nu.5,440.00.Yearly the NWFP species added up for collection by the farmers. So in 2012, *Piper peepuloides* sale was amounted to about Nu.400,000.00 followed by *Piper longum* with about Nu.100,000.00 and the lowest by the sale of *Swertia chirayata* with about Nu.1,280.00. Similarly in 2013, the highest earning obtained from the sale of *Rubia cordifolia* with about Nu.89,000.00 followed by Daphne spp. with about Nu.55,000.00 and the lowest amount of about Nu.270.00 from the sale of Pouzolzia spp.

Among all NWFP species in Pemagatshel, *Rubia cordifolia* and *Swertia chirayata* maintain the continuity supply for four years and by Pouzolzia three years respectively within a span of six years. But, in the year 2012 the highest income generated was from the sale of *Piper peepuloides* followed by the *Piper longum*.

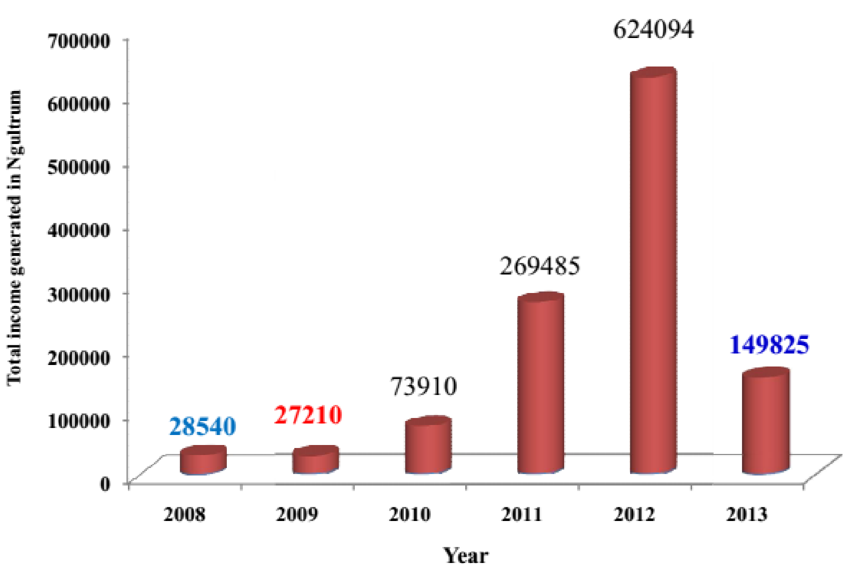


Figure 4: Total income generated by the NWFP Farmer Groups

Figure 4 shows a total income generated by the NWFP Farmers Groups by harvesting and selling 7 different NWFP species (As stated in previous paragraphs) in the form of raw products in the available existing market. The income generated showed from the year 2008 till 2013. In 2008, the NWFP Farmer Group has started and earned only Nu.28, 540.00, the lowest earning was Nu.27210.00 in 2009. The highest showed in 2012 with about Nu.624, 094.00. By observing at this figure, it can be determined that the trend is quite erratic because in 2013 the group didn't sell the spike of *P. longum* and *P. pedicellatum* as they have not collected. But in overall comparison, the income trend looks quite positive if neglect an income of 2009 which has hardly any difference with that of baseline data of 2008.

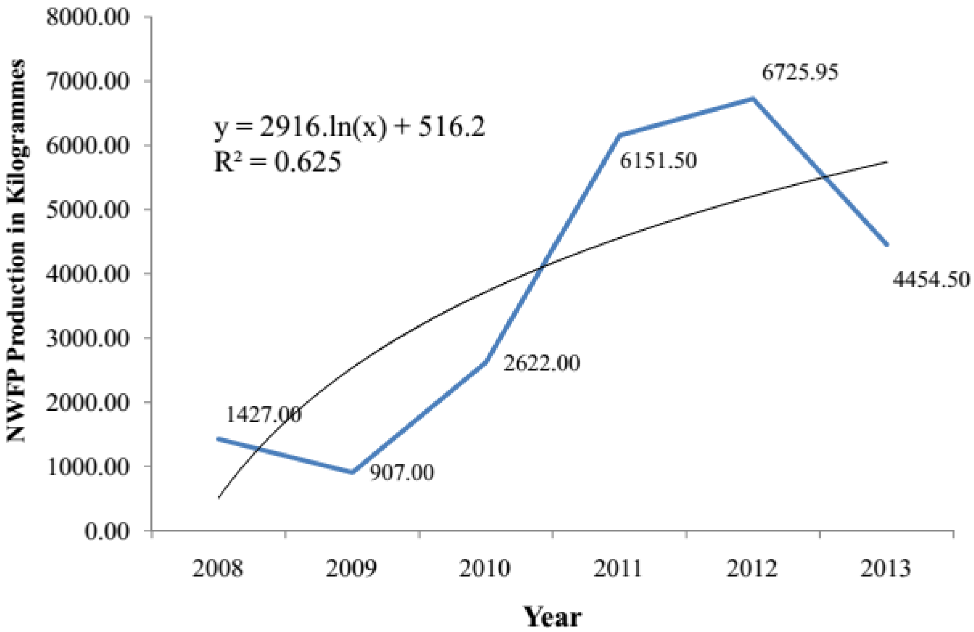


Figure 5: Year-wise total productions of NWFP in Kilogrammes

Figure 5 shows year-wise total production of all NWFP species that are collected and sold by the 14 NWFP Farmer Groups of Pemagatshel. The production data of 2008 is being kept as baseline data for rest of the production year. According to this figure maximum production was seen in 2012 with a total quantity of 6,725.95 Kg followed by 6,151.50 Kg in 2011 and the lowest being in the year 2009 with 907 Kg. In 2009 the farmers have not harvested 5 NWFP species which were Daphne spp., *Piper longum, Piper pedicellatum, Piper peepuloides, and Rubia cordifolia.* Similarly in 2013 too, the group didn't collect the spike of *P. longum* and *P. pedicellatum* (Fig.4). However, prediction in figure 5 is a model of linear regression with an exponential growth of production trend line where R^2 = 0.625 and y = 2916*ln(x) + 516.20. This model along with exponential trend line indicated that the annual production of NWFP is quite smooth except for the year 2009 as compare to baseline data of 2008. Otherwise, the production trend line grows positively determining the sustainability of the seven NWFP species that has been managing by the rural people of the district Pemagatshel.

b. Discussion

The poor section of people gives much importance and do value for Non Wood Forest Products and its resources. Poor households usually collect NWFP and earning from its trade, supplement the family income at the most critical period (Sharma, 1995). Thus, such people know how to manage NWFP and in judicious manner. After the introduction of Interim Framework for Management and Marketing of NWFP, the financial (generation of income from off-farm) situation of the rural people especially that of poor districts has been improved significantly. As Mukhia and Rai (2012) pointed out that other NWFP like *Ophiocordyceps sinensis* does impacted financially a lot to the highlanders of Bhutan and most of these highlanders come from other districts of Bhutan which do not fall under poverty districts. Mukhia, Rai and Wangmo (2013) also stated that the diverse NWFP species provide subsistence livelihood to economically disadvantaged people of Dagana which is also accounted as most poor district in Bhutan. Also NWFP is an important means for livelihood to people of peri-urban, urban and traders in the available markets. It plays a vital role of activity in any economic scenario thus, it is crucial to manage the resources sustainably. FAO (NWFP 7, 1995) expressed to recognize the traditional management systems of forest peoples and modern scientific experience for multiple-use management can yield both timber and non wood harvests on a sustainable basis if careful planning and monitoring of forests resources is done. Management of forest for NWFP resources can provide a sustaining source of livelihood and facilitate to uphold the forest resource for future generations. The dynamic integrated forest policy and rules should be the driving force for both development and management of NWFP resources within a sustainable forest management system.

Table 1 clearly indicated that, with the introduction of Interim Framework for management and marketing of the NWFP in 2009, there was an increased of NWFP yields along with its economic activities. It is significant that people in the observed district has been gained financially through such off-farm resource used (Fig.4). The resource sustainability predicted by linear regression is relatively strong. That determines the forest policy and resource planning and management is functioning considerably well (Fig.5).

VII. Conclusion

The sustainable management of forest for NWFP resources is very much critical for enjoying the resources by the people who dwells nearby the forest areas. The poor section of people with an appropriate guidance from the concerned authority would be the best possible means to manage any natural resources in a more sustainable manner. It is found out that the rural people of Pemagatshel, who are the members of NWFP Farmer Groups, have been considerably profited in financial term through sustainable use of available NWFP resources. This demonstrated that NWFP resources have a momentous potential to lessen rural poverty economically through self employment in NWFP economic activity during lean agricultural farming period. The financial flow due to NWFP resources for the last 6 years illustrated abruptly but, it is a positive trend of development in comparison to the starting year 2008. The exponential production trend of NWFP is pretty encouraging and satisfactory as it is deduced through the presentation of strong regression relationship among and between the production periods.

It can be concluded that, NWFP resources has been managing by the rural people of Pemagatshel is relatively sustainable benefitting prominently as an off-farm income to the community members of the NWFP Farmer Groups. It is construed that about 17% of the entire district population have been taking advantage out of the sustainable management, utilization and trade of the available Non Wood Forest Product resources in outskirt habitation of the Government Reserved Forests areas.

Lesson learnt out of the field observation

- Place-in policy has to be dynamic
- Roadmap, strategy and regulation should be the driving tools for sustainable development
- Management plan and guidelines should be the guiding tools for implementation of any policy
- Collaboration among relevant stakeholders is crucial in the issue of sustainability
- Willingness and participation of the community group must has to be an ideal situation to conserve the natural resources
- Rural poor communities easily motivated for the sustainable management of any natural resources
- Above all good governance is must in order to achieve the sustainability and to reduce poverty in the country

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Butterfly Diversity Of Dzamling Norzoed Community Forest, Tsirang, Bhutan – A Priliminary Study

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Abstract

A total of 116 species of butterflies distributed in five families have been reported from Dzamling Norzoed Community Forest, Tsirang district (Bhutan). *Nymphalidae* was the dominant family with 58 species in 10 subfamilies. *Lycaenidae* represented by 22 species, *Hesperiidae* by 15 species, *Pieridae* by 12 species and *Papilionidae* by 9 species respectively.

Key words: Dzamling Norzoed Community Forest, Butterfly, Tsirang, Bhutan, Indian Wildlife (Protection) Act.

I. Introduction

Dzamling Norzoed Community forest (DNCF) is located in Mendrelgang Block of Tsirang District of Bhutan. It is spread over 146.66 acres at an altitude of 200 to 1500 masl. It was declared as Community Forest in 2012 by Department of Forests and Park Service, Ministry of Agriculture and Forests, Royal Government of Bhutan to maintain and improve the biodiversity and ecological functions of forest land; sustainable supply of forest products and services in order to enhance the self-sufficiency; and improve the economy and living standard of local people and improve communal institutions that can sustainably manage forestlands in Bhutan (BAPFC, 2002).

The area has abundant flora and fauna. The vegetation consists of tropical broadleaf trees, shrubs, herbs, bamboos, wild banana along with horticultural (orange, guava) orchards and agricultural fields (paddy, maize). The region has variety of insects majority of them belongs to lepidoptera. The area is home for Gee's Golden Langur (*Trachypithecus geei*) and Great Hornbill (*Buceros bicornis*) which are protected under Forest and Nature Conservation Act 1995 of Bhutan, 1995.

Despite an area with rich biodiversity of flora and fauna, the area remains poorly documented in terms of butterfly community and hence lack data and information. There are no published data on the butterfly diversity of this region except Singh et.al. (2014) who reported 125 species of butterflies from the other parts of Tsirang district. The nearest records comprise the records of 213 species of butterflies by Singh (2012) in the lowland forest of Sankosh river catchment as a part of the biodiversity impact assessment for the proposed Sankosh hydroelectric power project. The present study provides baseline data on butterfly fauna of DNCF.

II. Materials and Methods

DNCF was surveyed for butterfly fauna during 2012 to 2014 in the months of July to October every year. The survey was conducted every Sunday between 10.00 - 15.00 hrs. however observations were made for the entire day if required. The butterflies were observed along paths inside and outside the forest and along streams. They were observed on both sides of the paths. Butterflies were caught in the net whenever required, identified and released. In case of uncertain identity photographs were taken.

The identification was done with the keys of Bingham (1905), Evans (1932), Talbot (1939, 1947), Wynter Blyth (1957), Smith (2006), van der Poel & Wangchuk (2007), Kehimkar (2008) and internet references (www.flutters.org; www.ifoundbutterflies.org). The classification follows Kehimkar (2008). Their status was decided on visual observations as common (C), very common (VC), not common (NC), rare (R), very rare (VR). This status does not correlate to the entire geographical distribution status of a corresponding species.

III. Results and discussion

A total of 116 species distributed in five families have been identified from the study area. The recorded species belongs to 82 genera representing in 22 subfamilies and are illustrated in *Appendix 1*. Nymphalidae was the dominant family with 58 species (49.6 %) followed by Lycaenidae 20 species (21.3%), Hesperiidae 15 species (16.0%), Pieridae 12 species (10.6%). The Papilionidae family was the least diverse with 9 species (7.4%) (Fig 2). Among 21 subfamilies recorded, Nymphalidae distributed in 10 subfamilies while Papilionidae in only 1 subfamily. Nymphalidae dominated the list by having most Rare (13 species) and Very rare (6 species) status (Plate 3). 28 species of butterflies are added to the known list of butterflies recorded by Singh (2012) and Singh et al. (2014) from lowland forest of Sankosh river and Tsirang district during the present study.

14 species of the butterfly from the DNCF were covered under protected species category of Indian Wildlife (Protection) Act (IWPA), 2002 like *Allotinus drumila* ***drumila (Plate 3A) comes under schedule I of the Act while*** *Aemona amathusia amathusia* ***(Plate 3B)***, *Melanitis zitenius zitenius* ***(Plate 3C)***, *Lethe sinorix sinorix* ***(Plate 3D)***, *Euthalia durga durga* ***(Plate 3E)***, *E. nara nara* ***(Plate 3F)***, *Spindasis lohita himalayanus* ***(Plate 3G)***, *Lampides boeticus* ***(Plate 3H)***, *Orthomiella pontis pontis* ***(Plate 3I)***, *Halpe homolea filda* ***(Plate 3J)*** comes under schedule II of the Act. *Euploea mulciber mulciber* ***(Plate 3K)***, *Euthalia lubentina* ***(Plate 3L)***, *Pelopidas assamensis* ***(Plate 3M)***, *P. sinensis* ***(Plate 3N)*** are also protected species under the schedule IV of the IWPA but none of these butterfly species are included in the protected list of Forest and Nature Conservation Act 1995 and Forest and Nature Conservation Rules of Bhutan 2006. Globally rare species like *A. a. amathusia, M. z. zitenius, L. s. sinorix, E. d. durga, E. sahadeva* ***(Plate 3O)***, *E. n. nara, A. d. drumila* and *O. p. pontis* were observed during the survey in the study area. These indicates the importance of extensive survey of butterfly fauna in the area to find out the species of conservation importance.

Table 1: Family composition of butterflies recorded from DNCF

Sl. No.	Family	No. of Species	%	Sub families	Status				
					VC	C	NC	R	VR
1.	Nymphalidae	58	50	10	9	15	15	13	6
2.	Papilionidae	9	7.8	1	1	2	2	4	-
3.	Pieridae	12	10.3	2	5	1	3	3	-
4.	Lycaenidae	22	19	6	4	4	8	4	2
5.	Hesperiidae	16	12.9	2	2	4	1	5	3
TOTAL		**116**	**100**	**21**	**21**	**26**	**29**	**29**	**11**

IV. Conclusion:

The preliminary survey of butterfly fauna in DNCF specifies many significant butterfly species which have conservation importance. This specifies that additional systematic research is necessary for getting a comprehensive data of the faunal diversity of butterfly in this area. Study on species specific details covering biology, host plant preferences, ecological requirements are necessary for adopting appropriate conservation strategies and focus on conservation of rare and endangered species. Such work may lead to the development of standard conservation and monitoring guidelines which could be of value in assessing the environmental stability of habitats in whole ecosystem and to predict the effect on the structure of butterfly populations. Further it may help to pay special attention to specific threatened species.

