CHAPTER 1

1. INTRODUCTION

The forest carbon has major role in mitigation and adaptation against the climate change, which is global burning issues (Seo & Mendelsohn, 2008). It is obvious fact, that the global concern is transferred to regional and then to local level as a take home message like matter of worrying and searching the reliable and possible actions for resolution. So, the concept of "Think globally and act locally" is possible function because there are inseparable nexus between global concerns and local actions (Tewari & Karky, 2007).

Very few research works have been done on carbon stocks potential and emissions in a single package. Thus, this research work is the building block showing the forest carbon stock change potential, evaluation of carbon stock for sustainable forest management, exploration of opportunity and challenges of forest carbon trade under REDD+ programme in one hand. The effects of deforestation and forest degradation on carbon stocks as well as emission from domestic use of forest products and cattle keeping are on the other hand.

1.1 Background

Forests comprise the largest carbon pool of all terrestrial ecosystems and the annual gross exchange of CO_2 between forests and the atmosphere (Searchinger *et al.*, 2008). Forests deliver a diverse range of benefits for economics, society and the environment. They play a vital role in global carbon cycle through exchange of carbon between the land and the atmosphere. Changes in land use necessarily have a strong effect on the terrestrial carbon pool (Achard *et al.*, 2002). The conversion of other land use into forests or forest enhancement help to capture the atmospheric CO_2, which play a pivotal role to balance the environment between the land and atmosphere but the opposite actions are also true (Somanathan *et al.*, 2006).

The role of forests is acknowledged as climate change mitigation and adaptation measures in the United Nations Framework Convention on Climate Change (UNFCCC), which committed industrialized countries and others to incentivize for the reduction of greenhouse gases emissions through Clean Development Mechanism

(CDM), Reducing Emission from Deforestation and Forest Degradation (REDD+) and ecosystem services (Tavoni *et al.*, 2007, Kinzig *et al.*, 2011). This demands the records of forest carbon stock and their change so that the carbon sequestration potential can be claimed to the REDD+ programme. However, the opportunity never comes alone challenges comes together, so it is needed to understand them too. Obviously, the forest enhancement is the useful indicator of forest carbon credit but it may not assure the promotion of biodiversity significantly.

The decrease in forest and forest quality means contraction of the carbon capture capacity of the green forest (Englin & Callaway, 1993). Unhealthy and over mature forests have very low photosynthesis function rate and low carbon sequestration. One of the major reasons of the low carbon sequestration is due to effects of drivers and underlying causes of deforestation and forest degradation as well as emission from use of fuel wood and cattle keeping in developing countries (Murray *et al.*, 2004). The resultant effect is increase in atmospheric GHGs, which cause the global warming and climate change (Smith & Scherr, 2003).

Several research questions raised related to forest carbon dynamics and sources of emission. They are: What are the specieswise carbon stock and their ecological value? Are there any effects of carbon stock on ecological valuation of the species? What are the carbon sequestration potentials in community managed forests? What are the opportunities and challenges of forest carbon trade under the REDD+ programme? Are the carbon stocks indicating for sustainable management in community managed forests, if not what are the conditions of the carbon stock of these forests? Are there any significant relationship between carbon stock and biodiversity? Are there any variation in carbon stock in community managed forests due to effect of drivers of deforestation and forest degradation? Are the means of CO_2 and CH_4 emission from domestic fuel and livestock keeping same in house hold of village living near the forest and distant from the forests? This research tried to answer all these questions. Thus, the rational is explored in same procession.

1.2 Rational of the Study

There are two major issues always move together in context of climate change. They are i. role of forest carbon stock and ii. the climate change process drivers like emission due to deforestation and forest degradation and use of fuel and dung of cattle in developing countries like Nepal.

The role of forest is one the major part to opportunity of carbon trade under the REDD+ programme as climate change mitigation and adaptation tools in the world but poverty is great challenge (Gomez-Baggethun *et al.*, 2010). So, the developing countries are working with the REDD+ programme, which may be major wheels to move the Payment for Environment Services (PES) (Wunder *et al.*, 2008). Nepal too has been working with REDD+ pogramme. About 1.57 billion people or more than 30% of the population of the 104 countries live in multidimensional poverty and South Asia shared middle class population expanded from 26% to 58% between 1990 to 2010 (FRA, 2011). In reality about 60 million people (especially Indigenous Peoples) are wholly dependent on forests (FRA, 2011). So, only managing the forests is not the reliable solution to reverse the forest depletion without managing the people.

The opportunity should be searched from wise use of forest resources (Adhikari *et al.*, 2004). The expert, global and local communities should find better option for motivation for forest management. One of the appropriate options is the showing ecological value of a particular forest species because people have been allured by the importance and aesthetic value of the forest plants. Equally, other convincing way is the carbon sequestration of particular species and their effect on ecological process. This research tried to cover these aspects.

The REDD+ comprises the forest carbon enhancement, sustainable management of forests and forest conservation including the reducing emission from deforestation and forest degradation. Obviously, the technical parts of the REDD+ is the preparation of REDD+ strategies, which compulsory require designing the monitoring, reporting and verification (MRV) and developing the reference level (RL). These elements essentially need sufficient data set of forest carbon and forest carbon change. Thus, such study was important for assessing the carbon stock and carbon stock change of different community managed forests.

Statistically, about 305.11 million ha forest managed by community and indigenous peoples in 36 countries and in Asia-pacific it was about 146.00 million ha (ITTO, 2009). In Nepal, there are 18133 community forests with managing area about 165265 ha and 19 collaborative forests having managing areas 54,000 ha. The community forest management is highly appreciated because of several successful and magical changes. Specially the most common ones are preventing deforestation and forest degradation and enhancing stocks but the doubt stands still to manage the forest through community forest in Tarai and inner Tarai due to increasing trade of timber after expansion of roads (Pokharel *et al.*, 2007). The goal of REDD+ programme is to maintain the sustainability in the forests and similar objective is of the sustainable forest management (SFM) under principles of ITTO. The sustainability covers production, ecological and economic and/or social functions of forest resources. These principles tie with the target of Future of Nepal's Forest 2020 (MoFSC, 2010a). However, there is uncertainty in sustainability because of doubtful statistics of inventory. Thus, several discourses in sustainability of community forest management and REDD+ programmes are worthwhile (Barry *et al.*, 2010). The evaluation of carbon stock and their sustainability in different management regime is one of the meaningful tools but such type of research has not done before. Hence, this study was focus on evaluating carbon stocks for sustainable management of community managed forests.

Global records showed the greatest jump in the number and value of carbon offset transactions to date. From 2009 to 2010, average forest carbon offset prices increased by 22% bringing the total value of the market to US$ 178 million. Looking ahead, there is both opportunity and challenges in the development of payments for forest carbon sequestration (Nelson *et al.*, 2009). Most of the developing countries are interested to capture the opportunity of forest carbon offset (Kim-Phat *et al.*, 2004) and Nepal is moving ahead since she has implementing the readiness preparation proposal and approaching to develop Emission Reduction Package (ER-Package). The Emission Reduction Programme Idea Note (ER-PIN) is selected to access upto US$ 70 million to carbon fund for expecting to reduce 14 million tonnes of emission between 2015 to 2020 from Tarai Arc Landscape (TAL) areas covering Rauthat to Kanchanpur Tarai districts (Koirala, 2014). However, several questions were raised on the ER-PIN boundary because there was scope of expansion. In this moment, what are the potentialities of forest carbon sequestration, what are the opportunities and challenging issues to forest carbon trade under REDD+ programme are major relevant research questions beyond the ER-PIN periphery thus this research tried to answer them and show the expansion scope.

Though biodiversity conservation is major concern for global communities, REDD+ programme has not equal focus in comparison to forest carbon enhancement. Approximately 8000 plant species, or 9% of the total number of plant species worldwide are currently under threat of extinction because of forest decline and impacts of climate change (Parimalam, 2012). Conservation biologists warn that 25 % of all species could become extinct during the next 20-30 years (Parimalam, 2012). Approximately 60% (15 out of 24) of the ecosystem services were found to be degraded (MEA, 2005). Similar condition has observed in tropical biome too, because of high logging and agriculture expansion (Khera *et al.*, 2001). Nepal is very rich in biodiversity (MoFSC, 2014) which is under threat because of deforestation and forest degradation ((Jha *et al.*, 1998). So the role of biodiversity is central issue in ecosystem function (Diaz & Hector, 2009). Specifically, the biodiversity and carbon sequestration are become complement (Nelson *et al.*, 2009). Since the REDD+ programme considers the biodiversity as co-benefit. There is different notion that whether the forest enhancement may guarantee the biodiversity conservation (Spash, 2008). Thus this was valuable area of research to assess the relationship between forest carbon and biodiversity.

The increasing GHGs are the major causes of global warming. Presently, the anthropogenic release of CO_2 exceeds more than seven times due to combustion of fossil fuels (Searchinger *et al.*, 2008). The emission from industries and transportation together contribute about 58.4 % to produce the GHGs in the world (Lenny *et al.*, 2007). Conversion of forests into other land use and forest degradation contributes about 17.4% green house gases (GHGs) emission (Deschenes & Greenstone, 2007). Obviously, the reverse activities can reduce same proportion of GHGs but the key concern is which will be efficient and effective function with minimum risks. Globally, the net change in forest area was estimated -5.2 million hectares per year in the period 2000–2010. In South East Asia, the estimated annual change in forest was 221 thousand ha between 2000- 2010 (FRA, 2011). FRA/DFRS (2014) showed the forest area was decreased by 32,000 ha with annual rate of 0.40% in Tarai since the last 19 years from 1991 to 2010 in Nepal (FRA/DFRS, 2014). The climate change experts believe that, halting deforestation and restoring the forest degradation will be the effective and efficient ways to reduce the GHGs because it has enormous alternative options (Diaz & Hector, 2009). The risks hit us that without identifying the drivers of deforestation and forest degradation and their clear effects, it is difficult to deal with the mitigation and adaptation roles of forests. Thus, this study has focused on exploration of drivers of deforestation and forest degradation and their effects on the forest carbon.

The energy demand is increasing steeply because of growing population. Global energy demand will grow by 35%, as the world's population expands from about 7 billion people today to nearly 9 billion people by 2040, led by growth in Africa and India. About 2.4 billion people depend on traditional energy, mainly for cooking and heating (IEA, 2002) and their livelihood is directly linked to livestock keeping, which is a major source of CH_4 emission (Dherani *et al.*, 2008). Rural populations in developing countries rely heavily on biomass burning as a primary source of energy (Yevich & Logan, 2003). The rural household energy consumption constitutes over 70% of the national energy use in Asian countries (Koopmans, 2005). The energy consumption is growing by almost 3% annually (CBS, 2011) in Nepal. About 5.4 million tons of dry livestock manure was estimated to be available for domestic energy use in Tarai (MoF, 2010). About 64 % of the population use firewood as the usual source of fuel for cooking followed by liquefied petroleum gas (LPG) (21.03 %), cow dung (10.38 %) and other materials (4.59 %). Not only that, more than 70% of people reliant on livestock based agricultural work. In rural areas, 75.1% households use firewood for cooking whereas 35.8 % households use firewood for cooking in urban areas. Fuel wood supplies almost 80 % of total energy demand. Consequence is the significant increase in CO_2 and CH_4 emission (CBS, 2011). The climate change process driver is closely related to the sources of GHGs. Each country has to submit a national communication report periodically to the Conference of the Parties of the UNFCCC. It is necessary in both cases, to indicate that local level plans and actions to quantify the CO_2 and CH_4 emissions. Obviously, research questions are raised like, what are the quantities of CO_2 and CH_4 emission by different socio-economic levels of rural communities living either near or far from the forest resources; what are the major sources of CO_2 and CH_4 emission and what will be the appropriate options to manage them, locally. Hence, this research was focused to answer them.

1.3 Research Objectives

Overall objective: The overall objective of the study is to compare the carbon stock change for three years in community managed forests and explore the opportunity of REDD+ in Nepal.

1.3.1 Specific Objectives

Followings are the specific objectives of the research.

1. To assess the species-wise Importance value index (IVI) and carbon stock
2. To assess the carbon stock in community managed forests
3. To identify the carbon sequestration potential and confrontation for carbon trade
4. To evaluate the carbon stocks for sustainable management of forests
5. To appraise the plant biodiversity status and its relationship with the forest carbon stock
6. To identify drivers of deforestation and forest degradation and its effects on carbon stocks in community managed forests
7. To quantify the CO_2 and CH_4 emission from domestic fuel and livestock keeping of household living near to forest and distant from the forests

CHAPTER 2

2. LITERATURE REVIEW

This research has two major concerns. The first one is broadly regarded to assessing the forest carbon stock status, forest carbon increment, potential opportunities of forest carbon trade and its embedded challenges including relevant policy update, evaluation of forest carbon for sustainability and relationship between carbon stock and biodiversity. The second one is linked with the effects of drivers of deforestation and forest degradation on forest carbon as well as CO_2 and Ch_4 emissions from domestic fuel and cattle keeping. Thus, the literature review starts with the carbon stock variation.

2.1 Forest Carbon Stock Variation

The carbon stocks vary according to forest types and geographical region in the world. Specifically, the above ground and below ground carbon including soil carbon are differed from pool to pool, place to place and region to region. The several authors have done research on these research areas.

2.1.1 Global Forest Carbon Stock Variation

The carbon stock is not same in all parts of the plant; they are varied according to the carbon resource pool. According to Forest Resource Assessment (FRA, 2011) the estimated total carbon stock was 161.8 t ha^{-1} in the world and among this there was 71.6 t ha^{-1} carbon in the main stem, 17.8 t ha^{-1} in litter and deadwood and 72.3 t ha^{-1} in soil. The estimated carbon stock in Asia was 125.7 t ha^{-1} and out of this, there was 60.2 t ha^{-1} in biomass, 5.8 t ha^{-1} in litter and deadwood and 59.6 t ha^{-1} in soil. The estimated total forest carbon stock was varied in the world and in the region. The world's total forest area was estimated to be just over 4 billion hectares, corresponding to an average of 0.6 ha of forest per capita in 2010. These forests store more than 650 billion tonnes of carbon, 44% in the biomass, 11% in dead wood and litter, and 45% in the soil. In Asia, the recorded carbon stock was 74453 million tonnes. Out of this, there were 35689 million tonnes of carbon in forest biomass, 3434 million tonnes in deadwood and litter 35330 million tonnes in soil. The average soil carbon was recorded 59.6 t ha^{-1} in Asia (FRA, 2011). The estimated carbon stocks in primary forest was 337 t ha^{-1} than secondary forest 274 t ha^{-1} (Ngo *et al.*, 2013) in Singapore. The mean carbon stock was estimated 114 ± 2.26 t ha^{-1} in managed forests, which comprises of 92% tree biomass and 8% of topsoil whereas it was 27.77 ± 1.66 t ha^{-1} in unmanaged forests which comprises of 80.8% tree carbon and 19.2 % soil carbon in Pakistan (Nijami *et al.*, 2009).

Trees, both in above and below ground biomass, continue to accumulate carbon until they reach maturity; at that point about half of the average tree's dry weight will be carbon. About 43-50% of the dry biomass of tree is carbon (Malhi & Grace, 2000). On the other hand, trees are long lived plants that develop a large biomass, thereby capturing large amounts of carbon over a growth cycle of many decades. The forests act as sinks by increasing aboveground biomass through increased forest cover and by increased level of soil organic carbon (SOC) content.

2.1.2 Carbon Stock Variation in Nepal

Available research papers especially on carbon stock variation in Nepal had reviewed and presented here.

The carbon stock of REDD+ piloting of Tarai Arc Landscape (TAL) of Nepal showed that, there was high variation in carbon stock in different pools according to canopy percentage (Table 1). Manandhar (2010) explored that, they were about 17.23 to 135.46 t ha^{-1} having canopy 0-10% to greater than 71%. Other high carbon was recorded in soil, they were ranged between 70.19 to 112.17 t ha^{-1} with canopy 0-10% to greater than 71% while they were very less in shrubs and litter. Total carbon stock of agro forestry area was recorded 109.83 t ha^{-1} (Manandhar, 2010).

The carbon stock differed according to the sites too, it is different in forests and agriculture land (Gautam, 2002). The highest total organic carbon was found to be 98 t ha^{-1} in natural forest. The total organic carbon content ranges from 33.2 to 55.5 t ha^{-1} and from 35 to 74.6 t ha^{-1} in annual cropping system and in the plantation orchard respectively. The soil organic carbon (SOC) was the highest (53.2 t ha^{-1}) in naturally grown forest followed by 52.6 t ha^{-1} in vegetable grown field and least in streamside. Other study also reported the highest SOC in the topsoil (0-10 cm depth) of grazing land with 34 t ha^{-1} followed by the cultivated upland (Bari) (20 t ha^{-1}), forestland (14 t ha^{-1}) and level terraces (Khet) (12 t ha^{-1}) (Gautam, 2002).