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Appendix 1. Species composition of butterflies recorded from DNCF during the survey.
(¥ - IWPA Schedule I, Ψ- IWPA Schedule II, # - IWPA Schedule IV)

Family/Subfamily	Species	Status
A. Family: Nymphalidae		
Libytheiinae	1. *Libythea myrrha sanguinalis* Fruhstorfer (Club Beak)	**C**
Danaidae	2. *Euploea mulciber mulciber* Cramer (Striped Blue crow) #	**NC**
	3. *Parantica aglea melanoides* Moore (Plain Tiger)	**C**
	4. *Parantica sita sita* Kollar (Chestnut Tiger)	**NC**
	5. *Parantica **melaneus plataniston*** Fruhstorfer (Chocolate Tiger)	**R**
	6. *Danaus chrysippus chrysippus* Linnaeus (Plain Tiger)	**C**
Charaxinae	7. ***Charaxes athamas athamas*** Drury (Common Nawab)	**C**
Morphinae	8. *Aemona amathusia amathusia* Hewitson (Yellow Dryad) Ψ	**VR**
Satyrinae	9. *Melanitis zitenius zitenius* Herbst (Great Evening Brown) Ψ	**NC**
	10. *Lethe mekara* Moore (Common Red Forester)	**NC**
	11. *Lethe sinorix sinorix* Hewitson (Tailed Red Forester) Ψ	**NC**
	12. *Lethe confusa confusa* Aurivillius (Banded Treebrown)	**C**
	13. *Lethe rohria rohria* Fabricius (Common Treebrown)	**C**
	14. *Mycalesis **perseus blasius*** Fabricius (Common Bushbrown)	**NC**
	15. *Mycalesis francisca sanatana* Moore (Lilacine Bushbrown)	**VC**
	16. *Mycalesis visala visala* Moore (Long-Brand Bushbrown)	**VC**
	17. *Ypthima baldus baldus* Fabricius (Common Five ring)	**C**
Heliconiinae	18. *Acraea issoria **issoria*** Hübner (Yellow Coster)	**VC**
	19. *Cethosia biblis tisamena* Fruhstorfer (Red Lacewing)	**C**
	20. *Cethosia cyane cyane* Drury (Leopard Lacewing)	**C**
	21. *Cirrochroa aoris aoris* Doubleday (Large Yeoman)	**VC**
	22. *Childrena childreni childreni* Gray (Large Silverstripe)	**R**
	23. *Argynnis hyperbius hyperbius* Linnaeus (Indian Fritillary)	**NC**
	24. *Vindula erota* Fabricius (Cruiser)	**NC**
Limenitinae	25. *Moduza procis* Cramer (Commander)	**VR**
	26. *Athyma ranga ranga* Moore (Blackvein Sergeant)	**NC**
	27. *Athyma perius perius* Linnaeus (Common Sergeant)	**R**
	28. *Athyma cama cama* Moore (Orange Staff Sergeant)	**R**
	29. *Athyma selenophora **selenophora*** Kollar (Staff Sergeant)	**C**
	30. *Pantoporia hordonia hordonia* Stoll (Common Lascar)	**R**
	31. *Neptis clinia* Moore (Clear Sailer)	**NC**
	32. *Neptis sappho **astola*** Moore (Pallas Sailer)	**C**
	33. *Neptis pseudovikasi* Moore (False Dingy Sailer)	**R**
	34. *Euthalia durga durga* Moore (Blue Duke) Ψ	**R**
	35. *Euthalia phemius* Doubleday (White-Edged Blue Baron)	**R**
	36. *Euthalia sahadeva* Moore (Green Duke)	**R**
	37. *Euthalia nara nara* Moore (Bronze Duke) Ψ	**VR**
	38. *Euthalia lubentina* Cramer (Gaudy Baron) #	**R**

	39. *Tanaecia julii* Lesson (Common Earl)	**R**
	40. *Abrota ganga ganga* Moore (Sargeant Major)	**VR**
	41. *Parasarpa zayla zayla* Doubleday (Bicolour Commodor)	**VR**
Cyrestinae	42. *Cyrestis thyodamas thyodamas* Boisduval (Common Map)	**C**
	43. *Pseudergolis wedah wedah* Kollar (Tabby)	**NC**
	44. *Dichorrhagia nesimachus nesimachus* Doyere (Constable)	**VR**
	45. *Stibochiona nicea nicea* Gray (Popinjay)	**NC**
Apaturinae	46. ***Rohana parisatis parisatis*** Westwood (Black Prince)	**C**
	47. *Euripus nyctelius nyctelius* Doubleday (Courtesan)	**R**
	48. *Herona marathus marathus* Doubleday (Pasha)	**NC**
Nymphalinae	49. *Symbrenthia lilaela khasiana* Moore (Common Jester)	**VC**
	50. *Symbrenthia hypselis* Godart (Himalayan Jester)	**NC**
	51. *Vanessa indica indica* Herbst (Indian Red Admiral)	**VC**
	52. *Vanessa cardui* Linnaeus (Painted Lady)	**C**
	53. *Aglais cashmiriensis aesis* Fruhstorfer (Indian Tortoiseshell)	**C**
	54. *Junonia iphita iphita* Cramer (Chocolate Pansy)	**VC**
	55. *Junonia orithya ocyale* Hubner (Blue Pansy)	**VC**
	56. *Doleschallia bisaltide* Cramer (Autumn Leaf)	**VC**
	57. *Hypolimnas bolina* ***jacintha*** Drury (Great Eggfly)	**R**
	58. *Kallima inachus inachus* Boisduval (Orange Oak leaf)	**NC**
Family: Papilionidae		
Papilioninae	59. *Papilio bianor polyctor* Boisduval (Common Peacock)	**VC**
	60. *Papilio polytes stichioides* Evans (Common Mormon)	**C**
	61. *Papilio nephelus chaon* Westwood (Yellow Helen)	**NC**
	62. *Papilio paris paris* Linnaeus (Paris Peacock)	**C**
	63. *Papilio memnon agenor* Linnaeus (Great Mormon)	**NC**
	64. *Graphium antiphates pompilius* Fabricius (Fivebar Swordtail)	**R**
	65. *Graphium cloanthus cloanthus* Westwood (Glassy bluebottle)	**R**
	66. *Graphium agamemnon agamemnon* Linnaeus (Tailed Jay)	**R**
	67. *Troides helena cerbus* Felder & Felder (Common Birdwing)	**R**
Family: Pieridae		
Coliadinae	68. *Eurema hecabe hecabe* Linnaeus (Common Grass Yellow)	**VC**
	69. *Eurema blanda silhetana* Wallace (Three Spot Grass Yellow)	**VC**
Pierinae	70. *Ixias pyrene pirenassa* Linnaeus (Yellow Orange Tip)	**VC**
	71. *Hebomoia glaucippe glaucippe* Linnaeus (Great Orange Tip)	**NC**
	72. *Ceporia nadina nadina* Lucas (Lesser Gull)	**C**
	73. *Pieris canidia indica* Evans (Indian Cabbage White)	**VC**
	74. *Pieris brassicae nepalensis* Doubleday (Large Cabbage White)	**VC**
	75. *Pontia daplidice moorei* Röber (Bath White)	**R**
	76. *Leptosia nina nina* Fabricius (Psyche)	**R**
	77. *Delias descombesi descombesi* Boisduval (Red Spot Jezebel)	**NC**
	78. *Delias acalis pyramus* Wallace (Red-Base Jezebel)	**NC**
	79. ***Prioneris thestylis thestylis*** Doubleday (Spotted Sawtooth)	**R**
Family: Lycaenidae		
Miletinae	80. *Miletus chinensis assamensis* Doherty (Common Brownie)	**NC**
	81. *Allotinus drumila* ***drumila*** Moore (Great Darkie) ¥	**NC**
Curetinae	82. *Curetis bulis bulis* Westwood (Bright Sunbeam)	**NC**
Theclinae	83. ***Remelana jangala ravata*** Moore (Chocolate Royal)	**R**
	84. *Zeltus amasa amasa* Hewitson (Fluffy Tit)	**NC**
	85. *Spindasis lohita himalayanus* Moore (Long-Banded Silverline) Ψ	**NC**
Lycaeninae	86. *Heliophorus epicles indicus* Fruhstorfer (Purple Sapphire)	**VC**
Polyommatinae	87. *Caleta elna noliteia* Fruhstorfer (Elbowed Pierrot)	**NC**
	88. *Castalius rosimon rosimon* Fabricius (Common Pierrot)	**NC**

	89. *Petrelaea dana* de Niceville (Dingy Lineblue)	**NC**
	90. *Leptotes plinius plinius* Fabricus (Zebra Blue)	**C**
	91. *Prosotas nora* ***ardates*** Moore (Common Lineblue)	**R**
	92. *Jamides alecto* C&R Felder (Metallic Cerulean)	**C**
	93. *Jamides bochus* Stoll (Dark Cerulean)	**C**
	94. *Lampides boeticus* Linnaeus (Pea Blue) Ψ	**C**
	95. *Pseudozizeeria maha maha* Kollar (Pale Grass Blue)	**VC**
	96. *Acytolepis puspa gisca* Fruhstorfer (Common Hedge Blue)	**R**
	97. *Orthomiella pontis pontis* Buttler (Straightwing Blue) Ψ	**VR**
Riodininae	98. *Abisara chela chela de Niceville* (Spot Judy)	**R**
	99. *Abisara fylla* Westwood (Dark Judy)	**VC**
	100.*Stiboges nymphidia nymphidia* Guerin (Columbine)	**VR**
	101.*Zemeros flegyas indicus* Fruhstorfer (Punchinello)	**VC**
Family: Hesperiidae		
Pyrginae	102.*Pseudocoladenia dan fabia* Evans (Fulvous Pied Flat)	**C**
	103.*Tagiades litigiosa litigiosa* Moschler (Water Snow Flat)	**NC**
Hesperiinae	104.*Oriens goloides* Moore (Smaller Dartlet)	**C**
	105.*Potanthus dara* Kollar (Himalayan Dart)	**R**
	106.*Potanthus pseudomaesa cleo* Evans (Common Dart)	**C**
	107.*Potanthus nesta* Evans (Sikkim Dart)	**VR**
	108.*Telicota bambusae bambusa* Moore (Dark Palm Dart)	**VR**
	109.*Pelopidas sinensis* Mabille (Banded Swift) #	**R**
	110.*Pelopidas assamensis* de Niceville (Great Swift) #	**VR**
	111.*Iambrix salsala salsala* Moore (Chestnut Bob)	**VC**
Heteropterinae	112.*Notocrypta curvifascia* Felder& Fleder (Restricted Demon)	**C**
	113.*Udaspes folus* Cramer (Grass Demon)	**VC**
	114.*Aeromachus stigmatus* Moore (Veined Scrub Hopper)	**R**
	115.*Halpe homolea filda* Evans (Absent Ace)Ψ	**R**
	116.*Borbo cinnara* Wallace (Rice Swift)	**R**

Plate 1. Sign board and forest habitat in the study area (Photo by: Irungbam Jatishwor Singh; Photo (iv) by Meenakshi Chib)

Plate 2. Papilio bianor polyctor gully bottoming on roadside stream inside DNCF (Photo by: Irungbam Jatishwor Singh)

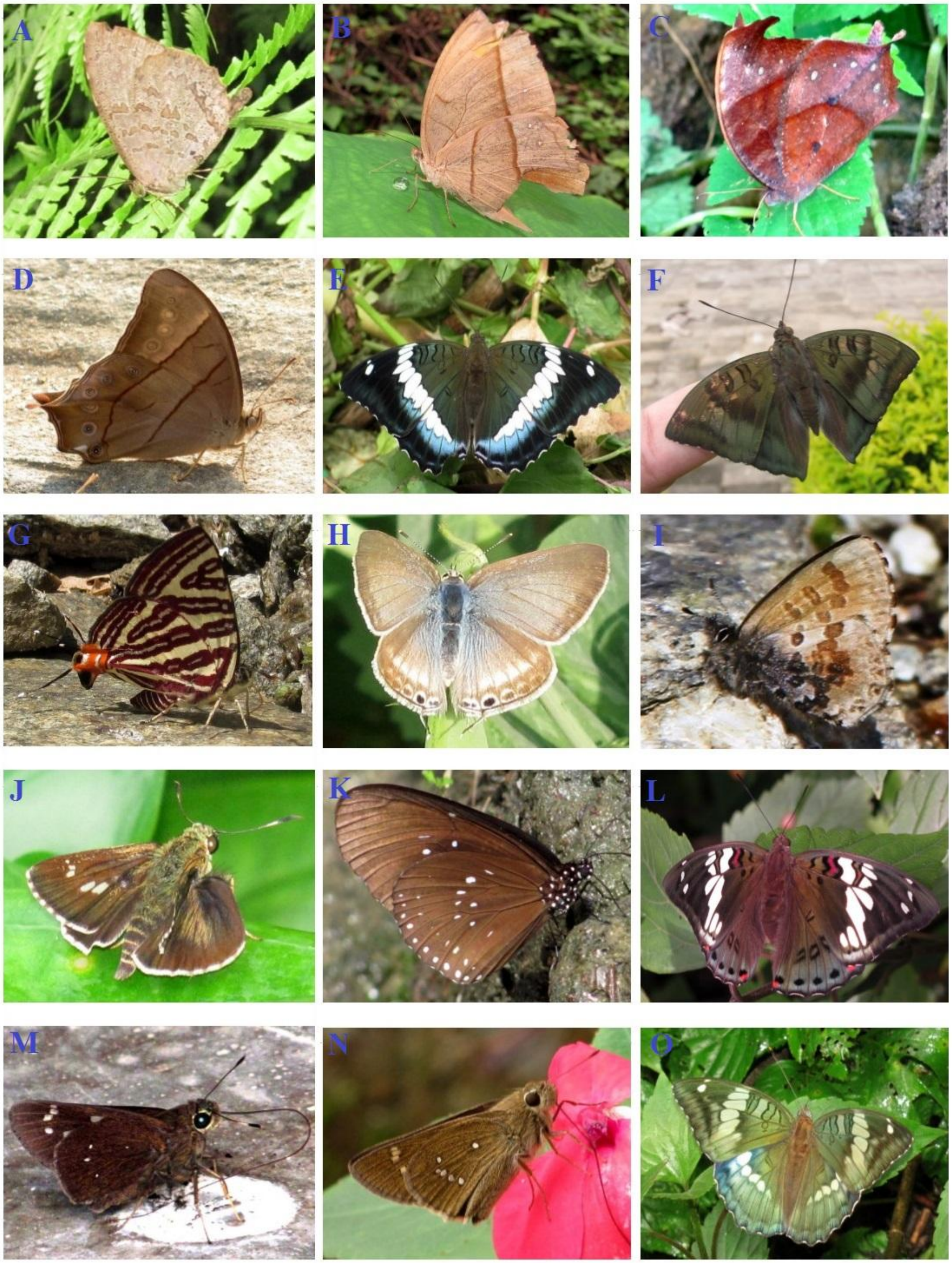

Plate 3. Butterflies protected under IWPA (2002) recorded from study area. A. A. d. drumila, B. A. a. amathusia, C. M. z. zitenius, D. L.s. sinorix, E. E. d. durga, F. E. n. nara, G. S. l. himalayanus, H. L. boeticus, I. O. p. pontis, J. H. h. filda, J. E. m. mulciber, K. E. lubentina, J. P. assamensis, K. P. sinensis, L. E. sahadeva. (Photo by: Irungbam Jatishwor Singh; Plate 3 (I) by Bhakta Ghalley)

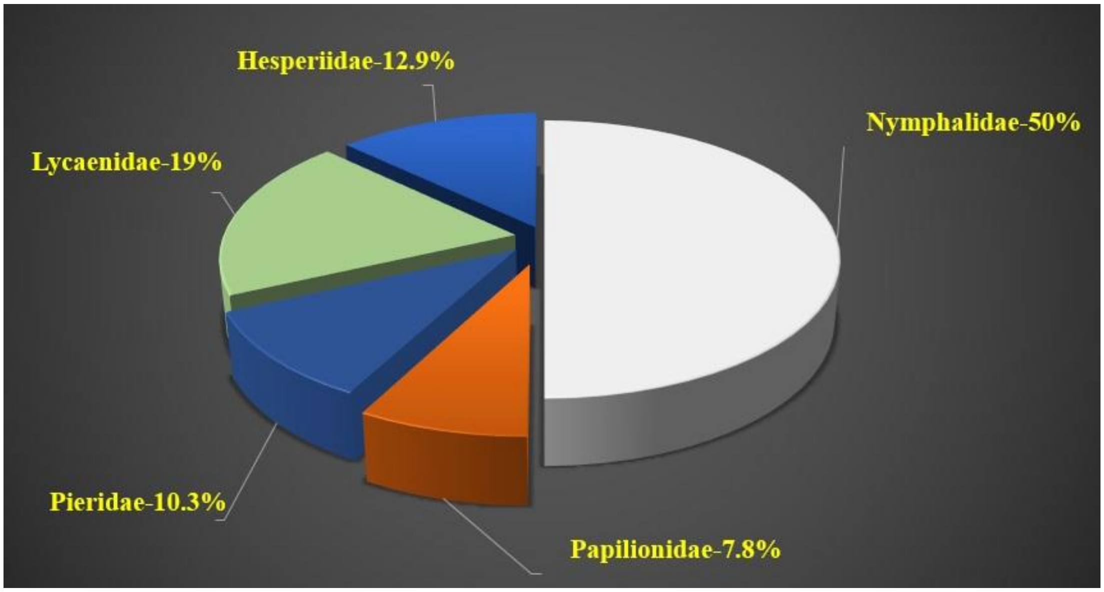

Figure 6. Percentage of butterfly species recorded in different families.

Figure 7. Status wise distribution of butterflies recorded from DNCF.

Economic Valuation of the role of Forests in providing Water Supply to the people of Kohima town, Nagaland, India

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Abstract

Water is now considered as the most important goods or services provided by the forests to the mankind. Forests are now considered more as a source of water than timber in most parts of the world. A study was undertaken in Kohima, the capital town of Nagaland, India, where the rivers and streams, which provide water supply to the people of Kohima town, originate from forests owned by the communities. Valuation of forest for providing water supply was undertaken based on the willingness of the people of Kohima town to pay for protection and conservation of these forests. Respondents were also asked to reveal their WTP for making payment to the communities for keeping such forests intact. These issues have been discussed in detail in the present paper.