Table 1: Record of carbon stock of REDD+ piloting in TAL areas, Nepal

Canopy cover	Unit	AGTB	Shrub	BGB	Litter	SOC	Total
0-10% Canopy Cover	t ha^{-1}	17.23	0.04	4.59	1.76	70.19	93.81
11-40% Canopy Cover	t ha	71.64	0.12	20.06	1.28	93.60	186.70
41-70% Canopy Cover	t ha	113.97	0.25	31.91	2.66	96.19	244.99
71-100% Canopy Cover	t ha	135.46	0.29	37.93	1.58	112.17	287.43
Agro forestry Area	t ha						109.83

(Manandhar, 2010)

Some more examples of carbon stock variation in different pools are presented here. FAO (2006) reported that the carbon in biomass, in dead wood of Nepal has been increased since 1990 to 2000. But it has been decreased by 6.74 % in biomass carbon and by 5.5% in dead wood from the year 2000 to 2005 (FAO, 2006). The research done by Khanal (2008) showed that the estimated above ground tree carbon stock was found to be higher 38.6± 3.9 t ha^{-1} Lipindevi Thulopakho community forest than 35.5 ± 3.4 t ha^{-1} in Jarneldhara community forest in Palpa district (Khanal, 2008). Tewari *et al.* (2007) estimated the biomass stock and biomass increment rate per year in three community forests of Nepal. In Namuna community forest of Eastern Nepal, the mean biomass was found to be 121.82 t ha^{-1} and the annual increment was 6.42 t ha^{-1} in Kafley community forest of central Nepal, it was found to be 104.71 t ha^{-1} with the annual increment of 2.96 t ha^{-1}. Similarly, in Manang community forest of western Nepal, mean biomass was found to be 64.06 t ha^{-1} with the annual increment of 2.18 t ha^{-1} (Tewari & Karky, 2007).

The carbon stocks of different sites of community forests had different record. According to Sharma (2010), total carbon stock of forest was 108.67 t ha^{-1} in Shree Salumbudevi community forest of Pukhulachi VDC of Kathmandu (Sharma, 2010). Similarly, Rijal (2010) observed that the estimated carbon stock in biomass and soil was 161.07±48.64 and 114.33±17.16 t ha^{-1} respectively while the mean total carbon stock of forest was 275.39±48.15 t ha^{-1} in Baspani community forest, Nuwakot (Rijal, 2010). Basnet (2011) estimated the carbon stocks in biomass and soil carbon stock were 52.34 and 53.61 t ha^{-1} respectively while the mean total carbon stock of forest was found to be 105.954 t ha^{-1} in Setidevi community forest of Thankot, Kathmandu. The higher quantity of SOC was recorded in the upper layer (0-20cm) than the lower layer (20-40cm) (Basnet, 2011).

Ale (2010) and Shrestha *et al.* (2012) also conducted some studies on estimation of carbon stock in Makwanpur and Dolkha districts. Ale reported that the natural forest had highest above ground biomass 321.77±69.48 t ha^{-1}, which was followed by planted forest biomass of 265.63±69.48 t ha^{-1} in Chitrepani community forests of Makwanpur district He found the greater SOC in the upper layer (0-10cm) followed by 10-20 and 20-30 cm depth (Ale, 2010). Shrestha *et al.*, (2012) recorded that the aboveground carbon stock was higher about 97.29 t ha^{-1} in natural forest than 160 t ha^{-1} in degraded site in Chitrepani, Siwalik region, Makwanpur district of Central Nepal. Similarly, the research based on six community forests of the Dolakha district, Nepal showed that, community forests accumulate approximately 2 t ha^{-1} carbon annually. There were recorded above ground carbon stocks 91.04 t ha^{-1} in Simsungure CF, 87.42 t ha^{-1} in Mahankal CF, 36.41 t ha^{-1} in Mathani CF, 411.32 t ha^{-1} in Sitakunda CF, 21.83 t ha^{-1} in Barkhe CF and 56.6 t ha^{-1} in Chyansi CF (Shrestha *et al.*, 2012). These forests have capacity to sink or sequestrate the carbon, which have opportunities for carbon trade.

Some research on carbon stock assessment was also done in central Tarai, Mahottary district too (Dutta & Mandal, 2010, Sah, 2014). However, they were especially focused on community forests not to other forest management regimes like collaborative forests, public plantations and community planted forests. This research tried to fulfill the gaps.

2.1.3 Ecological Value and Carbon Stock of Forest Species

The ecological value is based on the species dominance, frequency and density in the forests. Some studies on importance value index of the forest are presented here. There is intricate interrelationship between people and forests (Scherer-Lorenzen *et al.*, 2007). The green forests are living machine of oxygen production which is life gas of living beings so they are significantly valued. Importantly, the forests serve as ecosystem, biodiversity and capture of CO_2 produced by respiration of living beings (Milder *et al.*, 2010). This is why, life is impossible without green forests in the planet (Pimentel, 1980). However, people have been involved to destruct and deteriorate the forests. Some findings showed different values of carbon stock. As shown in table 2 the carbon stock of *Acacia nilotica* was 0.69 t/ tree, *Azadirachta indica* was 2.17, *Albizia lebbeck* was 1.35 (Chavan & Rasal, 2010). But this is not emphasized on per ha calculation.

Table 2: Examples showing Specieswise C stock

SN	Scientific name	Above ground mean C t	Below ground mean C t	Total t/tree
1	*Acacia nilotica*	0.6	0.09	0.69
2	*Albizia lebbeck*	1.18	0.17	1.35
3	*Azadirachta indica*	1.91	0.26	2.17
4	*Bauhinia raemosa*	0.31	0.04	0.35
5	*Butea monosperma*	2.1	0.31	2.41
6	*Cassia fistula*	0.55	0.08	0.63
7	*Dalbergia sisso*	0.46	0.06	0.52
8	*Delonix regia*	2.12	0.31	2.43
9	*Eucalyptus citriodora*	0.88	0.12	1
10	*Ficus bengalensis*	3.89	0.57	4.46
11	*Ficus religiosa*	4.27	0.64	4.91
12	*Hyophorbe amercalismort*	1.53	0.23	1.76
13	*Leucaena latisiliqua*	0.72	0.18	0.9
14	*Mangifera indica*	3.13	0.46	3.59
15	*Peltaforum pterocarpum*	2.01	0.29	2.3
16	*Pithecellobium dulce*	0.84	0.12	0.96
17	*Polyalthia longifolia*	1.2	0.18	1.38
18	*Pongamia pinnata*	1.57	0.23	1.8
19	*Tamarindus indica*	1.25	0.18	1.43
20	*Terminalia catappa*	0.15	0.02	0.17

(Source: Chavan & Rasal, 2010)

Other study was done by Pandya *et al.* (2013) on carbon stock of 25 plant species in Gujrat, India. Remarkably they found that the maximum carbon storage was 55.95 tC in *Tamarandus indica* followed by 44.81 tC in *Terminalia arjuna*. The lowest carbon storage value estimated in 1.77 tC in *Emblica officinalis*.

Moreover, the study done in India showed that the Importance value index of (IVI) of *Acacia catechu* was 46.47, *Albizia amara* was 53.63, *Anogeissus latifolia* was 24.10 (Devagiri *et al.*, 2012). The IVIs of some species were 43.56 of *Ficus ovate* of 10.11 of *Eucalyptus camaldulensis* (Abebe & Dessalegn, 2014). The study done in India was focused on calculation of IVI and carbon stock (Singh *et al.*, 2014) but these studies did not emphasize on effect of carbon on IVI ranking.

A study done in Africa showed the IVI of *Alstonia boonei* was 16.86, *Strychnos innocua* was 17.46, *Albizia adianthifolia* was 17.33 (Balinga, *et al.*, 2013). The study done in China showed that the IVI of *Lannea grandis* was 19.78, *Dillenia pentagyna* was 16.71, *Syzygium cumini* was 16.58 and this study emphasized on ranking of the species based on IVI (Meng *et al.*, 2011). The study done in Nepal showed IVI of *Shorea robusta was* 259.2, IVI of *Bombax ceiba* was 96.84 (Dangol & Shivakoti, 2001).

However, it was quite gap in ranking of forest species based on IVI of plant species in Tarai. In addition, the prioritization of species based on carbon and if new criteria like mix is made based on IVI and carbon, whether there was any effects on species ranking or not, this was also gaps in the study in Nepal.

2.2 Context of Forest Carbon Sequestration

The context of forest in forest carbon sequestration and forest based policies at global and national level show the potential opportunity for carbon trade and challenges. They help to evaluate the national level research gaps.

The forest carbon sequestration is process of capturing the carbon from the atmosphere. This process broadly depends up on the pools of forest ecosystem and mean annual carbon sequestration, which play a vital role in mitigation and adaptation in climate change dynamics. The carbon sequestration is the process of removing additional carbon from the atmosphere and depositing it in other reservoir principally through land use dynamics. The removal of CO_2 from atmosphere by increasing its uptake in soils and vegetation or in the ocean is a form of carbon sequestration. Terrestrial ecosystem plays a vital role in carbon sequestration. The carbon sequestration process involved in individual tree is an important concern in environmental system. The carbon sequestration in tree keeps the balance between the process of photosynthesis and respiration, which use and release CO_2 respectively. In practical terms, carbon sequestration occurs mostly through the expansion of the forests (Houghton, 1996). The process of carbon sequestration is the most rapid during the early stage of the life of tree while, as tree reaches maturity the above two processes become increasingly similar. Additionally, the rate of carbon sequestration is less particularly in over mature stage of the tree. Hence, the tree or forest expands the capacity of carbon sequestration also increases and vice-versa (Sedjo & Marland, 2003). Conclusively, sustainable forests are reliable sinks of GHGs (Levy *et al.*, 2004). Among these, the community forest management, which is a successful example of sustainable forest management is preferable option of carbon sequestration, primarily in developing countries (Klooster & Masera, 2000).

The carbon pools in a forest ecosystem can be broadly categorized into biotic (vegetation carbon) and pedologic (soil carbon) components. As tree grows, it sequestrates carbon in its tissue and as the amount of tree biomass increases (within the forest), the atmospheric CO_2 is mitigated. Trees both in above and below ground biomass, continue to accumulate carbon until they reach maturity; at that point about half of the tree's dry weight carbon fixed within plant biomass ultimately enters to the soil, where it may reside for hundreds of years (Houghton, 1996). Thus, forest ecosystem can capture and retain large amount of carbon. On the other hand, soil contains the major part of carbon in terrestrial ecosystem for long periods making it to be largest terrestrial carbon sink. Several authors have done the study on carbon sequestration as mentioned above like Houghton, Sedjo and Marland, Levy and Klooster.

Similarly, some more studies had focus on the role of forest as accumulation and storage of the carbon. The forest is a reservoir, the component of the climate system where a green house gas is stored; as well as a sink, any process that removes GHGs from the atmosphere. Forest biomass accumulates carbon over decades and centuries. Globally, forest acts as a natural storage for carbon, contributing approximately 80% of terrestrial aboveground and 40% of terrestrial belowground biomass carbon storage (Kirshbaum, 1996). Forest plays a profound role in reducing ambient CO_2 levels as they sequestrate 20-100 times more carbon per unit area than croplands (Brown & Pearce, 1994). Furthermore, carbon accumulation potential in forests is large enough that forests offer the possibility of sequestrating significant amounts of additional carbon in relatively short periods-decades. According to Upadhyay *et al.* (2005), revitalizing degraded forest land and their soils in the global terrestrial ecosystem can sequester 50-70% of the historic losses. Degraded forests have emitted their carbon than unmanaged forests nearing their climax stage as decay, burning and die-back are balanced by the growth of plants (Upadhyay *et al.*, 2005).

Here are some studies which highlighted on carbon sequestration. Trees absorb atmospheric CO_2 for the growth of woody biomass and increase the SOC content in the soil as well. Some studies of India, showed that the mean annual carbon sequestration were 3.25, 3.78 and 2.73 t ha^{-1} in Dhaili, Toli and Guna village forest Panchayats respectively. Nevertheless, it varied in Nepal. The studies showed that, the mean annual carbon stocks were 6.19, 2.81 and 2.25 t ha^{-1} in community forests of Lamatar, Ilam and Manang respectively. So, these are very limited studies done on carbon sequestration in Nepal enough (Tewari & Karky, 2007) while scope of this is very wide.

The above studies showed carbon sequestration in different types of forests like community forests in Nepal and village forest panchayats in India. However, there are several forest management regimes in Nepal. So, these do not cover the wide areas specifically collaborative forest, public plantation and community planted forests in Tarai. These were the gaps in studies in forest carbon sequestration.

2.3 Forest Carbon, Ecosystem, Environmental Services and Livelihood

The carbon sequestration is ultimately linked with the carbon trade. In this circumstance, the global and national policies status is essential to discuss. Thus, the studies done by Wunder, MEA and Walter are prime researches.

The forest carbon has been prioritizing as a part of ecosystem and environmental services. Equably, the forest carbon trade has been valuing under the reducing emission from deforestation and forest degradation (REDD+). Though the clean development mechanism (CDM) is also valuing the forest carbon, The REDD+ programme is considered as the best effective and efficient alternate way of the forest carbon trade. However, the broad framework of CDM and REDD+ programme is completely linked with the ecosystem and environmental services. The Ecosystem and environmental services differed according to their functions (Wunder, 2005).

Ecosystem services: The Millennium Ecosystem Assessment has defined the ecosystem services as the benefits of people obtain from ecosystems (IDRC, 2005). They are categorized into provisioning services, regulating services, cultural services and supporting services. Specifically, the provisioning services deal with the products obtained from ecosystem e.g. food, fresh water, fuelwood, fiber, biochemicals, genetic resources. Regulating services cover the benefits obtained from regulation of ecosystem processes e.g. climate regulation particularly floods control, water regulation, water purification, drought management, land degradation and disease management, detoxification. Cultural services is the non-material benefits obtained from ecosystems recreational, spiritual, religious, symbolic, educational, and non-material benefits. Lastly, supporting services describes about the services necessary for the production of all other ecosystem services e.g. soil formation, nutrient cycling and primary production (MEA, 2005; Walter *et al.*, 2002).

Payment for Ecosystem services (PES): The PES schemes exist mainly for four services. i. carbon sink functions : an electricity company paying farmers in the tropics for planting and maintaining additional trees, developed countries paying to developing countries for forest carbon management ii. hydrological functions: downstream water users paying upstream farmers for adopting land uses that limit deforestation, soil erosion, and flooding risks, iii. biodiversity functions: conservation donors paying local people for setting aside or naturally restoring areas to create a biological corridor, and iv. landscape esthetics/ecotourism functions: tourism operation paying a local community - not to hunt in a forest but used for tourists wildlife viewing (Wunder, 2005).

Wunder defined the principle of the PES as a voluntary, conditional agreement between at least one "seller" and one "buyer" over a well-defined environmental services - or a land use presumed to produce that services i.e. if the provider continuously secures the provision of the service (conditionality). The theory indicates that PES schemes can make both sellers and buyers of environmental services better off and at the same time help to better protect the resource base.

The Costa Rican Forest Law, as cited in Mayrand & Paquin, 2004, provides a definition of environmental services as follows: "Those services provided by forests and forestry plantations that have an impact on environmental protection and improvements. They are the following: mitigation of greenhouse gas emissions (fixing, reduction, sequestration, ware housing and absorption); protection of water for urban, rural or hydroelectric use; biodiversity protection to conserve it and for sustainable, scientific and pharmaceutical use; genetic research and improvement; protection of ecosystems, life forms and natural scenic beauty for tourism and scientific ends" (Mayrand & Paquin, 2004).

The forest management, enhancement and conservation are potential to improve the condition of climate while the deforestation and forest degradation cause the environmental degradation and lastly leads toward the impacts of climate change. The research is broadly fitted with the set of functions of ecosystem and environmental services, which a healthy forest does. So, the regulatory service covers the principle of ecosystem services and carbon sequestration.

Here the appraisal of the carbon sequestration is the intent of this research work in one way. The forest shrinkage and environmental degradation by the use of fuel and cattle keeping are worrying fact for process drivers of the climate change. Thus, the assessment of these drivers is essence of the research work on other way.

Income generation and livelihood promotion: Several researches have carried out on different issues in community forests. Some of the important studies are related to income generation from community forests for livelihood promotion. The past studies showed that the amount of income generated by forest user groups varies widely and depends on the size, condition and type of forests, the level of forest utilization, the type and proximity of markets and the kind of income-generation activities practiced. Overall, however, the cash income of most forest user groups is very low. In 1994-95, the average income for 17 districts of middle hills (comprising 369 forest user groups) was 18400 rupees (NRs) or US$ 340 (Hunt, Jackson and Shrestha, 1996). The annual income of almost all of the forest user groups was lower than the average household income about NRs 32200, or US$ 600 (Malla, 1992). Only one district (with nine forest user groups) had an average income above NRs 100000 (US$ 1850), partly because one group had a very high income, NRs 790800 (US$ 14640). The other 360 forest user groups (97.7 percent) had less than NRs 35000 (US$ 650) average income. Some 317 forest user groups (86 percent) had an average income below NRs 20000 (US$ 370), while 200 (54 percent) had an average income of less than NRs 7500 (US$ 140). Some forest user groups reported no income. The other study done by Pokharel et al (2007) showed that the mechanisms for policy amendment and revision for community forestry need to be based on real life experiences rather than ad hoc and top-down decision-making. It is likely that the ‘one size fits all’ approach to the community forestry policy will not work (Maharjan et al., 2009).

2.4 Policies for Forest Carbon Trade

The past record showed that, there was massive deforestation in the world even in developed countries because of human disturbance for at least 6000 years. Forests were cleared; cultivated and cut for agriculture practice, pasture purpose, timber and firewood use. This trend was continued until industrialization period. However, the reforestation and afforestation were resumed from last century. So some of the past policies were concentrated for agriculture expansion but during the last century the policies were switched to revert the land into forest lands in developed countries. However reversing the forest cannot guarantee the restoration of ecosystem diversity.