I. Introduction

Nagaland is one of the seven sisters' states of Northeast India, which was formally inaugurated on December 1st, 1963, as the 16th state of Indian Union. It is bounded by Assam in the West, Myanmar on the East, Arunachal Pradesh and part of Assam on the North and Manipur on the South. The population of the state is 19,80,602, of which 14,06,861 (71.03%) and 5,73,741 (28.97%) people reside in rural and urban areas, respectively (Census, 2011). There are 16 tribes in Nagaland. The major tribes include Angami, Ao, Chakesang, Lotha, Naga, Rengma, Sangtam, Sema and Zeliang. Each of them traditionally occupies a distinct area of the state. The Angami and Rengma are the predominant tribes who reside in Kohima District. Kohima, the capital town of Nagaland, is a picturesque place, situated amidst lush green wealth of the nature. It is spread over an area of around 20 sq. km. It was established way back in 1881 as a sub-division of the formerly Naga Hills district within Assam. There are 12 circles, 4 rural developmental blocks, 180 inhabited and 22 uninhabited villages in Kohima district.

The Greater Kohima, which includes Kohima Village, Jakhama and Jotsoma along with Kohima town, is the second largest urban area of Nagaland after Dimapur-Chumukedima. It has a population of about 100,000 people. Kohima Village, also known as 'Bara Basti', is the second largest village of Asia. The state has a peculiar pattern of land ownership, in which land is owned either by the village community as a whole or by a clan or *khel* within the village or by the individuals. There are no records for conferring such ownership rights but the individuals rights are exclusively determined by traditions, which is also referred to as customary laws. These customary laws are un-codified but are very effective, and in the event of any dispute, traditional village council interprets it (AAR Forest, 2011-

12). The discourse of ownership of land has changed over the years, especially in Kohima and Dimapur where the concentration of settler is very high (GON, 2009). The residents of Kohima suffer from acute shortage of water. The perennial water resources are no more adequate to meet the requirement of growing population of the state capital.

I.1 Climate

Kohima lies north of the Japfü Barail intersection. Due to its elevation, Kohima features a more moderate version of a humid subtropical climate. The climate is pleasant and moderate, which is not too cold during winters and not very hot during summers. December and January are the coldest months when frost occurs, while snowfall occurs occasionally at higher altitudes. Summers are not too warm and last for a few months. The temperature varies from 4^{o}C in winter to about 25^{o}C in summer. The average annual rainfall varies from 150 cm to 280 cm. Most of the rainfall occurs during June to September, and there is only about 15 cm of rain from December to May resulting into severe shortage of water during this period. The average monthly precipitation, mean maximum and minimum temperature data of Kohima based upon 1952-1992 data are mentioned in Table 1.

Table 1: Monthly mean maximum and minimum temp^{o} and total rainfall data of Kohima based upon 1952-1992 data

Month	Mean maximum ^{0}C	Mean minimum ^{0}C	Mean rainfall (mm)
January	16.6	8.1	11.7
February	17.9	9.3	35.4
March	22.1	12.7	47.6
April	24.1	15.6	88.7
May	24.4	16.9	159.2
June	24.9	18.1	333.8
July	25.0	18.8	371.8
August	25.4	18.9	364.0
September	25.0	18.1	250.1
October	23.4	16.6	126.0
November	20.6	13.1	35.2
December	17.7	9.4	7.8

(Source: www.imd.gov.in)

I.2 Forests and water

Forests are spread over around 8,629 sq. km. area, which is approximately 52.04% of the total geographic area of the state (AAR Forest, 2011-12). There are three categories of forests i.e. government owned forests, govt. controlled forests and forests owned by village councils or individuals (Table 2). The state govt. has control only over on 11.07% of the forest, which is around 6% of the total geographic area of the state, while the rest of the forests are under the control of communities or individuals. The details of different categories of forests and area under each categories are mentioned in Table 2.

Table 2: Details of different categories of forests in Nagaland

Legal status	**Area (sq. km.)**	**% of the forest area**	**% of the geographical area**
Government owned forests			
i. Reserved forests	62.26	0.72	0.37
ii. Purchased forests	192.47	2.20	1.16
iii. Protected forests	34.69	0.40	0.20
iv. Wildlife sanctuary	202.02	2.31	1.21
Government controlled (Privately owned) forests	516.79	5.98	3.11
Village owned forests			
i. Virgin forests	4,778.27	55.40	28.82
ii. Degraded forests	2,842.80	32.90	17.14
	8,629.30	100.00	52.04
Ownership			
i. State Government	1008.23	11.07	6.00
ii. Private/Communities	7621.07	88.30	46.00

(Source: AAR Forest 2011-12)

Kohima falls under the extended areas of globally recognized Eastern Himalayan Biodiversity Hotspot. It is a part of the Arakan extension, having influence of unique bio-geographic zones. Puliebadze Wildlife Sanctuary (9 sq. km.) is an important catchment area of Kohima Town. Dzuku valley (100 sq. km.) and Japfu peak, the two important features in the area are located adjacent to the sanctuary and have been designated as Important Bird Areas. The Khonoma Nature Conservation and Tragopan Sanctuary, another important community protected areas, are adjacent to the Dzuku valley. All these sites form a single large continuous area of approximately 200 sq. km. or so and are very important for ensuring the long term water security for the people of state capital (AAR Forest 2011-12).

Water constitutes a major natural resource of the state. It differs from other resources in that it is arguably more fundamental than any other resource to life itself, supporting a huge array of ecosystem services to every economy and society (MEA, 2005). Water contributes directly and indirectly to virtually all other ecosystem services, which includes: water cycling as a supporting service; water-flow regulation, water purification and waste treatment as regulating services, and water as a provisioning service including the provisioning of plants, fish and other organisms grown in or with water (TEEB, 2010). Furthermore, as well as being needed for all biotic and economic production processes, water also has important cultural, spiritual and recreational values. This fundamental threefold value, sustaining life, economies and cultures creates enormous range of competing demands on water resources. Some of the facts about role of forests and water are mentioned below (Science Daily, 2008):

- Forests provide natural filtration and storage systems. Forest vegetation and soils help improve water supply by controlling water yield, peak flows, low flows, sediment levels, water chemistry and quality. Increase in water yield after forest harvesting is transitory; it decreases over a period time as forests re-grow.

- Forests use more water than shorter types of vegetation because of their higher evaporation rates. Water use efficiency differs between forest species; and soil water availability fluctuates at each stand of trees. Canopies protect the ground from runoff which also means higher interception. Root systems influence the groundwater recharge.
- Demand for water continues to rise due to population growth, while forest area is decreasing day by day, and the remaining forest lands are threatened by fire, invasive species, diseases and climate change. One of the biggest threats to forests, and the water that derives from them, is the permanent conversion of forestlands to residential, industrial and commercial uses.

I.3 Water Supply of Kohima town

The water supply for Kohima Municipal Council (KMC) area is drawn through gravity from the Dzuna River and Phesama stream. The Dzuna River and Phesama spring are located respectively around 13 km and 8 km away from the town. The designed capacity of Dzuna River source is 7 million liters per day (MLD). However, the full capacity is available only during the monsoon season (SIPMIU, 2011). The designed capacity of Phesama stream is 0.3 MLD. This source is seasonal due to low yield during lean months. There are 19 service reservoirs (SRs) in Kohima, of these, 17 SRs receive treated water through a 300-mm diameter CI main from Jotsoma water treatment plant. The other two SRs receive water directly from Phesama source. The condition of all these 19 service reservoirs (SRs) is not satisfactory due to old age and hence requires replacement (SIPMIU, 2011). Kohima is unique in the sense that four different systems of water supply exist there. These are briefly discussed below:

I.3.1 Public Health and Engineering Department (PHED)

PHED is the Nodal department for implementation of programmes on water supply, sewerage and sanitation. It caters domestic water to around 40% population; but at a very low per capita rate. It supplies approximately 1.8 MLD water through an internal water distribution network; and the normal rate of water supply is once in three days. The average water supply level during lean months is only 18 liters per capita per day (lpcd) (SIPMIU, 2011). The remaining population gets water from community springs and wells, private cable water suppliers, water tankers suppliers and through rainwater harvesting whenever possible. The supplies from all these sources become uncertain, irregular, erratic and meager in quantity during the lean months i.e. from January till June.

I.3.2 Cable water suppliers (Overhead water pipes)

Kohima is probably the only place in the country, which is having a unique system of water supply i.e. through overhead plastic pipes, also called as water cables, criss-crossing the city in bunches. There are many such cable water suppliers in Kohima town who collect water from natural springs located on their own lands or in nearby areas through which water is collected into the reservoir or tanks and supplied to different customers through overhead pipelines. There are 5 such water suppliers in the Forest Colony area. One such supplier, Mr. Kekhronyipe Mero, was contacted during this study and the information provided by him for this system is mentioned below:

Water is collected from a natural source, which is located in the forest area. Besides this, he has made a ring well too. Around 20,000 liters water is collected in a day. He has 51 customers and the whole family works very hard to supply water to their customers. The length of cable pipes varies from 200m to 1 km. The diameter of pipes varies from ½" to ¾" or even 1 inch. The cost of the pipes is borne by the customer. The life spans of these pipes vary from a year (Guwahati supply) to three years (Kolkata supply). Most of the times, these pipes are taken through telephone poles. The telecom department probably does not have any objection for laying out these pipes due to acute scarcity of water in the town. These pipes are also carried through private premises for which sometimes the suppliers provide 10 to 15 minutes water supply free of cost. It takes around 30 minutes to fill up a syntax tank of 500 liters capacity.

Water is supplied daily for one hour to 5 customers @ Rs. 500.00 per month i.e. approximately 400 liters water during rainy season and 300 liters during dry season (December to April). All other customers receive 2 hours supply @ Rs. 1,000.00 per month. No charges are paid to the govt. or village council for this arrangement.

I.3.3 Water tanker suppliers

Another category of water suppliers are the truck owners who supply water on demand through tankers. They normally keep two 1,000 liters capacity syntax tanks on the truck, collect water from different water source owners @ Rs. 100.00 per 1,000 liters water during rainy season, which is increased to Rs. 200.00 during lean season. The demand of water is very low during rainy season i.e. one to two trucks in a day, which increases to 30 trips or more during winter months.

I.3.4 Village Council Committee, Jotsoma

In Jotsoma village, the village council committee supply water on monthly basis to various govt. departments and army units @ Rs. 4,000.00 per month. Each department takes around 10 trips of 8,000 liters capacity tanks fixed on the trucks from these sources. Besides this, they also supply water to private tanker owners @ Rs. 150.00 per 2,000 L capacity and the number of tankers increases to as high as 150 tankers in a day during lean season.

One of the customers residing in the Upper Forest Colony, who receives water from private cable supplier, informed that they are 7 members family and they receive around 500 liters water daily from private supplier @ Rs. 500.00 per month. The supply of water is reduced gradually to around half during winter months. The main reason of getting water supply from a private supplier is that PHED is not supplying water in that region.

Water scarcity is an acute problem in the state capital and in the extreme situations of dry spells, PHED supply water through tankers to various colonies at fixed rates. For example, the department issued a circular in the second week of March 2011 requesting the public of Kohima to avail water sold at "extremely subsidized rates. They requested the representatives of the colonies, panchayats and ward councilors to approach the department for supply of water @ Rs. 2,000.00 per 10,000 liters of water, and distribute it in their colony as per the needs of the households. PHED also set up an assistance booth near its office and installed help lines for public members seeking water to buy. The supplied water was reportedly fetched from Zubza and Jotsoma village (www.morungexpress.com).

II. Methodology

The main objective of this study was to assess the value of forests in providing water supply to the people of Kohima town based on their willingness to pay for improving the condition of forests in and around catchment area of Dzuna River and Peshama spring so as to improve the quality as well as supply of water. Since most of the water supply of Kohima town comes from these two sources and people knew this fact, and since the frequency of water supply is very poor in Kohima, i.e. twice a week or so, the value of water retention and water supply function of forests was assessed by assuming the fact that the people of Kohima town shall be willing to pay for improving the flow of water from these sources. The detailed methodology is discussed below:

The entire area of Kohima Municipal Council (KMC) was considered as a universe for this study. The KMC area has been divided into 19 colonies (Table 4). A preliminary questionnaire was developed based on the discussion held with the selected people having knowledge of the issue and interest in the subject. It was again circulated to selected audience and their suggestions were incorporated. It was a useful exercise and helped in developing a good questionnaire and methodology. The questionnaire was divided into four parts. The first part covered details about the respondents who filled the questionnaire, locality, age, family size, education status, average monthly income, etc. Part two covered questions related to the duration and quantity of water supplied by the PHED, monthly charges paid, quality of water, requirement of water, and few questions on rain water harvesting. The third part of the questionnaire was related to asking respondents to reveal their willingness to pay in terms of money in case supply of water is improved, while the fourth part was related to get their idea about payment of compensation to the people living in and around Dzuna and Peshama catchment forests for encouraging them to maintain the status of land as good forest for improving water retention and water supply function of these sources. The primary sampling unit was a household, which were selected based on occupation, age, income, education, status, family size etc. All these factors play an important role in deciding their willingness to pay therefore; efforts were made to cover at least a minimum of 10 respondents from each ward/ colony i.e. a minimum of two respondents under following categories from each ward:

- Occupation	- Age	- Family size
- Monthly Income	- Education	- Gender

The ward wise and locality wise details of the respondents covered during the study are mentioned in Table 4.

Table 4: Ward/Colony wise details of households covered during the survey in Kohima

S.N.	Colony/Ward	No. of HH covered	S.N.	Colony/Ward	No. of HH covered
1.	AG Colony	10	11.	New Market Colony	12
2.	Agri Ward	10	12.	North Block	10
3.	Bayavu Ward	10	13.	Officer Hill	12
4.	D Block	10	14.	Paramedical Colony	11
5.	Kitsubozou Colony	10	15.	Perizie High School colony	10
6.	Lerie Ward	10	16.	Poterlane Ward	10
7.	Lower Chandmari	11	17.	PR Hill	10
8.	Midland Ward	8	18.	PWD/Upper PWD	10
9.	Naga Bazar Ward	10	19.	Upper Chandmari	10
10.	New Market	10		**Total**	**194**

III. Results and discussion

The details of the socio-economic status of the respondents covered during this study are mentioned in Table 5. It indicated that family size wise maximum respondents had 5 to 7 members in a family followed by family size of up to 4, 8 to 10 and above 10, respectively having 50%, 36.60%, 12.37% and 1.03% respondents. Age class wise maximum respondents belonged to the age group category of 25 to 45, followed by up to 25, 45 to 60 and above 60 years category, respectively having 48.45%, 34.02%, 15.46% and 2.06% respondents.

Table 5: Socio economic details of the respondents surveyed in Kohima town

S.N.		Category			
1	**Family Size**	**Up to 4**	**5- to 7**	**8 to 10**	**Above 10**
	No. of respondents (%)	36.60	50.00	12.37	1.03
2.	**Age class (Years)**	**up to 25**	**25 to 45**	**45 to 60**	**60 and above**
	No. of respondents (%)	34.02	48.45	15.46	2.06
3.	**Education status**	**Illiterate**	**High School**	**Intermediate**	**Graduate & above**
	No. of respondents (%)	-	13.48	20.72	65.80
4.	**Occupation**	**Government service**	**Student**	**Unemployed**	**Business/ Pvt. job**
	No. of respondents (%)	40.21	19.07	14.95	25.77
5.	**Monthly Income (Rupees per month)**	**Not disclosed**	**up to Rs. 10,000/-**	**Rs. 10,001 to Rs. 25,000/-**	**Above Rs. 25,000/-**
	No. of respondents (%)	34.54	20.10	20.62	24.75
6.	**Gender**	**Male**		**Female**	
	No. of respondents (%)	48.45		51.55	

Occupation wise 40.21% respondents belonged to government job category, followed by respondents having private jobs or business, unemployed and students, respectively having 25.77%, 14.95%, and

19.07% distribution in the total number of respondents covered. Literacy wise maximum respondents belonged to graduate and above category, followed by intermediate and high school category, respectively having 65.80%, 20.72% and 13.48% respondents, while none of them was illiterate. Monthly income wise maximum number of respondents were in above Rs. 25,000/- per month category, followed by Rs. 10,001/- to 25,000/-, and up to Rs. 10,000/- category, respectively having 24.75%, 20.62% and 20.10% respondents, while 34.54% respondents did not disclose their income. Gender wise percentage of male and female respondents covered in this study was 48.45% and 51.55% respectively.

III.1 Demand and supply status of water in Kohima

The average daily requirement of water as reflected by the respondents was assessed and for most of the households (61.86%) it was over 100 liters per day, followed by 24.75%, and 5.67% households, respectively having 50 to 100 liters, 20 to 50 liters of water requirement daily, while 7.73% respondents, mostly students, did not specified any quantity of water (Table 6). The normal supply of water by PHED was mostly twice a week to most of the respondents (48.97%), followed by alternate day supply, once in a week and daily supply of water, respectively having 31.44%, 17.52% and 2.06% respondents under these categories. The duration of water supply was one hour for 85.05% respondents, followed by one to four hours water supply to 12.37% respondents, while only 2.06% respondents got more than four hours of water supply. 72.83% respondents were not satisfied with the quantity of water by PHED, while around one fourth (27.17%) respondents were satisfied with quantum of water supply, while 10.30% did not give any response to this query.