Developed countries experienced the deforestation in the past and drivers were about same, which are happening present in developing countries. The policies of forest carbon enhancement are based on the foundation of long history of deforestation and the REDD+ programme is emerged on top of this. In this manner, it is essential to show the history of policies regarding forest depletion and forest enhancement in national context for REDD+ programme (Skutsch & Van Laake, 2009).

2.4.1 Reducing Emission from Deforestation and Forest Degradation (REDD)

The clean development mechanism (CDM) and REDD+ programme are two facets of same climate mitigation and adaptation coin and both play a vital role to address the problems associated with climate change.

It is essential to evaluate the pros and cons of Clean Development Mechanism (CDM) before dealing with the Reducing Emission from Deforestation and Forest Degradation (REDD+) programme. The main objectives of CDM, which is defined in Article 12, of the Kyoto Protocol; are (i) to encourage the sustainable development of non-Annex I countries by means of institutional capacity building and technology transfers, and (ii) to enable Annex I countries to meet their bonded by the Kyoto commitments cost-effectively. The Clean Development Mechanism (CDM) is limited to afforestation and reforestation. In other words, they allow to certify the certified emission reduction (CER) of new plantation done after 2000 where there was no forest before 1990 but they do not allow crediting for reduction emission of existing sinks through sustainable forest management (Murdiyarso & Skutsch, 2006). It means no entry for the community based forest management, which are either natural forests or planted before 2000 under CDM; while these forests significantly contribute in restoring the degraded forest and halting deforestation in developing countries like Nepal. Thus, Reducing Emission from Deforestation and Degradation (REDD+) has become as an exciting programme for mitigating climate change to respect the contribution of carbon credits of such types of community based forest management (Karky & Baskota, 2009).

The Bali action plan (2007) under UNFCCC (COP-13) agreed to carry out the meaningful action to reduce emissions from deforestation and forest degradation. This offers the opportunity for financial incentives to developing countries for reducing emissions from deforestation and forest degradation. Latter, the COP-15 broadened the scope and renamed as REDD+, which extended to include the role of forest conservation, sustainable management of forests and forest enhancement (UNFCCC, 2009). According to Angelsen and his co-workers, the REDD+ has four types of co-benefits. The first one is related to the forest biodiversity conservation (Angelsen *et al.,* 2009). The second one is financial flow for socio-economic benefits, such as reducing poverty, supporting livelihoods and stimulating economic development. The third one has focused on the actions for sparking the political changes toward better governance, less corruption, and more respect to the rights of vulnerable communities. The last one is emphasized on the actions for boost the capacity of both forests and humans to adapt the measure of the climate change (Angelsen *et al.*, 2009).

2.4.2 Strength of National Policies to Restore Forest Resources

Some policies and plans are helpful to reduce deforestation and forest degradation. They are described here in brief.

The forest nationalization act of private forest 1957 has considered as a responsible policy for mass deforestation and forest degradation in Nepal but importantly there has positive impact of this as well. This was the beginning era of increased national control on the forest resource and consequence was government owned forest. However, the gap had felt that what would be the legal action, if the deforestation and forest degradation had continued. Realizing the situation, forest act 1962 had implemented.

Latter, the law enforcement had realized as a big problem to control illegal logging without participation of local community in Nepal. The Ninth Forestry Conference held in Kathmandu in 1974 had special emphasis to prepare the national forestry plan, which had completed in 1976. The plan recognized the role of local communities in forest management. Immediately, the Forest Act 1962 had amended in 1979 to define new types of forest management regime namely Panchayat Forest (PF) and the Panchayat Protected Forest (PPF). This was the foundation of community based forest management in Nepal. It had implemented since 1979.

Master Plan Forestry Programme, 1988 had provided six primary programme and six supportive programme. The primary programme are community and private forestry, national and leasehold forestry, wood-based industries, medicinal and aromatic plants, soil conservation and watershed management and conservation of ecosystems and genetic resource while the supportive programme are policy and legal reforms, institutional reforms, human resource development, research and extension, Forest resources information system and management planning and monitoring and evaluation (HMG/N, 1989). These programmes are supported by forest act 1993 and forest rules 1995. However, the deforestation and forest degradation especially in Tarai has not completely stopped.

There are three main policy documents regarding the REDD+ in Nepal. The readiness plan idea note (R-PIN), Readiness Preparation Proposal (R-PP) and Emission reduction plan Idea Note (ER-PIN). The R-PIN is the first policy document for REDD+ initiation in Nepal. Presently, Nepal has been implementing the readiness preparation proposal. The main purpose of R-PP is to prepare the REDD+ strategy in Nepal so that the REDD+ piloting will be next step. However, the forest carbon trade is not possible perhaps before 2020. The third one is the ER-PIN, which has emphasis on the promotion of REDD+ piloting at sub-national level project in Nepal. However, there are many gaps in REDD+ policy in Nepal like policy of forest carbon benefit, carbon ownership, policy of forest carbon trade, REDD+ institutional framework, sub national level MRV designing and RL development in Nepal (Koirala, 2014).

Principally, 3 phases have proposed under the REDD+ programme for carbon trade. The first phase has focused on REDD+ readiness; the second phase will be the demonstration and sub national level piloting work and third phase may be the performance based payment. Nepal is implementing the Readiness preparation proposal (R-PP). Hopefully, the demonstration phase will be started by 2015 in Nepal since the ER-PIN (emission reduction plan idea note) has agreed to be funded by the forest carbon partnership facility under the World Bank, so that the demonstration activities will be started soon. The forest carbon trade is dependant up on the international REDD+ dynamics. It is guessed that, this phase may be started by 2020 (Koirala, 2014). Nepal as an early mover may be benefited from such opportunity but it is not an easy task.

The climate change policy (2011) has been emphasizing mainly on five major different climatic issues in Nepal. They are: i. implementation of National Adaptation Programme of Action (NAPA) ii. identification and implementation of medium- and long-term adaptation actions for the impacts of the climate change and climate-induced disaster-prone areas iii. communities, and people adopting a low carbon emissions iv. climate-resilient development path for sustainable socio-economic growth and developing a mechanism for optimal utilization of international, regional and local funding sources and v. reducing emissions from deforestation and forest degradation (REDD+) (MoE, 2011).

The weak enforcement of the policies is the main problem in developing countries like Nepal. In addition, there are some conflicting policies, which work to fueling the deforestation and forest degradation.

2.4.3 Conflicting Policy and Practices

Conflicting policies and practices have been functioning as a catalyst in forest depletion in Nepal. It includes i. earning of national revenue ii. felling and export of the Tarai Sal iii. Nationalization of Private Forests Act iv. construction of the east-west highway during the 1960's and v. some local level practices.

i. Earning of national revenue: Nepal has witnessed of substantial shifts in forest policy and management approaches since the beginning of the 20th century when serious public concern regarding the use of the country's forest resources began. Main focus of the Nepalese government was on maximizing the utilization of the resource either through exploitation of quality forests for exports to earn national revenue or through the conversion of forestlands to agriculture in order to widen the tax and increase food production (Griffin *et al.*, 1988).

The Rana rulers established a timber administration office, converted later into the timber export office, and employed British forestry experts from the Indian Forest

Service in 1920s to supervise felling and export the railway slippers from Tarai Sal (S*horea robusta*) forests for the construction of the Indian railways. Timber for railway sleepers was granted by the Rana government to British in India and the profits seem to have contributed to the wealth of only Rana families who owned nearly a quarter of a million hectares of the Tarai fertile forests land at that period (Hobley, 1996).

The Nationalization of Private Forests Act 1959 had badly effect on the forest resources. This policy encouraged people to convert forest lands into the agriculture land encroached forestlands with the hope of getting it registered as private property once the land was cleared and cultivated (Wallace, 1981). Nearly 100,000 ha forests were illegally encroached during the same period (Joshi, 1993).

The construction of the east-west highway during the 1960's and other road networks further accelerated migration from all over the country. New settlement on the southern border of the forest has caused its depletion to surge northwards to the south, resulting in massive deforestation in the Tarai (Whelpton, 2005). During the Panchayat regime, the introduction of a resettlement programme from the mid-1960s onwards was closely linked to opportunities for the extraction of timber to sell in India (Ghimire, 1992).

In 1964, the Resettlement Company was established under the Ministry of Agriculture to settle large populations of hills people in the Tarai (Adhikari, 2013). This company encouraged clear felling of the forest in many parts of Tarai and inner Tarai. The aim was to solve the problem of population growth by clearing the forests of the Tarai during the 1960s and 1970s for use by hill migrants as cultivable land (Satyal, 2004). Politicians perceived forest land as a needed resource for hill migrants and other vulnerable groups to convert into land for agriculture and settlements undermining the value of forest resources. However, much of this land has been claimed by politicians for themselves, their relatives and followers through the drafting of false land registration certificates with the help of corrupt authorities.

The effect of conflicting policy was also observed in Mahottari district. There was dense forest in this district before 1940. Bijalpura- Janakpur-Jaynagar, a 51 km narrow gauge Railway was constructed in 1934 objectively to export Sal (*Shorea* *robusta*) timber sleeper to India. Presently only 32 km Janakpur (Nepal) to Jaynagar (India) railway is operational on plate one. During the Rana's regime, export of Railway slippers was considered as one of the most important sources of revenues thus destroyed huge area of Tarai Sal forests in Janakpur region. This was the first organized forest destruction in this zone. Local senior citizens shared that Gauri Narayan Giri "Ditha" and his private company was the main timber contractor to clear the forest and supplied timber to India during Rana's regime. In addition, large tract of riverine forest was also destroyed by flood in 1954. The resettlement program in 1956 also converted huge area of Tarai forests into agriculture and settlements areas (DoF, 1994).

2.5 Sustainable Forest Management and Forest Carbon

Several countries have been practicing the participatory forest management. They are Nepal, India, Indonesia, Tanzania, Kenya, Mozambique, Mexico, Vietnam and Amazon countries are some of them. It is evaluated that the community managed forests are more effective and efficient than the government managed forests. The communities have themselves been involved in the preparation of the plan, which includes the protection of the forest, utilization of the forest products and development of the forests. So, they have effectively been implementing the community forest plan to manage the forest. On the other hand, they have been applying their indigenous knowledge and skill. However, sustainable forest management is in question (Pokharel *et al.*, 2007).

Around 20% of the world´s forests are de-facto owned and/or managed by communities. Notably, 70% of the forest area is the legal property of communities in Mexico (Klooster & Masera, 2000). About 30% of the forests are managed under the community forest in Nepal. There are more models of participatory forest management in Nepal. Collaborative forest management model that includes the distant households also as users is other types of forest management regime in Nepal especially in Tarai. Another type of community based forest management is public plantation in which the especially deprived poor landless community who are living most climate vulnerable area particularly in Tarai manages the public land under agro-forestry system. In addition, open and degraded lands in community forests are also managed for plantation purpose as community planted forest.

The ITTO emphasizes on the sustainable development theory in “sustainable forest management”. Without sustainable forest management nothing could be discussed about sustainable forestry development (ITTO, 2012). In this context, some questions are raised for evaluation of sustainability in carbon stock of community and collaborative forests as well as public plantations and community planted forests. Are such types of community based forest sustainably managed or not; are the carbon stocks showing sustainability or not, are these forests potential for carbon trade, and if so what are the principle challenges? Several questions are unanswered in these types of community managed forests especially in Tarai. These queries were considered as the research gaps.

2.6 Collective Actions and Community Managed Forests

Forest resource is second reservoir to absorb the carbon dioxide if it is managed properly. The reverse is also true, the forest depletion, burning and decaying of the forest resource are causes of the emission. Since the forest resource is common pools, the management needs collective action to reduce the depleting factors specially developing country like Nepal. The communities generally manage these pools based on their common interests and goals in Nepal. Obviously, any positive results will be certainly appreciable for them while any negative impacts will be tragedy for entire community. Thus, the tragedy of commons, theory of collective action, environmental and ecosystem services are sincerely valued to conceptualize this research work.

The collective action requires the involvement of a group of people, it requires a shared interest within the group and it involves some kind of collective action, which works in pursuit of that shared interest. This action should be voluntary to distinguish collective action from actions of hired labor. The collective actions include collective decision-making rules setting to conduct the group and design the management rules, implement the decisions, and monitor the adherence to rules. Members can contribute in various ways to achieve the shared goal: money, labor or kind contributions (Olson, 1965).

Since Garrett Hardin’s article in science (Hardin, 1968), about “the tragedy of the commons” has come to symbolized the degradation of the environment to be expected whenever many individuals use a scarce resource. Each man is locked into a system for compelling him to increase his herd without limit. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom to use the commons. The consequence will be more damage and tragedy will start. Hardin was not the first to notice the tragedy of the commons. Aristotle long ago observed that "what is common to the greatest number has the least care bestowed upon it. Everyone thinks chiefly of his own, hardly at all of the common interest" (Olson, 1965).

Understanding the concept of common property and their management is essential for dealing with wide range of issues. They are about the overused of resources (e.g. water resource depletion, overgrazing, firewood shortages, overfishing, etc.) and pollution or degradation of environment (acid rain, use of agro-chemicals, waste dumping, carbon dioxide discharges and global warming) are occurred or simply where individual action is not enough to achieve the required result (pest management, water management). The forest resource as common pool resource, its depletion contributes to the environmental degradation and consequence is global warming, whereas its enhancement functions just reverse to this (Olson, 1965).

The empty, idle, and “natural” environments need protection from harmful large-scale developers, loggers, and ranchers, as well as from farmers, hunters, and gatherers. To do so the collective action is significantly essential to stepping against these factors for better forest resource management. Co-management involving the community can play a vital role to manage the forest of Nepal’s Tarai rather than working only with traditional institution in this dynamic condition (Nagendra & Karmacharya, 2005). To sustain long-term use of renewable resource systems like forests, collective action is needed to limit resource use and to undertake various forms of active management (Amy & Elinor, 2004). Agrawal and Ostrom (2001) stated that, the coalition of actors in forest management respecting the local knowledge can play a vital role to add in work efficiency in halting the deforestation and forest degradation and storing degraded resource (Agrawal & Ostrom, 2001). Share management responsibility with either local communities or a range of stakeholders plays a vital role in Tarai's forest management (Acharya, 2000). Other similar thought supports that the development of community-based resource management has led to devolution of forest management from centralized government control to local user groups (Adhikari *et al.*, 2004).

Collective action functions where the individuals undertake collective effort based on mutual interests and the expectation of mutual benefits. The management of common property resources requires collective action. There are several examples of collective actions applied for forest protection, which work effectively to motivate for we-feeling. Some of them are, the Chipko (to stick) movement by Sundarlal Bahuguna in 1970 in Uttar Pradesh; the Arabari experiment by Dr. Ajit Banerjee in the early 1980s in West Bengal in India and community plantation by Dr. Tejendra Bahadur Singh Mahat in Thokarpa village of Sindhupalchok district, Nepal before 1961 (Griffin *et al.*, 1988). Without community's effort, it was impossible to stop the contractors to harvest trees in Uttarpradesh and Bangladesh. Similarly, the open lands, which were claimed by Biratabal (traditional land owner) were possible for plantation because of the common efforts of local community. In this way, the community participation has started as a collective action to manage the forest resource (Karna, 2008). The collective actions are not uniform at all the levels so the consequences are heterogeneous and forest carbon change is uncommon in different types of management regime. Biophysical data on forest conditions can be used to discern the effectiveness of collective action for forest management. If forest users have developed rules for forest management, whether formal or informal, and those rules effectively alter behavior (i.e., they are rules-in-use), changes will occur in the patterns of forest use (Amy & Elinor, 2004). Changes in pattern of forest uses are interlinked with the emission through the burning or decaying of biomass as firewood and timber. On the other hand, the forest carbon enhancement is the contribution in removal of emission for cleaning the environment, which is the asset to offer the ecological and environmental services.

Managing the forest is the result in adding the value of forest carbon sequestration potential. So, the people's personal interest is essential to get rid of forest depletion. If the people care to protect the forest, this is the name and respect of collective action because the care is impossible without the common interests of group of individuals. Ultimately, the theory of collective action is applied. Common interest and commitment are needed to work under the theory of collective action. The people's participation is popularly successful in forest management in Nepal. This is the best example of collective action. Lastly, the result may be carbon enhancement where the world's concern focuses. The gaps are exploration of carbon enhancement in differently managed forest, this research emphasized on the assessment of forest carbon enhancement.

2.7 Biodiversity Status and its Relationship with Forest Carbon

Several authors show the status of forest biodiversity, role of forest and earth's dynamics through the valuable researches emphasizing role of plants. Forests play an important role in regulating the Earth's climate (as shown in table 3). The biodiversity, species, genetic material and ecological diversity allure the people's mind. The rapid growth of population is a big challenge to feed the poor people generally in developing countries and consequently, forest areas have been changed into other land uses. The resultant effects are specifically loss of forest and ultimately loss of the biodiversity as well (Healy, 2008). Changes in biodiversity due to human activities have been more rapid in the past 50 years than ever before, and the most rapid changes in ecosystems are now taking place in developing countries. There have been about 100 species recorded extinct in the last 100 years, and if less well-documented but probably highly extinctions are included. The extinction rate is as much 1,000 times above the background rates in fossil records (MEA, 2005). The MEA estimated that between 10% and 50% of species in well-studied higher taxonomic groups are now threatened with extinction (based on IUCN criteria of threats). It found that genetic diversity has declined globally, particularly among domesticated species. There has been a fundamental shift in the pattern of intraspecies diversity in farmers' fields and farming systems as a result of the 'Green Revolution' since 1960, (MEA, 2005).