Table 6: Details of the response about the demand and supply of water in Kohima town

Query	**Response**			
Sources of water supply	**Govt. supply**	**Natural Springs**	**Both**	**Others Tanker**
No. of respondents (%)	39.18	32.47	8.76	53.09
Daily requirement of water (Liters)	**< 20 L**	**20 to 50 L**	**50 to 100 L**	**> 100 L**
No. of respondents (%)	7.73	5.67	24.75	61.86
Frequency of distribution of water	**Daily**	**Alternate day**	**Once a week**	**Twice a week**
No. of respondents (%)	2.06	31.44	17.52	48.97
Duration of water supply	**< 1hour**	**1 to 4 hrs**	**4 to 8 hrs**	**> 8 hrs**
No. of respondents (%)	85.05	12.37	1.03	1.03
Whether supply of water is sufficient?	**Yes**	**No**	**No response**	
No. of respondents (%)	27.17	72.83	10.30	
Whether collect water from natural springs	**Yes**		**No**	
No. of respondents (%)	48.69		51.31	
Source of water supply	**Govt. supply within the house**	**Collect water form public distribution point**		**Others**
No. of respondents (%)	63.00	35.80		2.31
Distance of public distribution point form the house	**< 50 m**	**50 to 100m**	**>100m**	
No. of respondents (%)	42.85	26.19	30.95	

It was interesting to note that only around forty percent of the respondents of the town were getting water supply through PHED, around one third (32.47%) respondents were collecting water from natural sources in and around their houses, while 8.76% respondents were getting water from both of these sources. 63% respondents were getting water through PHED piped water supply right in their houses, while 35.80% respondents were collecting water from public distribution points near their houses. Maximum number of respondents (42.85%) were having public distribution points near their houses (50m), followed by 30.95% and 26.19%, respectively having public distribution points located over 100m and 50 to 100m distance from their houses. Besides this, 53.09% respondents were getting water through miscellaneous sources of supply such as through tankers and private piped water supply.

III.2 Shortage in supply of water

The shortage of water was maximum during January to April as reported by 73.48% respondent. The extent of water shortage was more or less same from May to August and September to December, while few of them had shortage of water throughout the year. Most of the respondents (77.20%) were meeting this shortage by purchasing extra quantity of water from the water tanker suppliers. 16.58% respondents mentioned that they managed with the shortage of water by reducing the consumption of water, while 6.22% respondents met this shortage by fetching extra quantity of water from nearby natural sources of water. Most of the respondents (31.02%) assigned climate change as the main reason responsible for the shortage of water, 26.53% respondents opined that it was due to the increase in demand of water due to population increase, 24.90% respondents assigned it to drying of natural springs, while few of them opined that the shortage of water was due to the decrease in the quantum of annual rainfall in and around Kohima town (Table 7).

Table 7: Details of the response regarding shortage of water supply in Kohima

Period of maximum shortage of water	**Jan to April**	**May to Aug**	**Sept to Dec**	**Throughout the year**
No. of respondent (%)	73.48	12.61	12.17	1.74
Reasons of shortage of water supply	**Decrease in Rainfall**	**Drying of springs**	**Increase in demand**	**Climate change**
No. of respondent (%)	17.55	24.90	26.53	31.02
How do you adjust to the shortage of water	**Purchase extra quantity of water**	**Collect water from natural springs**	**Compromise with the daily consumption of water**	
No. of respondent (%)	77.20	6.22	16.58	
Do you have private connection for supply besides having PHED connection?	**Yes**		**No**	
No. of respondent (%)	20.62		79.38	
Duration of water supply from pvt. suppliers	**< 1 hrs**	**1 to 3 hrs**	**3 to 5 hrs**	
No. of respondent (%)	80.34	18.03	1.64	

III.3 Purchase of extra quantity of water

Results indicated that 30.05% respondents purchased around 500 liters of water in a month from the private suppliers to meet the shortage of water, followed by 25.91%, 25.39% and 18.65% respondents, respectively purchased more than 2000 liters, 500 to 1,000 liters and 1,000 to 2,000 liters of extra water in a month from the private suppliers. Maximum number of respondents purchased extra quantity of water for a period of 1 to 3 months, followed by 28.35% and 18.65% respondents purchasing extra quantity of water for one month and 3 to 6 months, respectively, while only 5.15% respondents purchased extra water for almost throughout the year to meet their requirement of water (Table 8).

Table 8: Details about the purchase of extra quantity of water

Do you purchase extra water to meet demand	**Yes**	**No**		
No. of respondent (%)	85.56	14.44		
Quantity of water purchased in a month (liter)	**Up to 500**	**500 to 1000**	**1000 to 2000**	**Above 2000**
No. of respondent (%)	30.05	25.39	18.65	25.91
How many months do you purchase extra quantity of water from tankers?	**< 1 month**	**1 to 3 months**	**3 to 6 months**	**6 to 12 months**
No. of respondent (%)	28.35	41.24	25.26	5.15

III.4 Quality of water supplied

The quality of water supply was good as reported by 53.89% respondents. 41.11% respondents mentioned that it was not good, while 8.25% did not respond to this query. 63.40% respondents were using water filter for drinking purpose, while 36.60% were not having water filters, may be because of their poor economic status (Table 9). Besides this, 24.21% respondents were using boiled water for drinking purpose. NFHS (2009) has reported that about 89% households treat drinking water to make it potable, i.e. 86% boil the water, 17% use a ceramic, sand or other filter, 1% strain the water through a cloth and 3% treat it in some or other way.

Table 9: Details of the responses regarding quality of water supplied by PHED in Kohima

1.	**Quality of water supplied by PHED**	**Good**	**Not good**	**No response**
	No. of respondent (%)	53.89	46.11	8.25
2.	**Do you use water filter?**	**Yes**	**No**	**NR**
	No. of respondent (%)	63.40	31.96	4.64

III.5 Rain water harvesting

It was interesting to note that 87.56% respondents were undertaking rain water harvesting measures to supplement their daily requirement of water, while remaining 12.46% respondents were not undertaking any such measures probably because they were staying in Kohima on rental basis, therefore, not having sufficient space in and around their rented accommodation for rain water harvesting. It was also interesting to note that around 34.54% respondents were able to meet 15% to 30% of their total requirement of water by undertaking rain water harvesting measures, followed by

26.29%, 24.23% and 14.95% respondents, who were able to meet respectively 5 to 15%, up to 5%, and up to 30% of their total requirement of water by undertaking rain water harvesting measures (Table 10).

Table 10: Details of responses about rain water harvesting by the households of Kohima

Do you undertake rain water harvesting?	**Yes**	**No**	**NR**	**Other**
No. of respondent (%)	87.56	11.92	0.52	0.52
How much of your water requirement do you meet from Rain water harvesting?	**Up to 5%**	**5% to 15%**	**15% to 30%**	**Above 30%**
No. of respondent (%)	24.23	26.29	34.54	14.95
Is there any community reservoir developed for collection of water	**Yes**	**No**	**No response**	
No. of respondent (%)	12.89	77.83	9.28	

III.6 Willingness to Pay for improving supply of water

Results indicated that 68.55% respondents were willing to pay for improving the condition of catchment forests in and around Dzuna River and Peshama stream for improving the water retention and water supply function of these sources of water supply to Kohima town. Out of them, 36.08% were willing to pay Rs. 10.00 to Rs. 100.00 per month for this purpose, followed by 23.71%, 20.62% and 19.59%, respectively willing to pay up to Rs. 10/-, above Rs. 200/- and Rs. 100/- to 200/- per month for this purpose. Besides this, 28.36% respondents were not willing to pay for this purpose, while 3.09% did not respond to this query (Table 11).

Table 11: Willingness to pay for improving water supply by PHED

Willingness to pay to PHED for improving supply of water	**Yes**	**No**	**No response**	
No. of respondent (%)	68.55	28.36	3.09	
If yes, amount of money willing to pay per month	**< Rs. 10/-**	**Rs. 10 to 100/-**	**Rs. 100 to 200/-**	**Rs. >200/-**
No. of respondent (%)	23.71	36.08	19.59	20.62
WTP in case family income increases by Rs. 1,000 per month	**Yes**	**No**	**No Response**	
No. of respondent (%)	68.04	26.29	5.67	
Amount of Rs. WTP per month (Rs.)	**< Rs. 10/-**	**10 to 30/-**	**30 to 75/-**	**Above 75/-**
No. of respondent (%)	4.48	21.64	34.33	38.06

While inquiring about the willingness to pay if monthly income of the respondents increases by Rs. 1,000.00 per month, 68.04% respondents were willing to pay additional amount for improving the supply of water, 26.29% respondents were not willing to pay from this additional income, while 5.67% respondents did not respond for this query. Out of the total respondents who were willing to pay from the additional income, 38.06% were willing to pay Rs. 75 to Rs. 100.00 per month for this purpose, followed by 34.33%, 21.64% and 4.48%, respectively willing to pay in the range of Rs. 30 to 75/-, Rs. 10 to 30/- and up to Rs. 10/- per month for this purpose. The average willingness to pay from this extra income was Rs. 134.10 per month, which was Rs. 22.97 higher than the normal WTP of the respondents. The details of category wise response on WTP are discussed below:

III.6.1 Family size and age group

The minimum WTP of Rs. 5.00 per month was quoted by the respondents having a family size of above 10. This figure may not be valid as only 0.52% respondents belonged to this category. The mean WTP increased to Rs. 64.85 to Rs. 129.37 and Rs. 146.44, respectively quoted by family size of 4, 8 to 10 and 5 to 7 (Table 12). The maximum number of respondents (14.95%) who were not willing to pay any amount for this purpose belonged to family size of up to 4, followed by 10.31%, 2.06% and 0.52% respondents, respectively belonging to a family size of 5 to 7, 8 to 10 and above 10.

It was interesting to note that the average WTP of the respondents below 25 years of age and respondents above 60 years of age was almost same i.e. Rs. 78.33 and Rs. 80.00, respectively. It increased gradually from Rs. 122.39 to Rs. 151.16, respectively in the age groups of 25 to 45 and 45 to 60 years (Table 12).

Table 12: Family size and age wise details of WTP

S.N.	Family size	%	Mean WTP (Rs.)	Age	%	Mean WTP (Rs.)
1.	Up to 4	35.56 (14.95)*	64.85	Below 25	34.02 (7.73)*	78.33
2.	5 to 7	46.39 (10.31)*	146.44	25 to 45	48.45 (14.95)*	122.39
3.	8 to 10	12.37 (2.06)*	129.37	45 to 60	15.46 (5.15)*	151.16
4.	Above 10	0.52 (0.52)*	5.00	Above 60	2.06	80.00
5.	Not disclosed	4.64 (1.03)*	87.78	Age not disclosed	2.58	83.33

* = Figures in parenthesis indicate % respondents not willing to pay any amount

III.6.2 Occupation and monthly income

The minimum mean WTP of Rs. 67.77 and Rs. 87.93 was quoted by the students and unemployed respondents, respectively. It was interesting to note that they were also willing to pay from their family income to improve the flow of water. The maximum mean WTP of Rs. 165.56 was quoted by the respondents having government jobs, while the average WTP of people in business or self employed and social workers was Rs. 103.40 per month.

Table 13: Occupation and monthly income wise details of WTP

S.N.	Occupation	%	Mean WTP (Rs.)	Income	%	Mean WTP (Rs.)
1.	Students	19.07	70.97	Up to 10,000	20.10 (6.70)*	94.28
2.	Unemployed	14.95 (4.64)*	88.10	10,001 to 25,000	20.62 (6.18)*	100.00
3.	Business / Self employed	25.77 (9.28)*	121.40	Above 25,000	24.75 (8.76)*	180.01
4.	Govt. job	40.72 (6.18)*	133.07	Income not disclosed	34.54 (10.31)*	83.86

* = Figures in parenthesis indicate % respondents not willing to pay any amount

It was interesting to note that the average mean minimum WTP of Rs. 83.36 was quoted by the respondents who did not reveal their monthly income. The mean WTP of the respondents increased with the increase in monthly income. It increased to Rs. 94.28, Rs. 100.00, Rs. 180.01, respectively quoted by respondents having a monthly income of up to Rs. 10,000/=, Rs. 10,000/= to Rs. 25,000/= and above Rs. 25,000/=(Table 13).

III.6.3 Education status and Gender

The minimum mean willingness to pay Rs. 52.14 was quoted by up to 10th category respondents, which increased gradually with higher literacy level i.e. up to class 12th and graduates and above categories, respectively having mean WTP of Rs. 91.81 and Rs. 132.72 (Table 16). The average WTP was Rs. 117.50 and Rs. 97.15 per month, respectively for male and female respondents (Table 14).

Table 14: Education status and Gender wise details of WTP

S.N.	Education	%	Mean WTP (Rs.)	Gender	%	Mean WTP (Rs.)
1.	Illiterate	-	0.00	Male	48.45	121.76
2.	Up to class Xth	13.40 (4.64)*	52.14	Female	51.55	101.15
3.	Up to class XIIth	20.72 (7.73)*	91.81			
4.	Graduate and above	65.80 (19.07)*	132.72			

* = Figures in parenthesis indicate % respondents not willing to pay any amount

The average willingness to pay for all above mentioned categories was estimated at Rs. 111.13 per month. By multiplying this value to 68.55% (13,578.38) households of Kohima town i.e. who were willing to pay for this function of forests, the total economic value of this function was estimated at Rs. 1,81,07,584.40 per year. This is the amount, which the people of Kohima town are willing to pay in a year for improving the water retention and water supply function of forests for improving the water supply. It can be considered as the economic value of the role of forests in providing water supply to the people of Kohima town. Accordingly, per household and per capita value for the entire population of Kohima town was estimated at Rs. 914.14 and Rs. 182.83 per year or Rs. 76.18 and Rs. 15.24 per month, respectively.

Estimation of per hectare value of water retention and water supply function of forest was a difficult task as it was not possible to assess the actual area of catchment forest responsible for performing this function for the people of Kohima town. Therefore, buffer of different radii i.e. 2.0 km to 5.0 lm were generated by using satellite imageries to find out the extent of forest area available in and around Kohima town. The extent of forest area, condition of forests and per hectare value of forest as estimated under different radii are mentioned in Table 19.

Table 19: Valuation of water retention and water supply function of forest (Rs./Ha/yr)

Radius of buffer around Kohima town (km)	Forest area in the buffer zone (ha)	% of dense forest in the buffer zone	% of open forest in the buffer zone	Value of water retention and water supply function (Rs./ha/year)
2.0	3,780.86	24.89	34.40	4,789.28
2.5	5,019.61	27.97	35.14	3,607.37
3.0	6,423.67	30.51	36.05	2,818.88
3.5	7,895.46	31.36	36.86	2,293.42
4.0	9,572.03	32.24	38.10	1,891.72
4.5	11,394.90	33.93	38.18	1,589.10
5.0	13,367.53	35.47	38.16	1,354.59

Thus by taking a buffer of 2 km radius around Kohima town, per hectare value of water retention and water supply function of forest was estimated at Rs.4,782.28 per hectare per year. This value got gradually reduced to Rs. 3,607.37, Rs. 2,818.88, Rs. 2,293.42, Rs. 1,891.72, Rs. 1,589.10 and Rs. 1,354.59, respectively for a buffer of 2.5, 3.0, 3.5, 4.0, 4.5 and 5.0 km due to simultaneous increase in the area of forest.

IV. Payment for Ecosystem Services

Attempts were also made in this study to get an idea of respondent's view to pay compensation to the people living in around catchment areas of these water sources for keeping the forests intct and in good conditions for ensuring water supply to the people of Kohima town. The details of the responses received for various queries are mentioned in Table 15.

Results indicated that 56.70% respondents were aware of the fact that water supply of Kohima town comes from Dzuna River and Peshama stream, 35.05% were not aware of this fact, while 8.25% did not respond to this query. 63.40% respondents were of the opinion that catchment forests in and around these rivers/streams play important role in maintaining the flow of water to these sources. 44.85% respondents were of the view that the flow of water from these sources has reduced over a period of time, and 63.92% of them were of the opinion that the local tradition or customary laws were responsible for maintaining these forests in good condition; 25.77% disagreed with this query, while 10.30% did not respond to this query.

The percentage of respondents in favour of payment of compensation to the people who were responsible for maintain good forest in and around the catchment of the water sources was quite high i.e. over two third (69.03%) respondents were willing to pay for water retention and water supply function of forest. The minimum amount quoted for compensation varied from Rs. 100.00 to a maximum of Rs. 1.5 lakh per year. It was also observed that 16 of them did not mention any amount may be because of the fear of making actual payment in future

Table 15: Payment of compensation to the people of catchment areas

Do you Know that water supply to Kohima town comes from Dzuna and Peshama stream?	**Yes**	**No**	**No Response**
Number of respondent (%)	56.70	35.05	8.25
Do you consider that catchment forests in and around Dzuna and Peshama help in maintaining the flow of water in these rivers (?)	**Yes**	**No**	
Number of respondents (%)	63.40	36.60	
Do you think that over a period of time flow of water has reduced in these rivers?	**Yes**	**No**	**No Response**
Number of respondent (%)	44.85	34.56	20.62
Do you know that people of Dzuna and Peshama villages are responsible for maintaining the catchment forest in and around Dzuna and Peshama rivers?	**Yes**	**No**	**No Response**
Number of respondent (%)	63.92	25.77	9.28
Do you think that the people of Dzuna and Peshama catchment forests should be paid compensation as payment for ecosystem services for protection of the area	**Yes**	**No**	**No Response**
Number of respondent (%)	69.07	30.93	Nil
If yes, the amount of compensation to be paid per month	**Up to Rs.1000.00**	**Rs. 1000 to 5,000/-**	**Above Rs. 10,000.00**
Number of respondent (%)	81.36	7.62	11.02

An analysis of the socio-economic details of the respondents who quoted over Rs. 10,000.00 per month as payment for ecosystem services for the people of the catchment forests for maintaining the area as good forest cover revealed that 13 respondents quoted over Rs. 10,000.00/month, of which 7 were male and 6 were female. It was interesting to note that of these 6 were in government jobs, 2 were having their own business, 3 were students, and one each was pensioner and unemployed. It was also interesting to note that the maximum amount of two lakh rupees was quoted by a male respondent who was having his own business with a monthly income of Rs. 22,000.00 only. The second highest amount of Rs. 1.5 lakh per month was quoted by three female respondents, of which one was student;

another was unemployed, while the third one was having a private job with a monthly income of Rs. 5,000.00 only, therefore, these values were not taken into consideration for estimation of final values.