Some studies done in different part of earth showed the relationship between biodiversity and carbon stocks, Generally carbon stock of natural forest increases with increase in biodiversity up to climax stage because forests with rich biodiversity fill the gaps in forest and contains larger stocking and canopy cover (Scherer-Lorenzen *et al.*, 2007). Though majority of studies show that there is a positive relationship between species richness and carbon stock, the relationship is not universal due to influence of species composition and application of management practices (Slik *et al.*, 2009). Study shows that species richness has greater effect on carbon sequestration than species composition in a natural tropical forest of Panama (Piotto, 2008) while species composition has greater positive effect on soil carbon due to fast litter decomposition than species richness (Erskine *et al.*, 2006). The impacts of changes to forest management on both carbon stocks and biodiversity are often complex and non-linear due to several anthropogenic factors, succession and site quality (Murphy *et al.*, 2008). The relationship between carbon stock and biodiversity under different types of management in different locality is listed in table 3.

Table 3: Relationship between carbon and biodiversity under different types of management

Ecological Zone	Location	Forest Stand Type	Type of relationship Biodiversity vs Carbon	Positive (+) Negative (-) Neutral (0)	References
Tropical humid	Australia	Planted (commercial)	Higher tree growth rates with increase sp. richness	+	Erskine *et al.* (2006)
Tropical rainforest	Panama	Planted (experimental)	Significant effects of plant species richness on total litter production; litter decomposition not affected by plant species richness	+	Scherer-Lorenzen *et al.* (2007)
Tropical rainforest	Panama	Planted (experimental)	No significant differences in root or microbial biomass	0	Murphy *et al.* (2008)
Various (Review)	Tropics	Planted (experimental)	Mixed plantations had higher diameter growth rate.	+	Piotto (2008)
Tropical rainforest	Borneo	Natural	Plant diversity negatively correlated with organic carbon content	-	Slik *et al.* (2009)

There are very few studies on relationship between carbon stock and biodiversity. A part of research done in CF of Chitwan and Kailali by Karna (2012) and Sah (2014) respectively showed, there is relationship between biodiversity and carbon stock in community forests. However, these studies were focused on specifically one type of site and forests which may not be generalized. This indicates the demands of more researches.

2.8 Drivers of Deforestation and Forest Degradation

The drivers of deforestation and forest degradation are the main climate change process drivers in developing countries like Nepal. They are categorized mainly into two categories and presented briefly. They are: i. drivers of deforestation and forest degradation and their effects on forest carbon and ii. extent of forest change.

2.8.1 Drivers of Deforestation and Forest Degradation and Their Effects on Forest Carbon

The deforestation has been defined as a ‘measurable sustained decrease in crown cover’ below a 10–30% threshold while degradation, defined as a loss of biomass density without a change in the area of forest cover (i.e. decrease in crown cover that does not fall below 10–30% threshold) (UNFCCC, 2006). Each country’s forest context is unique: the drivers of deforestation and degradation are different, their forests are at different stages of the forest transition and their economies are at different stages of development. Thus, the drivers of deforestation and forest degradation are categorized under two main categories particularly under the direct and indirect. Proximate or direct drivers of deforestation and forest degradation are human activities and actions that directly affect on forest cover and on carbon stocks. Agriculture expansion is listed as the proximate driver for around 80% of deforestation worldwide while weak forest sector governance and institutions including conflicting policies beyond the forest sector, and illegal activity (related to weak enforcement) are considered as the critical underlying drivers of deforestation and degradation. Population growth is the next most commonly reported underlying driver (51%), followed by poverty (48%) and insecure tenure (48%). Moreover, 41% of countries explicitly mention international and market forces, particularly commodity markets, prices, and foreign direct investment as key underlying drivers. Oil palm plantation in Indonesia, Beef and Soybean production in Brazil, agriculture expansion in Africa and Asia are some of the examples of deforestation and forest degradation. The noticeable impact is inevitable loss of forest carbon stock and also increase of GHGs emission (Kissinger & Herold, 2012).

Readiness Preparation Proposal (R-PP) has indicated nine drivers in preliminary analysis in Nepal, they are high dependency on forest and forest products (timber, firewood and other NTFPs), Illegal harvest of forest products, unsustainable harvesting practices, forest fire, encroachment, overgrazing, infrastructure development, resettlement, and expansion of invasive species (Acharya *et al.*, 2010) . However, these drivers are not same in Tarai to high hills, and their nature and intensity of damage the forests are differed.

A study done on forest degradation in Nepal was assessed the drivers and their extent of damage in Nepal (Acharya *et al.*, 2012). So such gaps are noticed as a research study specially in Tarai. Other recent study done to assess the drivers of deforestation and forest degradation in Nepal by forest action (Anonymous, 2014) identified four proximate drivers namely illegal logging, fuelwood consumption, encroachment and roads construction and eleven priority underlying causes like demand of forest products, poverty, weak law, corruption, weak law enforcement, weak land tenure, political instability, social discrimination, population growth, migration and limited access to technology (Anonymous, 2014).

These studies have not emphasized on effects of drivers of deforestation and degradation on carbon. This gap was analyzed so this research tried to identify the drivers and their effect on carbon stock.

2.8.2 Forest Cover Change Context

The extent of annual forest change is varied in the world. The global annual forest change was recorded to -0.13 from -0.2% in between 2000-2010 from 1990-2000. Similarly, this rate of forest change was 0.28 from -0.01 in between 2000-2010 from 1990-2000 in South Asia (FAO, 2010). This indicates the positive change in forest cover in last decades than previous period. The government of Nepal has been carrying out periodic forest inventories to determine the total forest cover of the country. According to the Water and Energy Commission, the forest area of Nepal in 1964/1965 was 45.3% (FSRO 1964) but it was found only 42.7% in 1978/79 as per the Land Resource Mapping Project (LRMP, 1986). The Master Plan for Forestry Sector estimated the forest area of Nepal was 42.2% in 1985/86 (HMG/N, 1989). The Department of Forest Research and Survey has estimated the forest area cover of Nepal to be 39.6% in 1994. While a direct comparison of these results has some methodological flaws, the different studies show a clear trend of deforestation in Nepal, with an annual rate of 1.7% in between 1978 to 1994. The annual rate of deforestation was recorded higher in Tarai but in Mahottari it was 0.06% in between 1990 to 2000 (table 4) based on analysis of Landsat TM (DoF, 2005). The change context of forest has effect on the forest carbon. It showed the negative change in forest cover and positive changes in shrub area, which are evidences of emission of deforestation and forest degradation. The forest resource assessment is on the way of the updating the status of the forest resource. The department of survey and research is responsible for this. The national forest inventory was started since 2010 and expected to complete by 2014.

Table 4: Context of Forest cover change

Data source	Year	Forest		Shrub		Total	
		thousand ha	%	thousand ha	%	thousand ha	%
FSRO	1964	6402	45.3	-	-	6402	45.3
LRMP	1978/79	5616	38.1	689	4.6	6285	42.7
HMG/N	1985/86	5424	37.4	706	4.8	6210	42.2
DFRS	1999	4268	29	1560	10.6	5828	39.6

Source: FSRO, 1964; LRMP, 1986; HMG/N, 1989; DFRS, 1999

2.9 Emission due to Energy Consumption and Cattle Keeping

The emission from energy consumption and cattle keeping are the main causes of the increasing atmospheric GHGs concentrations. Some major concerns regarding the increasing pattern of CO_2 and CH_4 concentrations are described here, in brief.

The atmospheric concentrations of CO_2 and CH_4 in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO_2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution (Searchinger *et al.*, 2008). It is very likely that the observed increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use. Carbon dioxide (CO_2) is the most important anthropogenic GHGs. Its annual emissions have grown from 21 to 38 gigatonnes (Gt) between 1970 and 2004. The rate of growth of CO_2 equivalent emissions was much higher during the recent 10-year period of 1995-2004 (0.92 $GtCO_2$-eq per year) than during the previous period of 1970-1994 (0.43 $GtCO_2$ equivalent per year) (Lenny *et al.*, 2007). Similarly, Methane (CH_4) is a greenhouse gas currently contributing about 15 % of global anthropogenic greenhouse gases emitted every year when assuming a greenhouse warming potential (GWP) of 21 times carbon dioxide (CO_2) over 100 yrs. As CH_4 has a relatively short perturbation lifetime of 12 yrs in the atmosphere, the GWP over 20 years is considerably higher about 72 times that of CO_2. With this shorter time horizon, CH_4 emissions account for about 35% of global anthropogenic greenhouse gas emissions (Lenny *et al.*, 2007).