Water is a precious natural resource. Its availability is highly dependent on the global hydrological cycle and local and regional water management regimes. It differs from other resources with respect to its high variability in time and space. Localities vary in terms of water abundance and scarcity, with climatic and seasonal variations affecting precipitation and evapotranspiration to a great extent. The state has already started feeling the impacts of climate change. There has been a change in monsoon pattern and data indicated that the number of rainy days have reduced while the intensity of rainfall has increased thus leading to increased run off, soil erosion, and more numbers of drought and storm incidents. Water scarcity especially during winter months has become a regular feature for the residents of Kohima. The issue became so serious that there were suggestions of having "Winter Capital and Summer Capital" somewhere where water is available (Sandham, 2011). The villagers of Dzuna and Phesama catchments have developed a feeling of apprehension that their water sources will run dry if they are continuously tapped for the purpose of state capital (Sandham, 2011). The capital normally used to get only 1.5 million liter of water per day during lean period against the requirement of 10 million liter of water per day. The department had taken up projects to tap water from the Zaru River, which is one of the tributaries of the Dzuu River, some 25 kms away from the capital, and once it is completed, it will provide at least 3.8 million liter of water per day during the lean period (NEPS, 2012). Another important issue is the quality of water supplied by private parties and individuals. During the lean season, those who are residing in and around the state capital have been undergoing untold miseries not only for paying exorbitant price in buying water from individuals and private parties but also for not getting water to buy at times. During scarcity water is sold at Rs. 20.00 a bucket (PTI, 2012).

There have been few studies in India on valuation of role of forests in providing water retention and water supply functions to the society. Chaturvedi (1992) estimated the economic value of role of forests in supplying water to the people of Almora town at Rs. 4,745/ha/yr. Reddy and Ratna (1999) observed that on an average people were willing to pay five percent of their income for ensuring proper water supply in Rajasthan. Costanza *et al.* (1997) estimated values for water retention and water supply at US$ 8 and US$ 6, respectively. Verma (1999) estimated value of watershed function for H.P. forests at Rs. 5.16 lakh per hectare per year, which was almost 69% of the total economic value of forest based on Chopra and Kadekodi (1997) study on Yamuna basin. Kadekodi *et al*. (2000) estimated the average annual WTP of households for irrigation and drinking water at Rs. 208.00 and Rs. 43.00, respectively. Bisht (2012) estimated per hectare economic value of water retention and water supply function of Kosi watershed at Rs. 2,683.04, Rs. 1,475.64 and Rs. 536.60, respectively for very dense, moderately dense and open category of forests. In comparison to this, per household WTP for the people Aizawl, Mizoram was estimated at Rs. 8,051.65 per hectare per year, which is very high probably due to the acute shortage of water in that region.

Tewari *et al*. (2012) in a study in Shivalik Himalayas presented the results of water yield from a catchment forests for a period of forty years (1963 to 2003). They concluded that initially the results were highly encouraging as due to protection and management there was drastic reduction in water yield. However, the trend changed after few years probably due to the siltation of the check dams and other soil conservation structures and reduction in the ground cover due to infestation by *Lantana* *camara*. Nunez *et al.* (2006) estimated the economic value of water supply as an ecosystem service of Chilean temperate forests in the production of drinkable water by using the change in productivity method (production function approach) to derive benefit estimates per cubic meter of stream water, per household per hectare. Because the benefits of an ecosystem service can enhance an economic activity (i.e. drinkable water production), willingness to pay for such service can be measured by estimating its value as an input factor in a productive activity (Freeman, 2003; Barbier, 2007). Alyward (2002) also expressed that despite the literature on water quality impacts is fairly well spread out and valuation studies exist since at least 1970 (Wilson and Carpenter, 1999), valuation of watershed services as provided by tropical forests is still scarce (Lele, 2009) and specific to a region, therefore cannot be applied to other areas. Therefore, understanding the role of forests as providers of water related services and the way economic valuation should measure these services still needs clarification and further development. It is becoming clear that the forests of the future may need to be managed as much for a sustainable supply of clean water as any other goal, but even so, forest resources will offer no "quick fix" to the insatiable, often conflicting demands for this precious resource (Science Daily, 2008).

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Decadal changes in Net Primary Productivity over Mizoram state in India

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Abstract

We analysed three decades terrestrial Net Primary Productivity (NPP) over Mizoram state, India from 1981 to 2010. Significant increase (5 to 26%) in NPP was observed over Mizoram during the study period. Northern parts (Chhimlung, Phaisen, Bairabi, Hriphaw) of Mizoram indicated NPP change from 2 to 10%, whereas southern parts (Phura, Laki, Zawngling, Saihaward, Lungtian) showed high NPP change from >10% to 26%. This satellite data based analysis as well as our recent ground survey in the study region revealed that, this increasing trend in NPP was basically associated to horticulture and agriculture development in the state. This systematic and longterm NPP analysis will be useful to strengthen our understanding the role of regional landcover types and impact of their change in the national and global carbon cycle.

Keywords: *NPP, Mizoram, CASA, Decadal change*

I. Introduction

Net primary productivity (NPP) is a key component of the terrestrial carbon cycle, and it is defined as the accumulation of dry matters by green plants per unit time and space. Regional NPP estimates are very useful in modeling regional and global carbon cycle as. (Bonan 1995; Hunt et al. 1996; Chen et al. 2000). The estimates are also important for determining crop yield (Patel et al. 2006); forest growth and production (Milner et al. 1996; Amiro et al. 2000); impact of human-induced land degradation (Wessels et al. 2007); and impact of climate change on terrestrial-biosphere (Keeling et al. 1996; Thompson et al. 1996; Nemani et al. 2003). Direct measurement of NPP is time and labor-intensive and an existing NPP database is insufficient to determine spatio-temporal variability of NPP at larger scale. It is, therefore, required to develop satellite data driven processed based models to quantify the spatio-temporal variability of terrestrial NPP (Liu et al. 1997). Normalized Difference Vegetative Index (NDVI) and Simple Ratio (SR) are the most commonly used indices for representing vegetation condition (Running et al. 2004), land cover properties in the form of land/vegetation cover types, and soil properties. Due to less complex and easily amenable to remotely sensed data, Light Use Efficiency (LUE) models are widely used for estimation of terrestrial Net Primary Productivity at large spatial scale. Satellite data based LUE models such as C-Fix (Veroustraete 1994), CASA (Field et al. 1995), GLO-PEM (Prince and Goward 1995), SDBM (Knorr and Heimann 1995), TURC (Ruimy et al. 1996), and Moderate Resolution Imaging Spectro radiometer (MODIS) NPP algorithm (Running et al. 2004) have been developed and validated to evaluate spatio-temporal variability of NPP over continents or global land surface (Sabbe et al. 1999; Potter et al. 2003; Zhao et al. 2005). Among existing process-based models, CASA is less complex and require minimum input data to describe processes of carbon exchanges in terrestrial vegetation and soil, and it is easily amenable to satellite-derived variables. The model has been used by several researchers to determine patterns of NPP and CO_2 sink at various spatial scales (Field et al. 1995; Thompson et al. 1996; Potter et al. 2003).

Net primary productivity of forests in Northeast India particularly for Mizoram state is less known. Seasonal and inter-annual variability of NPP due to landuse dynamics and influence of regional meteorological parameters on seasonality of NPP is not understood in detail over these humid tropical regions. Shifting cultivation is still very much practiced Northeastern states of India, especially in Mizoram state and this practice is the main cause for depletion of forest cover and has eventually resulted in fluctuations net primary productivity of the state. Thus, in the present study, a long-term satellite data based analysis was carried out over Mizoram state to assess inter-annual variability of net primary productivity for the period 1981-2010. The paper also included ground truthing evidences of NPP change in major regions of the state.

II. Study area and Landcover types

The study area is Mizoram with a total geographical area of 21, 087 sq. km and situated between the coordinates of 21°58' & 24°35' N latitude, and 92°15'E & 93°20'E. The physiography of Mizoram can be broadly divided into hills and valleys. The state is known for its, diverse vegetation ecosystems and biodiversity (Figure 1). Based on the classification by Agrawal et al.,(2003), six landcover types are found in the region, *viz.*, evergreen needleleaf forest (ENF), evergreen broadleaf forest (EBF), deciduous broadleaf forest (DBF),Grassland, Agriculture and Abandoned/current Jhum. Bamboo is one of the forest vegetal components that are abundantly found covering most of the forest area either in pure large patches or in mixed form (as under-storey vegetation) with other tree species.

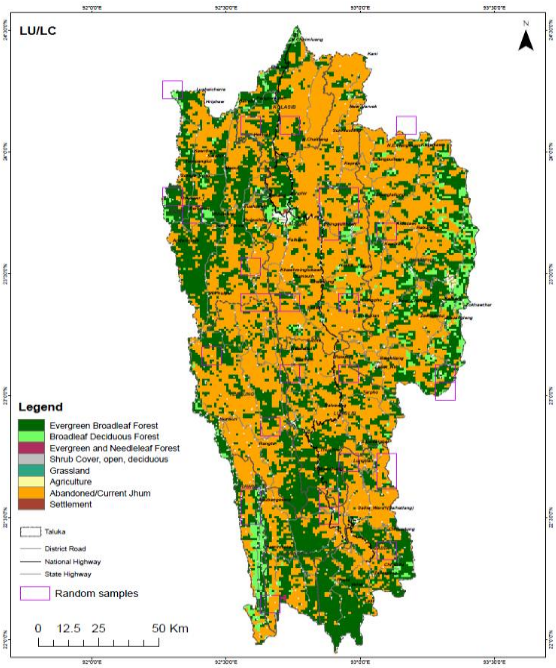


Figure 1: Land cover map showing different vegetation types in Mizoram state.

Recent analysis by MIRSAC, 2008 (Mizoram Remote Sensing Applications Centre) reported that, shifting cultivation which is still very much practiced in the state is the main cause for depletion of forest cover and has eventually resulted in fluctuations in the forest cover of Mizoram every year. The general climate of Mizoram is one of the most pleasing one in the country with moderate temperatures throughout the year. The summers are not very hot as the temperature remains between 20° to 30°C. The winters are very pleasing and cool with temperatures ranging from 21° to 11°C. Mizoram witnesses heavy rainfall in all parts of the state during the rainy season. Monsoon starts from June and lasts till the month of August. An annual average rainfall of 3000 millimeters is recorded in the state. During the months of March to April, heavy storms occur in most parts of the state.

III. Data used and their sources

Data sets and their sources used in the present study are summarized in Table 1. The long sequence of Normalized Difference Vegetative Index (NDVI) was obtained from Advanced Very High Resolution Radiometer (AVHRR) sensors onboard series of National Oceanic and Atmospheric Administration (NOAA) satellites. Acquisition instigated in 1981 and is still on-going, but pre-processed data sets are made available to science community up to 2006. The data is gridded with a spatial resolution of 8 km x 8 km, generated by removing cloud contamination and performing atmospheric calibration at the Earth Resources Observation System (EROS). This time series dataset has been widely used in last two decades for characterization of interannual variation in vegetation dynamics at regional (Yu et al., 2009; Li et al., 2012; Yin et al., 2012; Bala et al., 2013; Nayak et al., 2013) and global scale (Milesi et al., 2010; Goetz et al., 2000).

We utilized meteorological data (air temperature, precipitation and incident solar radiation) to derive temperature and moisture stress coefficients. Mean monthly temperature and cumulated monthly precipitation with 0.5° spatial resolution were acquired from Climate Research Unit (CRU) at University of East Anglia (UEA). Downward monthly shortwave radiation with 1/2x2/3° spatial resolution was obtained from Modern-Era Retrospective Analysis for Research and Applications (MERRA).

MODIS annual NPP product gridded at 1 km spatial resolution was acquired from 2000 to 2010. The data was used in the study to extend NPP data series from 2007 to 2010. Landcover information, developed based on time series SPOT NDVI data was obtained from Agrawal et al. (2003).

IV. Model and Methodology

We used an improved CASA (Carnegie-Ames-Stanford) ecosystem model (Yu et al., 2009) to estimate net primary productivity (NPP) over Mizoram for the study period 1981 to 2010. The model estimate NPP based on light use efficiency (LUE) approach. Framework of the improved CASA model with detailed steps involved in estimating the NPP is depicted in Figure 2. The model calculates NPP as a product of Absorbed Photosynthetically Active Radiation (APAR) and biome specific maximum LUE, which is corrected for spatio-temporally varying stress constraints resulting from the temperature and water. The model can be expressed generally as in equation (1) (Potter et al. 1993):

$$N(x,t)=\sum_{t} r\times S(x,t)\times F(x,t)\times \varepsilon_{max}(x,t)\times T1(x,t)\times T2(x,t)\times W(x,t) \quad (1)$$

where $N(x,t)$ is Net Primary Productivity (NPP) over a given location (x) and time interval (t), r is the ratio of the solar radiation which can be used by the vegetation with the total solar radiation. $S(x,t)$ is the monthly total incident solar radiation (MJ m^{-2} $month^{-1}$). $F(x,t)$ is the fraction of Photosynthetically Active Radiation (fPAR) at location (x) and time (t). $\varepsilon_{max}(x,t)$ is the maximum light use efficiency of the vegetation in favourable conditions, $T1(x,t)$ is the stress coefficient resulting from the extreme low and high temperature to vegetation photosynthesis. $T2(x,t)$ represents the decreasing trend of LUE of the vegetation when the environmental condition changes from the optimal temperature to a lower or higher temperature. $W(x,t)$ is the moisture stress coefficient, respectively.

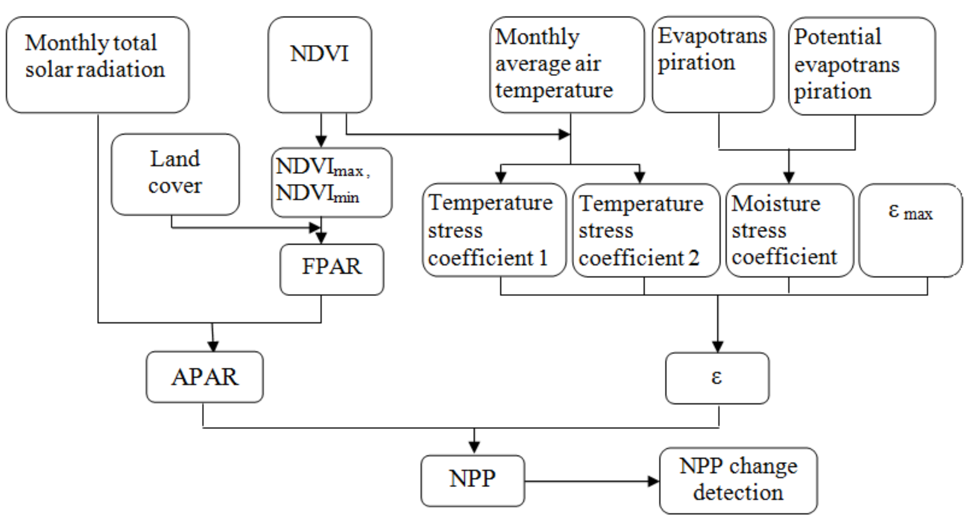


Figure 2. Framework of improved CASA ecosystem model depicting the modeling steps, the input requirements and their spatio-temporal resolutions.

Detailed description of the model and inputs required to estimate terrestrial NPP is given in (Potter et al., 1993, Field et al., 1995). NOAA AVHRR provides NDVI data till 2006, however to study NPP variations in Mizoram until 2010, NPP derived in the present study from NOAA AVHRR NDVI data and NPP obtained from MODIS data were merged through developing biome specific empirical models. In order to study decadal change in NPP over Mizoram, the most common approach generally use in literature to detect change (Eq. 2) was used in this study to compute grid level relative deviation (RD) of NPP over Mizoram state for the study period 1981 to 2010.

$$RD(\%)=100\times\frac{(C2-C1)}{C1} \quad (2)$$

where C1 indicate mean NPP for the study year from 1981 to 1990 and C2 is mean NPP of the study year from 2001 to 2010.

V. Results and Discussion

1 Spatial variability of NPP over Mizoram

Spatial distribution of decadal mean Net Primary Productivity (NPP) over Mizoram for the study period 1981 to 2010 is depicted in Fig. 3. Mean NPP in Mizoram varied from 200 to 1200 gC m^{-2} $year^{-1}$. Parts of Northern and Southern Mizoram showed NPP between 200 to <650 gC m^{-2} $year^{-1}$, whereas parts of Southeastern Mizoram and most of the Central Mizoram regions showed a very high NPP ranged from >650 to 1150 gC m^{-2} $year^{-1}$. This high NPP in the regions could be due to forest type composition and availability of enough solar radiation and soil moisture.

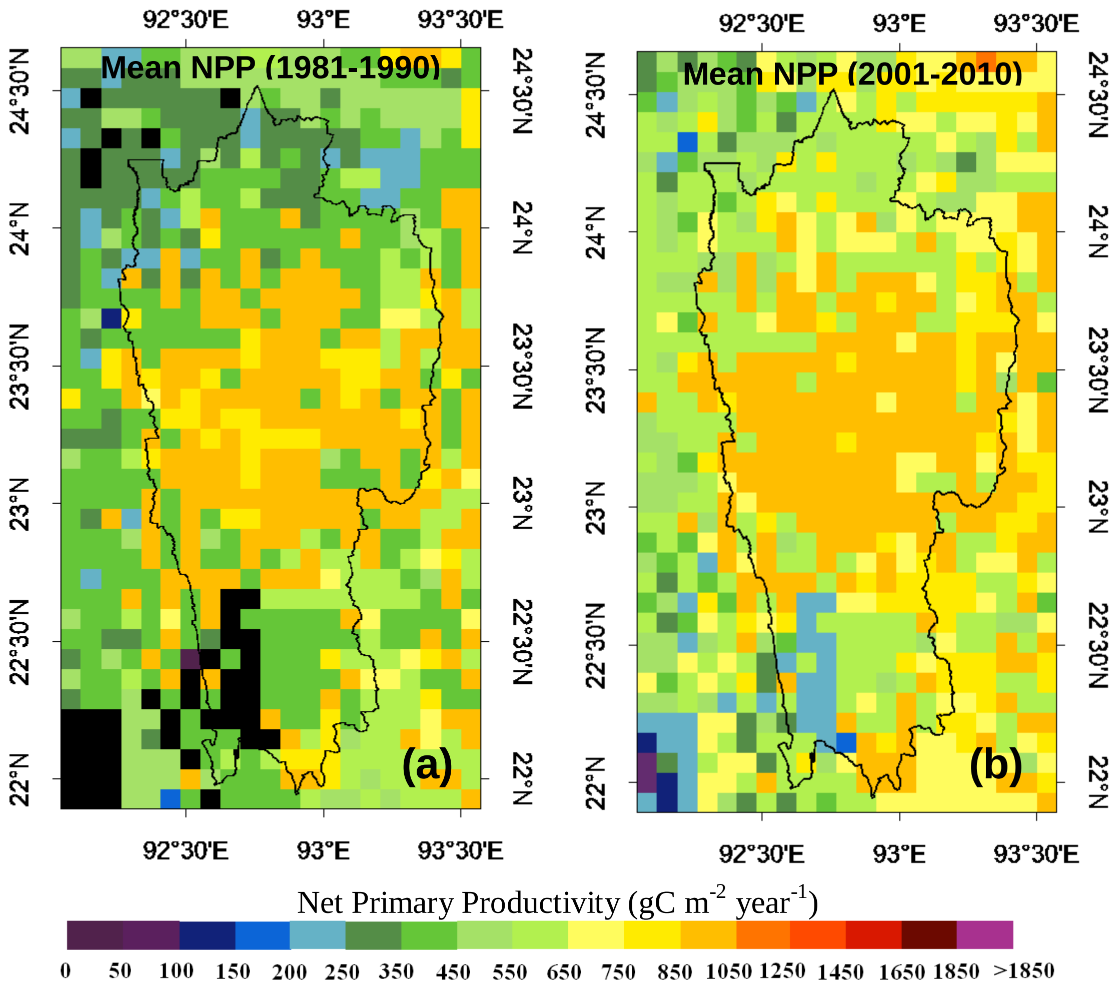


Figure 3. Decadal mean net primary productivity over Mizoram

2 Percentage change in NPP over Mizoram

Percentage change in Net Primary Productivity (NPP) over Mizoram for the study period 1981 to 2010 is depicted in Fig. 4. Overall, an increasing (5 to 26%) trend in NPP was observed in Mizoram during the study period. Northern parts including Chhimlung, Phaisen, Bairabi, Hriphaw etc showed NPP change between 2 to 10%, whereas southern parts comprising Phura, Laki, Zawngling, Saihaward (Saihatlang), Lungtian etc indicated NPP change from >10% to 26%.

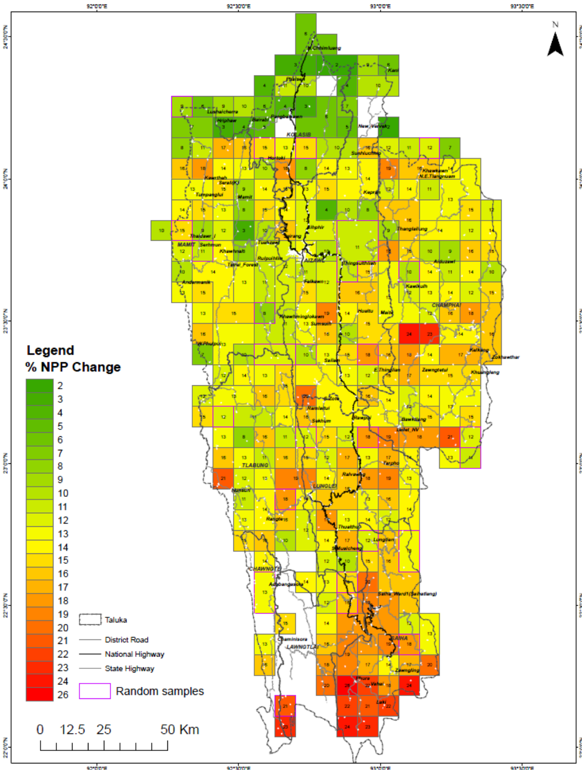
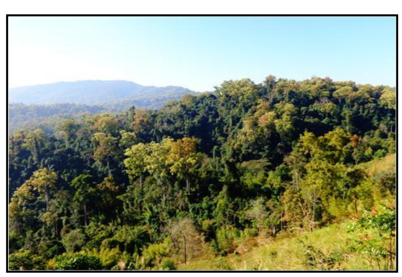


Figure 4. Percentage change in NPP over Mizoram state for the study period 1981 to 2010.

Our recent ground truthing in Mizoram state revealed that, large horticulture plantation and agriculture practices during recent decade (2001-2010) was the basic reasons for positive change in NPP. The highest NPP change (16 to 26%) in Mizoram was observed over Southern Phura during the study year. Ground thrusting information in the region revealed that, area is completely covered by very dense and tall evergreen forests (Figure 5). However, the positive change in the region might be only due to regeneration of new forest. Change around Lunglei (12-19 %) was due to regeneration of forests with mosaics of jhum cultivation and large horticulture plantations (banana, bamboo, teak, orange, pineapple etc). Change around Biate (12-14%) could be attributed to plantation of horticulture crops like tea, orange and bamboo clusters with agriculture practices are the major reasons for increase in NPP. Increase in NPP (12-23%) around Khawzawl might be due to high density of jhum cultivation practices.

Very dense forest in valley. Upper portion of the valley is covered by Teak

Tea plantation at Biate village

plantations Lat: 22° 12' 52"; Lon: 92° 53' 41")

Tung Plantation (Lat: 23° 14' 38; Lon: 93° 07' 06")

Village after Khawhai, the grid showing 23% change in NPP

Pine forest, Agri (40%), forest (60% mixed with Pine, bamboo, tung + banana plantation) (Sialhawk to Khawhai)

Fire/smoke observed at 1420hrs near Khawzawl

Valaphai valley, Current jhum, old cultivated lands, abandoned jhum. This valley is on fault line (East west) of Mizoram (Lat: 23° 10' 29"; Lon: 93° 03' 12").

Figure5. Ground Truthing Information in Mizoram state

VI. Conclusion

The present analysis was carried out to assess decadal change in net primary productivity (NPP) over Mizoram using multisensor satellite data and improved CASA ecosystem model. Significant change in NPP was observed during the study period from 1981 to 2010. The present satellite based analysis and extensive ground survey in Mizoram indicated that, large horticulture plantation and agriculture development in recent years were the major reasons for positive change in NPP over Mizoram. This analysis will be helpful for strengthening our understanding the role of regional landcover types and impact of their change in the global carbon cycle.

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Dualistic development and economic benefits: Experience from Community Forestry in Nepal

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Abstract

This paper attempts to generalize the theoretical construct of dualistic development and stylized typology model in community forestry in Nepal. This paper draws inferences from critical review of few forest based enterprises implemented under different hypothetical projects/program to reinforce the logical interpretation of potential spillover effect of dualistic development on economic development at community level in general and in particular to income distribution at household level. It further examines the strength, weakness and threat associated with the particular enterprising and institutional practices adopted by local community for economic development and prosperity. Using Gary Fields' stylized development typologies, this paper dwells on the applicability of this framework to scale up the best community based forestry practices in Nepal.

It also examines the possible impact of community based forestry practices on income distribution on dualistic development, without spearheading a specific approach, this paper intends to garner a policy discourse on the stylized and dualistic development approach.

The paper proposes way forward options for further discussion to stimulate policy dialogue to revisit the role of community forestry in socio-economic development of local community in general and in particular to targeted communities. Paper concludes with key message that this discussion is very timely and critical in the context of recently concluded sixth National Community Forestry Workshop which laid out the corner stone of long-term vision for Community Forestry in Nepal.

I. Background

Nepal's forest resource constitutes nearly 39.6 percent of the total land area. The area of the forest is about 4.3 million hectares while shrubland measures 1.6 million hectares. Except private ones, the government owns all types of the forest. Nearly one-third forests are being managed by local institutions under participatory forest management regimes. The remaining area is being managed under Protected Area management system and government managed forests. The protected area management system accounts more than 23 percent of total land mass and almost 18 percent of the forested area. The forest resource continues to decline at an alarming rate of 1.3 percent annually which is even higher in the case of the Hills and the Mountain. The rapid decline in forest resource in spite of a widely appreciated participatory forestry programme (community forestry) puts forestry sector in the spot light of development discourse.

Deforestation and forest degradation have been a persistent problem in Nepal. The annual rate of deforestation in the Hills between 1978/79 and 1994 stood at 2.3 percent per annum while deforestation in the Terai for the comparable period remained 1.3 percent (DFRS, 1999). The Terai region (plain areas of Nepal constituting about 20% of the total area of the country) experienced a sharp reduction in deforestation in the late 1990s (DoF, 2005).

Community Forestry in Nepal: Almost one third of the forest areas (1.71 million hectares) throughout the country has been handed over to the local communities as community forests for ensuring communities primarily to fulfill their basic needs of forestry products, besides their active participation on conserving biodiversity, and instigating social development at local level. Morethan 18,000 Community Forest User Groups (FUGs) are managing forests throughout the country and are implementing different programmes related to forest conservation and livelihoods improvement. With wide spread community forestry, there is dilemma regarding further development of community forestry: Should the future course be "traditional sector enrichment" or "modern sector enlargement" ? With this backdrop, we resort to give introduction of the paper to our reader.

II. Introduction

This paper analyses how community forestry can affect income distribution in a dualistic economy when aid to one sector induces effect on the other. It further discusses how development fund should be channeled in community forestry keeping in mind the dualistic development. The economies is comprised of a modern sector mainly concentrated in urban areas and have export focus while traditional is predominated by agriculture sector often termed as backward sector. Suppose a development fund originating from the national treasure or from foreign aid mainly stemming from development partners, is made available for use in either of two ways in community forestry: (1) to expand production and employment in the economy's modern sector (a process termed "modern sector enlargement" for hypothetical example: AUSAID assistance to establish a pole treatment plant at Panchkhal with export focus) or (2) to enhance productivity in the domestic sector (a process termed "traditional sector enrichment" for example say DFID support to improve agriculture through the use of compost making utilizing leaf litters collected from community forest).

This paper dwells on the possible effect on income distribution on dualistic development and without spearheading a specific approach, intends to garner a policy discourse on the stylized and dualistic development approach in community forestry.

Nepal’s Finance Minister in his budget speech of Fiscal year 2013-14 has vowed to transform Nepal into a developing country by the year 2022, that demands a renewed dialogue on future pathway of community forestry (GovN, 2013).

III. Methodology

This paper is mainly based on the field experience of the authors, who worked in different districts of Nepal in the initial development stages of community forestry. The two examples, namely pole treatment plant and compost making using the leaf-litters are two case studies that represent modern sector enlargement and traditional sector enrichment respectively. The paper is mainly based on the stylized typology used by Gary Field and is based on the theoretical framework, mainly to assess impact of dualistic development on income distribution.

IV. Discussion

As already mentioned, in this short paper, we are using Gary Fields' stylized development typologies (Todaro and Smith, 2004) to explain shifting of Lorenz curves and consequent impact on income distribution:

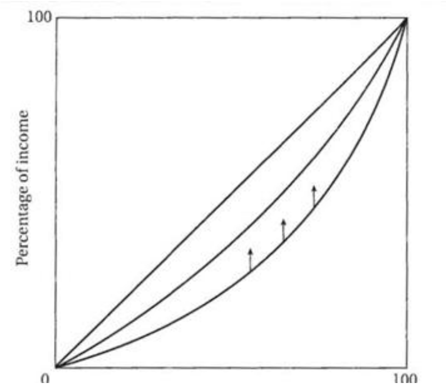
1. The modern-sector enlargement typology in which two-sector economy develops by enlarging the size of modern sector. While maintaining constant wages in both sectors as depicted by the Lewis model, we attempt to assess effect on income distribution. Example is enterprises development or rapid industrialization due to forward and backward linkages of community forestry development in Nepal. One real example of modern sector enlargement in community forestry is given in box-1.
2. The modern-sector enrichment growth typology, in which the economy grows but such growth is limited to a fixed number of households in modern sector, with both the numbers of farmers and their incomes held constant in the traditional sector. Example is development of industries like saw-mill due to forward linkages of community forestry.
3. Traditional sector enrichment growth typology, in which all the benefits of growth are divided among traditional sector households, with little or no growth occurring in the modern sector. This process roughly describes the increased production of cereal crops and livestock due to increased availability of farm-inputs (leaf-litters, fodder etc) from the community forests. It helps in policies focused on achieving substantial reductions in absolute poverty even at very low incomes and with relatively low growth rates.

V. Reflections

In the following section we are trying to use three stylized cases and Lorenz curves to demonstrate the validity of the following propositions. We have just reversed the order presented above.

1. In the traditional-sector enrichment typology, growth in the traditional sector results in higher income of farming households. It leads to a more equal relative distribution of income, and that culminates into reduced poverty. Thus, the traditional-sector enrichment growth ultimately causes Lorenz curve to shift uniformly towards the line of equality. This shift closer toward the line of equality, as portrayed in figure 1 explains reduced poverty with traditional sector enrichment.

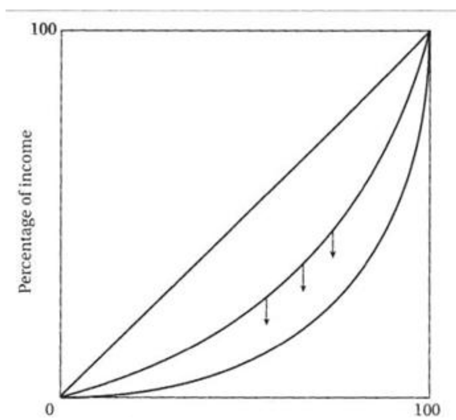
Figure-1: Traditional-sector enrichment and consequent poverty reduction



Percentage of income recipient households
(Modified from Todaro and Smith, 2004)

2. In the modern-sector enrichment growth typology, growth results in higher incomes of households in urban areas. However, it leads to a less equal relative distribution of income among the urban and rural sector. It will produce no change in poverty. Modern-sector enrichment growth causes the Lorenz curve to shift downward and farther from the line of equality as shown in figure-2. This aggravates inequality with households in lower scale of income having reduced share of income will either have no effect or aggravate poverty.

Figure-2: Modern-sector enrichment with no change in poverty or even aggravated poverty

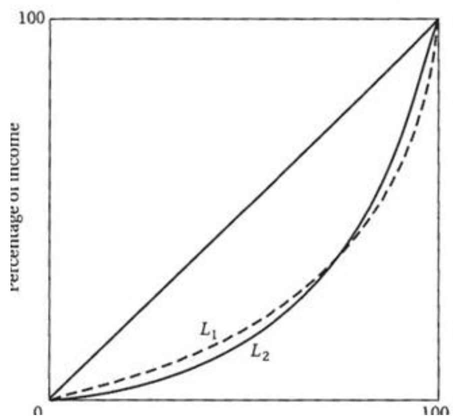


Percentage of income recipient households
(Modified from Todaro and Smith, 2004)

3. Finally in the case of modern-sector enlargement growth propelled by Lewis, absolute income of the urban household rises sharply and absolute poverty in urban locality is reduced. However, the Lorenz curve will always cross at somewhere in the midway so that we cannot make unambiguous statement about the changes in relative inequality among the households. The inequality in income distribution may improve or worsen in the long run. According to Fields, if this style of growth experience is predominant, inequality is likely first to worsen in the early stages of development and then to improve in later stages which is more similar to

Kuznets' inverted U hypothesis. The crossings of the Lorenz curve as suggested by Fields is demonstrated in figure 3.

Figure-3: Modern-sector enlargement with initial aggravation and subsequent reduction of poverty



Percentage of income recipient households
(Modified from Todaro and Smith, 2004)

We can give the explanation for the crossing of the Lorenz curves in figure 3 as follows:
The poor households who remain in the traditional sector have their incomes unchanged. Mainly because there are no investments of development fund in this sector. Hence, these incomes now represent a smaller fraction of the larger total income accrued due to modern sector enlargement. So the new Lorenz curve, L2 , lies below the old Lorenz curve, L1, at the lower end of income distribution scale. Each modern-sector household receives the same absolute income as before, but now the share received by the richest income group is smaller than before. It explains why the new Lorenz curve lies above the old one at the higher end of income distribution scale. Hence, it can be safely interpreted that somewhere in the middle of the distribution, the old and new Lorenz curves must cross each other.

VI. Conclusion

These three typologies offer different predictions about what will happen to inequality in the course of economic growth in community forestry. With modern-sector enrichment, inequality would rise steadily, while under traditional-sector enrichment, inequality would fall steadily and under such circumstances allocating the development fund for purposes of traditional sector enrichment might be a better option. In contrast, under modern-sector enlargement inequality would first rise and then fall. If this admittedly highly stylized process of development were occurring, we would not be concerned about the temporary rise in inequality for two reasons. Firstly, in addition to being temporary, it would be reflecting a process rather than the phenomenon itself. Secondly, increased resources availed due to community forestry will result in a situation in which the member households of forest user group are, one by one, achieving incomes above the poverty line.

These observations tell us that we have to qualify our conclusion that inequality is bad in general sense. In particular, in some cases inequality may increase on temporary basis as we have observed in case of modern-sector enlargement growth. It is due to the causes that will eventually make everyone better off and ultimately lower inequality in long run. On the other hand, with modern-sector enrichment growth, the increase in inequality is not later reversed, and the poorest households of the forest user group do not escape their poverty. As a result, we need to be careful about drawing conclusion from short-run changes in economic statistics of community forestry before we get insights about the underlying changes in the real economy that gave rise to these statistics. The process of modern-sector enlargement growth suggests a possible mechanism that could give rise to Kuznets' "inverted-U" hypothesis which has been established in the course of development however the hypothesis itself is disputable.

VII. Way forward: *Dubidha* (Dilemma)

Different theoretical perspectives on dualistic development suggest different ways of allocating such a development fund. Those who follow Lewis, Fei and Ranis, Jorgenson and others might tend to regard modern sector as the leading sector and the trade as the engine of growth. If this path is followed establishing a sawmill or pole treatment plant at Panchkhal can be a good option to be pursued in community forestry. The underlying assumption is that the best use of additional development resources is to stimulate the modern sector, thereby achieving export-led growth. While the others believing traditional sector enrichment would tend to argue just opposite. If we follow Schultz and Adelman, we are inclined to believe that traditional sector (agriculture) has been deprived of resources and availability of community forests will complement the resources need of this sector. An influx of development fund in traditional sector would have a higher marginal product than in the modern sector besides reducing risk of higher unemployment (search unemployment) in the latter sector due to crowding effect. It ultimately leads to aggravating unemployment in urban areas while simultaneously lowering output in rural areas.

Those who favor Panchkhal pole treatment plant and advocate development resources to the modern sector tend to presume that economic growth is best achieved by shifting the locus of economic activity towards modern sector activities. The crux of development of modern sector lies on a number of assumptions: the marginal product of additional resources allocated to the modern sector is high; the labor required for production expansion is available; the additional products have market; and merely little output is foregone and finally job opportunities will attract job seekers that aggravate unemployment.

At the other end of the spectrum, the proponents of DFID's compost making training to the farmers to enhance agriculture, presume that economic growth is best achieved by targeting economic activity in traditional sector - which is starving for additional resources. The cruxes of argument; marginal product of additional resources allocated to the traditional sector is high; plenty of labor available (underemployment); increased agri-products have multiplier effect on the local economy; market is ensured and investment in agriculture ensures holistic development of the economy.

The preferred allocation of development resources between sectors visibly depend on the amount of modern sector enlargement and traditional sector enrichment that could be achieved under alternative resources allocations and structure of labor market. One of the practical significances of initiating such a discussion is as follows: Using additional development resources to expand modern sector exports and employment is most efficient when marginal product of the capital in modern sector is high and trend of migration low. At the other paradigm when the marginal product of capital is higher in the traditional sector compared to modern sector and wide spread unemployment/underemployment, under such circumstances allocating development fund for enrichment of the traditional sector might be a better option.

The sixth national community forestry workshop, initiated a policy discourse for the destination of community forestry: traditional sector enrichment or modern sector enlargement? It requires further discourse and perhaps only the stakeholders of community forestry will be able to direct - an answer at this point is perhaps beyond the scope of this paper.

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Estimation of Carbon Stock in Trees Outside Forests (TROF) Systems of Nuwara Eliya District in Sri Lanka

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Abstract

The potential of Trees Outside Forests (TROF) systems to act as a sink for carbon (C) is highly recognized by scientists. However, estimations of C stocks of TROF systems are incomplete and sketchy in Sri Lanka. Therefore, the objective of this study was to estimate the amount of carbon sequestrated by TROF systems in different agro-ecological regions in Nuwara Eliya district. To estimate the carbon stock of different TROF systems, 251 square shape sample plots of 400 m^2 were used. Measurement of various components of carbon pools were taken in sub plots of varying size in nested sample plots. Amount of biomass contents of each carbon pool was estimated using allometric equations developed for similar climatic conditions. Estimated biomass values were converted to carbon stocks using 0.47 carbon fraction. Carbon stocks of different TROF systems are varied according to agro-ecological regions. The highest amount of carbon stock in tea based system was estimated at 1,146.7 Gg in wet zone up country (WU_2) agro-ecological region whereas the same for homegarden was estimated at 500 Gg in intermediate zone mid country (IM_{1a}) agro-ecological region. Carbon stock of TROF systems of Nuwara Eliya district was estimated at 6,541.7 Gg of which over 94% was stored in tea based and homegarden TROF systems. Amount of atmospheric carbon content stored in TROF systems of Nuwara Eliya district was estimated at 24,008.04 Gg.

I. Introduction

The ability to accurately and precisely measure the carbon stored and sequestered in forests and Trees Outside Forests (TROF) systems is increasingly gaining global attention in recognition of the role of forests and TROF systems have in the global carbon cycle (IPCC, 2003; Brown, 2002). There are two key policy-related reasons for measuring carbon in forests. Firstly, according to the commitments under the United Nations Framework Convention on Climate Change (UNFCCC) signed by more than 150 countries requires that all Parties to the convention commit themselves to develop, periodically update, publish, and make available to the Conference of Parties (COP) their national inventories of emissions by sources and removals by sinks of all green house gases (GHG) (IPCC, 2003; Patenaude *et al*., 2005). Secondly, for potential implementation of the $REDD^+$ is aiming at creating of financial benefits to countries who manage their forests in sustainable manner while increasing the absorption of greenhouse gasses which ultimately result in reduction of global warming (Angelsen *et al*., 2009). Even though many measurement protocols for carbon pools are available (Brown and Masera 2003; Pearson *et al.*, 2005; IPCC 2006), no methodology has been accepted as comprehensive in estimating forest carbon stocks across a landscape. Much effort has made to develop tools and models that can ‘scale up’ or extrapolate destructive harvest data points to larger scales based on proxies measured in the field or from remote-sensing instruments (Brown 1997; Chave *et al.*, 2005; Saatchi *et al.*, 2007). Accordingly, the objective of this study was to estimate carbon stock of TROF systems in large area by using remotely sense data with ground base sample plot measurements.

II. Material And Methods

Study area and sampling of TROF systems

Nuwara Eliya district located in the central Sri Lanka (latitude 6^0 45' N and 7^0 15^0 N, longitude 80^0 25' E and 81^0 E) consists of 14 out of 46 agro-ecological regions of the country (Punyawardena, 2007) was selected as the study area. Map of spatial distribution of TROF systems prepared by Premakantha *et al*. (2008; 2012) using Landsat imagery was used in the study. Accordingly, the study area was classified into 5 broad TROF systems, namely tea based, homegarden, annual crop based, grassland and urban agricultural TROF systems. TROF system map was overlaid with the agro-ecological region map to identify homogenous vegetation strata for each TROF system. A total of 251 sample locations with an area of 400 m^2 (20 x 20 m) were located using a GPS and used to collect field data (Figure 1).

At each location, date, plot number, GPS locations in XY coordinates, land use, details such as address, slope, elevation, major and other uses of trees and the tree measurements were recorded. According to Kauffman and Donato (2012) many plot sizes and shapes can adequately describe forest composition, biomass and ecosystem carbon pools and no single plot size and shape is optimal. Therefore, nested sample plots were used to save time in collecting data on components of carbon stock. Data on live and dead trees greater than 10 cm dbh were taken from entire 20 x 20 m plot. Measurements for non woody vegetation were taken from 4 x 4 m sub plots while measurements for saplings, seedlings and small liana were taken from 3 x 3 m sub plots. Percent ground cover of herbaceous vegetation was visually estimated and recorded in 1 x 1 m plots. To collect litter, 30 x 30 cm sampling frame was used.

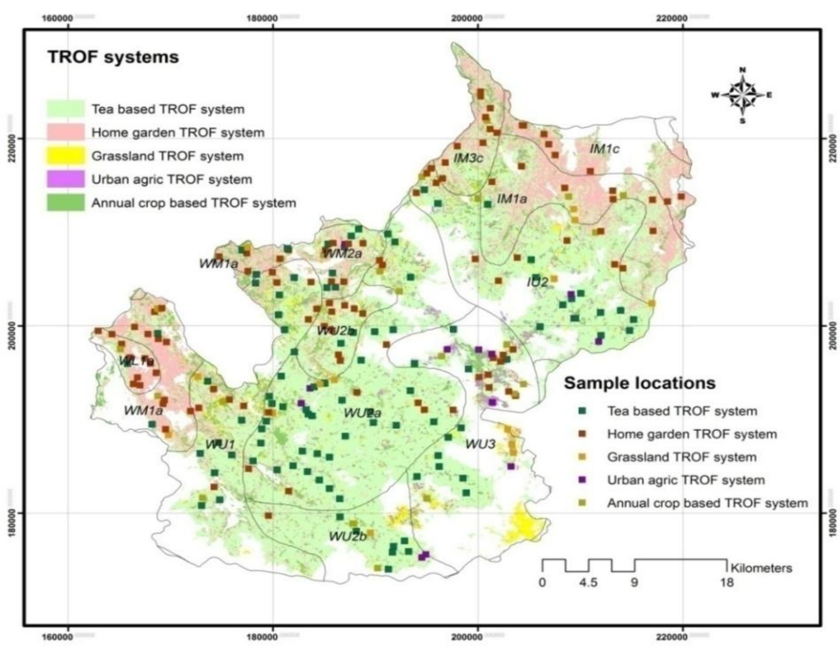

Figure 1: Distribution of five TROF systems and field sample locations in the study area.

Calculation of carbon stock

Globally accepted carbon estimation methodology has not yet been developed though many isolated studies have been carried out by scientists. The methodology used in this study considered the guidelines laid in the Good Practice Guidance for Land Use, Land Use Change and Forestry by IPCC (2003) and the methodology suggested by Pearson *et al*. (2005). In each TROF system, components of carbon pool differ in terms of structure and magnitude. Method of assessment of carbon also differs for components of carbon pools.

Estimation of above ground biomass

Live trees

No biomass equations have been developed for calculating biomass of trees grown in TROF systems. However, few equations are available for natural forests as well as for forest plantation species. An equation developed by Brown (1997) for the climatic region similar to Nuwara Eliya was used in this study and given below:

$Y = \exp(-2.289 + 2.649 \ln dbh - 0.021 \times \ln dbh^2)$ ………………………………………. (1)

Where, Y = biomass content (kg), dbh = diameter at breast height (cm)

Palm

Monocotyledon trees comprise of linear stems with no or very few branches. Equation developed by Brown (1997) was also used in this study to estimate biomass of monocotyledon trees as follows:

.

$Y = 4.5 + 7.7*H$ ………………………………………………………………………... (2)

Where, Y = biomass content (kg), H = height (m)

Liana

Liana is not common in TROF systems compared to natural forests but need to include in carbon assessment as they are occasionally found in some TROF systems. Equation 3 developed by Schnitzer *et al.* (2006) was used in this regard.

$Y = dbh^{2.657} * exp^{-0.968} * In (dbh)$ ……………………………………………….………….. (3)

Where Y = biomass (kg), dbh = diameter at breast height cm)

Dead trees

Trees shed their leaves when they die, so that the amount of foliage should be deducted when estimating carbon content of dead trees. Therefore, to calculate biomass content of a dead tree, firstly calculate the biomass content of the tree as if it is a live tree and then deduct 2.5% from the total biomass for recently dead trees. Biomasses of dead saplings were calculated by deducting 5% from the total biomass of a sapling as the fraction of foliage of saplings is more compared to mature trees.

Taper equation for dead trees

The very old dead trees usually do not carry branches on them and volume was calculated using the equation proposed by Pearson *et al.* (2005). Top diameter is calculated using diameter of the base and the height of the tree and volume is calculated using basal and top diameters and the height of the tree.

Volume of standing dead trees (cm^3)

$V = (\pi\ (0.01 \times ht)/12) \times (d^2_{base} + d^2_{top} + (d_{base} \times d_{top}))$……………………………...…(5)

Where v = volume (m^2), ht = Height (m), dtop(cm) = the estimated diameter at top of tree (cm), d_{base} = the measured basal diameter (cm)

$d_{top} = d_{base} - [100 \times ht \times (d_{base} – dbh)/130)]$…………………………………………..(4)

Where, ht = Height (m), dtop (cm) = the estimated diameter at top of tree (cm), d_{base} = the measured basal diameter (cm), If taper equation results in negative number, use 0 for d_{top}

Dead tree biomass (g)

Dead tree biomass = Volume (cm^3) x wood density (g cm-^{3})………………….…… (6)

Total biomass density (Mg ha^{-1})

Volume of stumps

Volume of a stump is estimated using Newton's formulae as the shape of stump is considered as a neiloid.

$V= (A_1+4A+A_2)/6 * L$……………………………………………..………..…..... (7)

Where, A = Average diameter of small and large ends of stump, A1=Diameter of small end of stump (cm), A_2 = Diameter of large end of stump (cm), L = Length (m) (Height of the stump)

Below ground biomass

Very few below ground biomass equations are available since formulating these equations are costly and time consuming as the process involves uprooting trees and separation even finest roots from the soil for the estimation. Thus, in this study, equation developed by Cairns *et al*. (1997) was used to calculate the below ground biomass of trees.

$BBD = \exp(-1.0587+0.8836 \times \ln(ABD))$ ……………………………………….…….(8)

Where, ABD = above ground biomass density (t/ha), BBD = below ground biomass density (t/ha)

Wood debris/Downed wood

Unlike in natural forests, wood debris/downed wood are rarely found in TROF systems as they are collected for fuelwood by the people. Even though the estimation of carbon content was not possible for this component due to removal of them by people, a considerable amount of carbon would have been contained in debris than in the litter.

Destructive harvesting of vegetative components

Biomass of the vegetative components for which relationship of volume is not strong with independent variables such as dbh, height or crown parameters was estimated by destructive harvesting method. Of these components, only the count of them was taken in the sample plots. Therefore, mean biomass content of these components had to be calculated. In case of tea, twenty five tea bushes from each group (seedling and vegetative propagated tea) were uprooted, roots were cut using a hand saw and leaves were separated from the stem parts and weighted. Finally, sub samples were taken from each component and weighed. Samples were oven dried at 50 ^{0}C until a constant mass was reached. Then ratio between wet and dry mass of sub sample were used to estimate the dry mass of the each sample. Biomass of a tea bush was calculated by adding the biomass of each component. Finally, mean biomass of tea bush was calculated by averaging the estimated value of all the tea bushes. These values were used to calculate the total biomass of the system. Same procedure was used for other components such as seedlings and non tree vegetations.

Total biomass

Total biomass density was calculated by summing up mean carbon density of each carbon pool.

Total biomass density = $B_{tAG} + B_{tBG} + B_{dtAG} + B_{dtBG} + B_{sp/adAG} + B_{sp/sdBG} + B_{dsp/adAG} + B_{dsp/sdBG} + B_{ntvg} + B_{Wdb} + B_{l}$…………………………………………………………………..(9)

Where, B_{tAG} = Above ground biomass of live trees, B_{tBG} = Below ground biomass of live trees, B_{dtAG} = Above ground biomass of dead trees, B_{dtBG} = Below ground biomass of dead trees, $B_{sp/adAG}$ =above ground Biomass of seedlings/saplings, $B_{sp/sdBG}$ = Below ground biomass of seedlings/saplings; $B_{dsp/adAG}$ = Biomass of dead seedlings/saplings above ground, $B_{dsp/sdBG}$ = Below ground biomass of seedlings/saplings, B_{ntvg} = Biomass of non tree vegetation, B_{Wdb}= Biomass of wood debris, B_{l}= Biomass of Litter

Total carbon density

In recent studies, percentage of carbon in biomass was considered in the range of 45-50. In this study total biomass was converted to total carbon by multiplying with 0.47.

Total carbon density (t/ha) = Biomass (t/ha) * 0.47…………………………………… (10)

Total carbon stock (Gg)

Total carbon stock of TROF systems were calculated by multiplying mean carbon density of all the carbon pool by the area of TROF systems (Kauffman and Donato, 2012).

TC = Total carbon density (t/ha) x Area (ha) x 0.001……………………………..….. (11)

TC = Total carbon dioxide equivalents (Gg)

Total amount of carbon sequestrated from a TROF system can be calculated by converting total carbon stock into carbon dioxide equivalents. Total carbon stock was multiplied by 3.67 to get the CO_2 equivalents (Gg) as the ratio of molecular weights between carbon dioxide and carbon is 3.67 (Kauffman and Donato, 2012).

$TCco_2 = 3.67 \times TC$…………………………………………………………………… (12)

Where, $TC\ co_2$ = Total carbon stock (Gg CO_2 equivalents), TC = Total carbon stock (Gg), (Kauffman and Donato, 2012).

III. Results And Discussion

Total carbon content of TROF systems of Nuwara Eliya district

The average biomass and carbon densities of TROF systems of Nuwara Eliya district were varied amongst TROF systems (Table 1). Lowest biomass and carbon density was recorded in annual crop based TROF system whilst highest biomass and carbon density was recorded in homegarden TROF system which is roughly seven times higher than that of annual crop based TROF system. Carbon density of homegarden TROF system is two times higher than that of tea based TROF system. Urban agricultural TROF system and Grassland based TROF system have more or less similar biomass and carbon densities.

Table 1: Average biomass and carbon densities of TROF systems in Nuwara Eliya district.

TROF system	Average biomass density (t/ha)	Average carbon density (t/ha)
Homegarden TROF system	195.10	91.70 (52.8)
Tea based TROF system	97.97	46.05 (8.5)
Urban agricultural TROF system	54.71	25.72 (10.8)
Grassland TROF system	52.97	24.90 (10.1)
Annual crop based TROF system	27.95	13.13(3.4)

*Standard deviation is in parenthesis

Though biomass and carbon densities are less in tea based TROF system compared to homegarden TROF system, it produces 2.4 million tons of biomass and 1.1 million tons of carbon than homegarden TROF system due to larger extent of the system. Low density TROF systems namely urban agricultural TROF system, grassland TROF system and annual crop based TROF system produces minute amounts of biomass and carbon compared to other TROF systems assessed in this study (Figure 2).

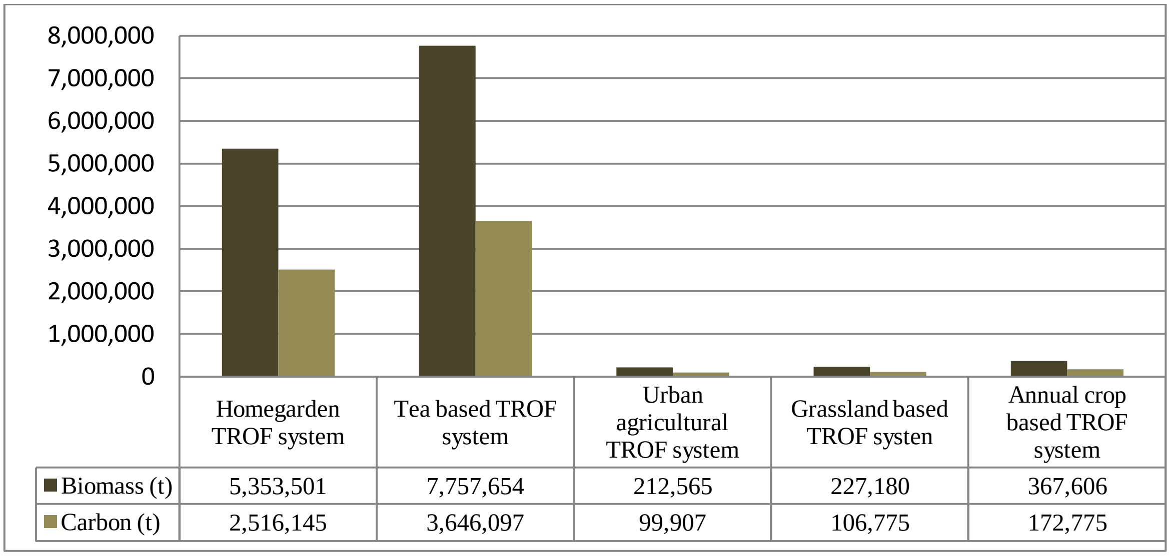

Figure 2: Total biomass and carbon stock of TROF systems in Nuwara Eliya district.

Trees are the major contributor to biomass in all TROF systems except in annual crop based TROF system (Table 2). However, contribution of tea bushes is also significant in tea based TROF system. Herbaceous vegetation and grasses together contribute substantial percentage towards biomass contents in low density TROF systems. Contribution to biomass and carbon content from different species of trees is also of varying magnitude (Table 3). Results show that *Artocarpus heterophyllus*, *Mangifera indica*, *Ceiba pentandra*, *Michelia champaca* and *Toona cinensis* accounts more than 60% of the biomass and carbon content in homegarden TROF system whilst *Gravillea robusta*, *Erythrina variegate*, *Albizia molucana*, *Toona cinensis* and *Eucalyptus grandis* accounts more than 96% of the biomass and carbon content in tea based TROF system.

Table 2: Biomass partitioning amongst different components of TROF systems in Nuwara Eliya district.

Component	Homegarden TROF system	Tea based TROF system	Urban agricultural TROF system	Grassland TROF system	Annual crop based TROF system
Trees (%)	92.4	53.7	77.9	75.8	3.9
Seedling and seedlings (%)	2.6	0.0	0.4	0.25	0.7
Deadwood (%)	2.8	0.0	0.0	0	0.0
litter (%)	0.3	0.0	0.2	0	0.0
Herbaceous vegetation (%)	1.9	0.0	21.4	23.9	95.3
Shrubs (%)	0.0	0.0	0.0	0.0	0.0
Tea bushes (%)	0.0	46.3	0.0	0.0	0.0

Table 3: Contribution of different species to carbon content in tea based and homegarden TROF systems.

Home garden TROF system		Tea based TROF system	
Species	**Carbon content (t/ha)**	**Species**	**Carbon content (t /ha)**
Artocarpus heterophyllus	17.69	*Gravillea Robusta*	17.01
Mangifera indica	11.24	*Erythrina variegata*	3.14
Ceiba pentandra	5.79	*Albizia molucana*	2.45
Michelia champaca	5.04	*Toona cinensis*	1.68
Toona cinensis	3.18	*Eucalyptus Grandis*	0.81
Eucalyptus grandis	2.95	*Cypress macrocarpa*	0.22
Persea Americana	2.18	*Gliricidia sepium*	0.21
Neolitsea cassia	1.93	*Michelia champaca*	0.21
Swietenia mahogany	1.74	*Acacia decurrens*	0.11
Gravillea robusta	1.70	*Calliandra calothyrsus*	0.08

In addition to variation of carbon densities in different components of a TROF system, carbon content also varied along the agro-ecological variation within a TROF system. Difference between the highest and lowest biomass densities according to agro-ecological regions in homegarden TROF system is

348.2 (t/ha). Difference between highest and lowest carbon densities according to agro-ecological region in other TROF systems is moderate. Table 05 shows the carbon densities of TROF systems according to agro-ecological regions. Biomass and carbon densities of different TROF systems in different agro-ecological regions are also varied (Tables 4 and 5).

Table 4: Biomass densities (t/ha) of TROF systems in terms of agro-ecological regions.

Agro ecological region	Homegarden TROF system	Tea based TROF system	Urban agricultural TROF system	Grassland TROF system	Annual crop based TROF system
IL_2	178.9	94.4	0.0	0.0	14.4
IM_{1a}	178.9	95.2	31.1	32.9	23.2
IM_{1c}	260.7	94.7	32.5	32.9	17.5
IM_{3c}	168.0	94.5	32.5	32.9	17.5
IU_2	411.9	123.0	32.5	45.8	35.4
IU_{3b}	0.0	122.5	0.0	45.8	35.4
IU_{3d}	411.9	122.5	32.5	0.0	35.4
WL_{1a}	166.4	84.1	0.0	0.0	30.8
WM_{1a}	176.2	68.0	32.5	25.7	31.6
WM_{2a}	151.6	88.2	85.2	23.2	31.8
WU_1	167.8	72.2	37.7	49.8	27.7
WU_{2a}	129.7	102.9	37.7	49.8	25.2
WU_{2b}	152.4	75.3	23.7	49.8	29.2
WU_3	63.7	107.4	61.3	70.6	33.5

Table 5: Carbon densities (t/ha) of TROF systems in terms of agro-ecological regions.

Agro ecological region	Homegarden TROF system	Tea based TROF system	Urban agricultural TROF system	Grassland TROF system	Annual crop based TROF system
IL_2	84.1	44.4	0.0	0.0	6.8
IM_{1a}	84.1	44.7	14.6	15.4	10.9
IM_{1c}	122.5	44.5	15.3	15.4	8.2
IM_{3c}	79.0	44.4	15.3	15.4	8.2
IU_2	193.6	57.8	15.3	21.5	16.6
IU_{3b}	0.0	57.6	0.0	21.5	16.6

IU_{3d}	193.6	57.6	15.3	0.0	16.6
WL_{1a}	78.2	39.5	0.0	0.0	14.5
WM_{1a}	82.8	32.0	15.3	12.1	14.8
WM_{2a}	71.2	41.4	40.1	10.9	15.0
WU_1	78.9	34.0	17.7	23.4	13.0
WU_{2a}	61.0	48.4	17.7	23.4	11.8
WU_{2b}	71.6	35.4	11.1	23.4	13.7
WU_3	30.0	50.5	28.8	33.2	15.8

Estimated carbon stock of TROF systems according to agro-ecological regions in Nuwara Eliya district is given in Table 6. IM_{1a} agro-ecological region holds the highest carbon stock in homegarden TROF system which account for nearly 20% of the total carbon stock. In case of tea based TROF system 30% of carbon stock contains in WU_{2a} agro-ecological region. Larger portion of carbon stock in grassland and annual crop based TROF systems is coming from wet zone up country regions (Table 6).

Table 6: Total carbon stock (Gg) of TROF system in Nuwara Eliya district.

Agro ecological region	**Homegarden TROF system**	**Tea based TROF system**	**Urban agricultural TROF system**	**Grassland TROF system**	**Annual crop based TROF**
IL_2	15.1	3.0	0.0	0.0	0.01
IM_{1a}	500.0	286.6	1.4	1.6	10.16
IM_{1c}	371.0	58.8	0.1	0.1	3.40
IM_{3c}	184.6	100.6	0.5	1.8	8.05
IU_2	394.1	880.6	9.5	12.3	26.45
IU_{3b}	0.0	0.6	0.0	0.3	0.00
IU_{3d}	1.9	11.9	0.1	0.0	0.12
WL_{1a}	100.3	25.0	0.0	0.0	1.23
WM_{1a}	339.7	54.4	0.1	1.0	10.81
WM_{2a}	168.9	95.0	42.4	1.5	15.81
WU_1	253.2	306.7	3.5	19.4	32.51
WU_{2a}	91.9	1,146.7	11.8	17.1	30.37
WU_{2b}	90.4	344.4	2.4	11.5	15.98
WU_3	5.0	331.8	28.1	40.3	17.88
Total	2,516.1	3,646.1	99.9	106.8	172.8

Tea based TROF system and homegarden TROF system contribute 56% and 38%, respectively to the total of 6,541.70 Gg of carbon in the TROF systems of Nuwara Eliya district (Figure 3). This shows that these two TROF systems together stored 94% of the carbon in the district.

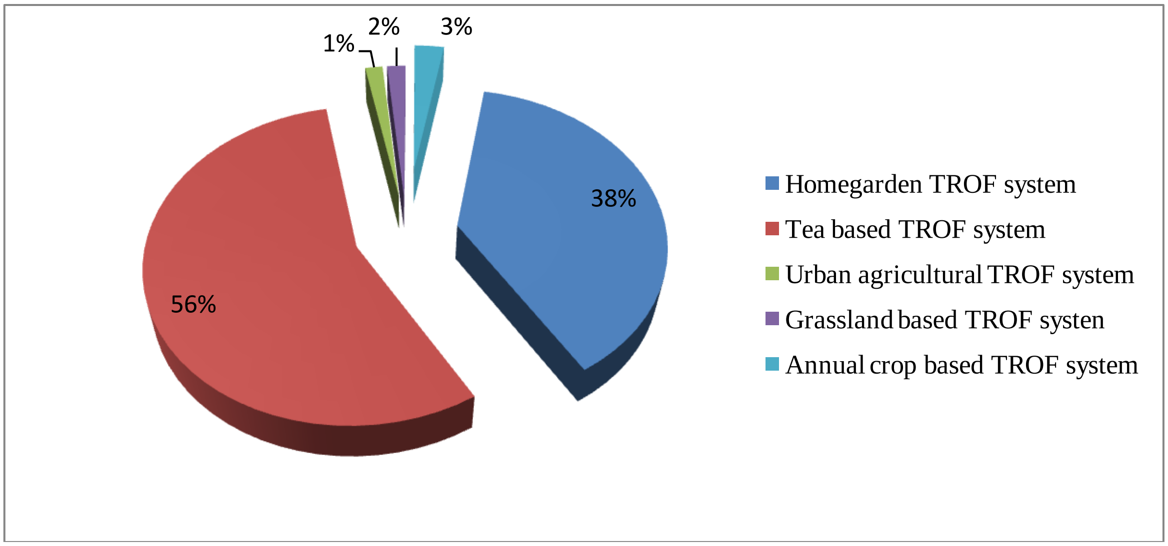

Figure 3: Proportion of carbon stored in different TROF systems in the Nuwara Eliya district.

Table 7 shows the amount of carbon dioxide equivalents in TROF systems with agro-ecological variation. It shows that carbon dioxide equivalents in tea based TROF system is nearly 4,000 Gg higher than in homegarden TROF system.

Table 7: Carbon dioxide equivalent in TROF system in Nuwara Eliya district

Agro ecological region	**Homegarden TROF system**	**Tea based TROF system**	**Urban agricultural TROF system**	**Grassland TROF system**	**Annual crop based TROF**
IL_2	55.5	11.1	0.0	0.0	0.02
IM_{1a}	1,835.2	1,051.7	5.3	5.9	37.30
IM_{1c}	1,361.4	215.8	0.2	0.4	12.49
IM_{3c}	677.6	369.1	2.0	6.6	29.53
IU_2	1,446.4	3,231.8	35.0	45.1	97.07
IU_{3b}	0.0	2.3	0.0	1.1	0.00
IU_{3d}	7.1	43.7	0.2	0.0	0.43
WL_{1a}	367.9	91.9	0.0	0.0	4.51
WM_{1a}	1,246.7	199.6	0.2	3.7	39.69
WM_{2a}	619.9	348.5	155.4	5.5	58.02
WU_1	929.2	1,125.7	13.0	71.2	119.30
WU_{2a}	337.4	4,208.3	43.2	62.8	111.45
WU_{2b}	331.7	1,263.8	8.9	42.2	58.64
WU_3	18.2	1,217.8	103.1	147.9	65.63
Total	**9,234.3**	**13,381.2**	**366.7**	392.0	**634.1**

There is no universally accepted methodology in estimating biomass content and carbon stock. Huge basket of choices available but none is technically precise and accepted by all the scientists. Estimation of total organic carbon requires a complete enumeration of the entire ecosystem's components that include saplings, vines and dead plant matter such as standing woody stems so that it is not only difficulty and lengthy but also tedious and expensive. Therefore, very little amount of studies have been done based on samples, even so they may not comparable as the methodology and the materials used are different.

Most allometric equations have been constructed for trees grown insides the forests, not for trees grown outside the forests. Typically it is expected that 30 percent more biomass form a tree grown outside the forest than that of a tree grown inside the forest from a same seed lot due to less competition for growth requirements exist outside the forests (Brown 1997). It should e noted that though allometric equation used in this study wasn't constructed for trees outside the forests, no adjustment made for the carbon stock considering above.

A number of studies have estimated the potential of agroforestry systems to act as effective carbon sinks (IPCC, 2000; Montagnini and Nair, 2004). Assuming mean carbon content of above ground biomass of 50%, average carbon storage by agroforestry practices has been estimated to be 9, 21, 50, and 63 /ha in semiarid, subhumid, humid, and temperate regions respectively. According to study carried out by Kaul (2010) in India average tree carbon density of non-forest area is 4 t/ha and in contrast average density of forests is 43 t/ha.

Mattsson (2012) estimated above and belowground carbon density of open forest and sub montane forest in Sri Lanka at the rate of 26 – 31 t/ha and 159-175 t/ha respectively. Costa and Suranga (2012) estimated an above and belowground density of 157 t/ha of monoculture and mixed plantation forests in Nuwara Eliya district in 2008. This study reveals that TROF systems such as homegarden and tea based TROF systems contain substantial amount of carbon stock which may have considerable mitigatory effect of global warming.

Results showed that total carbon density of TROF systems in Nuwara Eliya district of Sri Lanka varied greatly between major TROF systems. Further, to this carbon density greatly diverse within a TROF system too due to species composition and structure driven by climatic and soil factors apart from the anthropogenic factors. Difference of per hectare carbon values explain us what an amount of carbon dioxide can be released to atmosphere if land use change from one another. Most unfavorable land use change in term of release of carbon dioxide equivalents would be from homegarden TROF system (336.53 t/ha) to annual crop based TROF system (48.19 t/ha) is 288 t/ha .

Among the TROF systems studied highest potential in increasing biomass and carbon content exist in homegarden TROF system since it is a managed cropping system for producing timber and fuelwood with trees holding major share of land space (FSMP,1995). If the amount of biomass could be increased by 5% total with better management and introduction of more trees to system carbon stock would be increased by 125.76 Gg equaling to carbon dioxide equivalents of 461.52 Gg.

IV. Conclusions

Total carbon stock values of Trees Outside Forests (TROFs) in this study can be considered as the first of its kind for overall estimates of total carbon stock in the Sri Lankan TROF systems. It shows the importance of keeping high density TROF systems intact as they content huge amount of carbon stock than other TROF systems. It also shows that agro-ecological differences too need to be address for better estimates of carbon stocks in any circumstances. The methodology used in this study can be effectively used to estimate TROF resources and their biomass and carbon content in other areas of Sri Lanka as well.

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