Biomass is often the primary source of household energy in developing countries. Just over three billion people use biomass fuels for cooking and heating in developing countries and approximately 800 million people, mostly in China, use coal. Thus, it is anticipated that the use of solid fuels and especially biomass fuels will persist for many years to come. South Asia has nearly 1.5 billion inhabitants, who account for approximately a quarter of the world's population. Since nearly 70% of the population of this region lives in rural areas and approximately 74% relies on solid fuels for household energy requirements (Meng *et al.*, 2011). The solid fuel includes the fuel wood, cattle dung, paddy and wheat straw. These are the sources of GHGs emission.

Traditional and commercial energy sources are dominant in Nepal, which include fuel wood, animal waste, agricultural residue, and hydropower. Nepal predominantly depends on the fossil fuel for its energy requirements. Fossil fuel combustion oxidizes the carbon present in the fuel, resulting into CO_2 emission. Some carbon is also released in the form of CO_2, CH_4, and non-methane hydro carbon which is oxidized to CO_2 in a decade. Other emissions are N_2O, SO_2, and black carbon. The energy sector includes GHGs emission from the combustion of fuels for energy production.

The energy consuming sectors have been classified as follows: residential, commercial, transport, industrial and agriculture sector. The GHG inventory finds that about 71% of the total CO_2 equivalent emission from the energy sector in 2000/01 is from the fuel combusted in the residential sector for heating and lighting purposes. The overall GHGs emission trend from the energy sector is increasing. The energy sector emitted 3266 Gg of CO_2 equivalent in the base year 1994/95 (MoPE, 2004). According to the GHGs inventory, in the baseline year 2000/01, the energy sector in Nepal emitted 6894.64 Gg of CO_2 equivalent. Out of this, 2763.28 Gg was emitted as CO_2, 163.96 Gg as CH_4 and as 2.22 Gg as N_2O. The residential sector is the largest GHGs emitter (71%) from energy use that is about 130.96 Gg of CO_2 equivalent. The transport and industrial sectors each emitted about 12% of the total CO_2 equivalent emission in 2000/01 (table 5). The remaining 5% GHG emission was from fuel combusted in the commercial and agricultural sector (MoEST, 2014).

Table 5: Emission and removal from different sectors in Nepal

S.N.	Categories	CO_2 (Gg)	CH_4 (Gg)	N_2O (Gg)
	Total national emission and removal	-9882.14	667.53	30.55
1	Energy	2763.28	163.96	2.22
2	Industrial processes	130.96		
3	Agriculture		470.08	27.14
4	Land-use change and forestry	-12776.4	16.75	
5	Waste		16.74	1.19

Source:(MoEST, 2014)

Nepalese economy heavily relies on traditional source of energy. The main sources of energy are conventional like firewood, agriculture residues, cow dung, commercial energy, coal, petroleum product, electricity and renewable and most of them are increasing between 1990/91 to 2008/2009 due to increasing population. The conventional types of energy sources were increased from 5576 to 8185 thousand tons of oil equivalent; firewood consumption was increased from 4980 to 7301 thousand tons of oil equivalent; agriculture residues consumption was increased by 224 to 344 thousand tons of oil equivalent and cow dung consumption was increased by 372 to 540 thousand tons of oil equivalent (Table 6) (MoF, 2010).

The energy consumption and cattle keeping are diverse in Nepal. Here, Nepal is one of village dominant developing country where most of the poor habitants are using the fuelwood, dung cake, dung stick, leaves and straw for cooking and heating especially in Tarai. At the same time, rural communities also are keeping large number of cattle for agriculture works as well as for income generation. The consumption of firewood for energy and cattle keeping are main sources of CO_2 and CH_4 emission respectively.

The gaps were clearly observed on estimation of CO_2 and CH_4 emission from fuel consumption and cattle keeping respectively. At the same time other gap was found in the management effect of cattle dung for biogas production. These data can be helpful to quantify the CO_2 and CH_4 emission at rural level in order to prepare the country to manage these sources to reduce GHGs.

Table 6: Sources of energy consumption in Nepal

Sources	**1990/91**	**1995/96**	**2000/01**	**2005/06**	**2008/09**
	Unit: Thousand tons of oil equivalent				
Conventional	5576	6185	6824	7698	8185
Firewood	4980	5525	6068	6862	7301
Ag. Residues	224	248	299	329	344
Cow dung	372	412	457	507	540
Commercial	349	651	1016	1093	1147
Coal	42	72	174	243	181
Petroleum Product	257	507	734	686	775
Electricity	50	72	108	164	191
Renewable	4	10	29	53	64
Total	11854	13682	15709	17635	18728

Source: (MoF, 2010)

Some studies showed on fuel wood consumption and their risk of use to health hazard such as study done by Smith *et al.*, 2004 emphasized on indoor pollution from household use fuels while Ghimire (2006) showed energy issues in the rural areas. A study done by Bhattrai (2005) showed the tradition energy consumption should be reduced and alterative energy should be promoted in Nepal. A study done by Bajracharya (2010) showed the effect of improved stove in firewood consumption. She showed the use of improved stove can reduce up to 44% of the fuel wood consumption and reduce the CO_2 emission too. Another study done by Adhikari (2013) studied fuel consumption by the rural households and suburban people. These studies have special focus on assessment of firewood consumption and reduction measures but these studies did not include the assessment CO_2 and CH_4 emission from domestic fuel. In addition, the dung of the domestic animals were managed properly for biogas production, how it can reduce the CO_2 and CH_4 emission together was not studied.

CHAPTER 3

3. MATERIALS AND METHODS

The materials and method emphasize on the introduction of the research site, study site selection, the research flow diagram and method applied for data collection and analysis.

3.1 Description of Research Site

The geographical location of the research site, climate and demography are described here.

3.1.1 Location of the Research Site

The research sites were selected in Mahottari district, Tarai of Nepal. Specifically, the geographical location of this district is 26° 36' to 28° 10' N and 85° 41' to 85° 57' E. Total area of this district is 1002 square km. This district is divided into two main parts: they are Chure Bhawar, which occupies 14% and Tarai (plain) that covers 86% of the total area. The altitude ranges from 61 m to 808 m. Total recorded forest area of this district is 22456.7 ha. Out of this, there are 13028.9 ha forest in Tarai and 11427.8 ha in Chure Bhawar region. Among them, 7495.11 ha forest is managed under collaborative forests and 4790 ha forest is managed under community forests. Moreover, about 8000 ha forest which was converted into plantation area is managed by Sagarnath Forest Development Project while there are about 2000 ha encroachment areas, which are converted into agriculture land, temple, market, settlement and play ground (DFO, 2010). Though there are hundreds ha of public plantation and community planted forests in Mahottari district, they have not recorded yet.

There are four major rivers in this district namely Banke, Maraha, Jangaha and Ratu. These rivers are originated from Churia hills so they are seasonal. Infact, the seasonal flood and landslides damage a lot of agriculture land, cattle, wealth and health. Moreover, other small rivers are Bighi, Bhabshi, Budhikhola, Thalhi, Chhagar rivers are some of them. The main importance of this district is Jaleswarnath Mahadev which is symbol of god Shiva. The sculpture of the god Shiva is placed under the water, which means Jal in Nepali so the god is named as Jaleshwarnath. It is believed that, there is no lacking of water or rain in this district because of bless of god Jaleswarnath so there is high yielding of crops.

3.1.2 Climate

The annual temperature and rainfall vary according to the season and there was correlation between them.

The relationship was observed between the records of temperature and rainfall. As, the highest annual rainfall was recorded about 2388.7 mm in 1987, the average daily temperature was reported about 25^0C. On the other hand, the lowest record of rainfall was 474.3 mm in 2003 and second lowest was 504 mm in 1991 while temperature record was higher than 26^0C in both years 2003 and 1991. Both 1991 and 2003 showed the indication of drought years while higher rainfall in 1987 showed the flood.

The 30 years records of precipitation showed different pattern since 1981 to 2010. It was second highest record of rainfall 2058.8 mm in 1988. Then, declining rainfall for 3 years upto second lowest record in 1991, there was increasing record upto1533.2 mm in 1999. After that, there was decreasing record of rainfall for 4 years upto the least rainfall 474.3mm in 2003. At last, there were again increasing record of rainfall with some variation upto 1254.6 mm in 2010. No any evidence of rainfall repeatedly showed the record like 1987 and 1988. These indicate that, there was variation in rainfall pattern.In addition, there was increasing trend of temperature in Mahottari district. The lowest temperature was recorded about 24.25^0C in 1983. Other records of temperature were 24.7, 24.6 and 24.6 ^{0}C in 1989, 1999 and 2007 respectively. However, there were high records of temperature 25.3, 25.5, 25.9, 26.0 and 25.5 ^{0}C in 1988, 1990, 1995, 1998 and 2002 respectively. The records of average temperature showed remarkably higher than 26^0C both in 2003 and 2004 (figure 1).

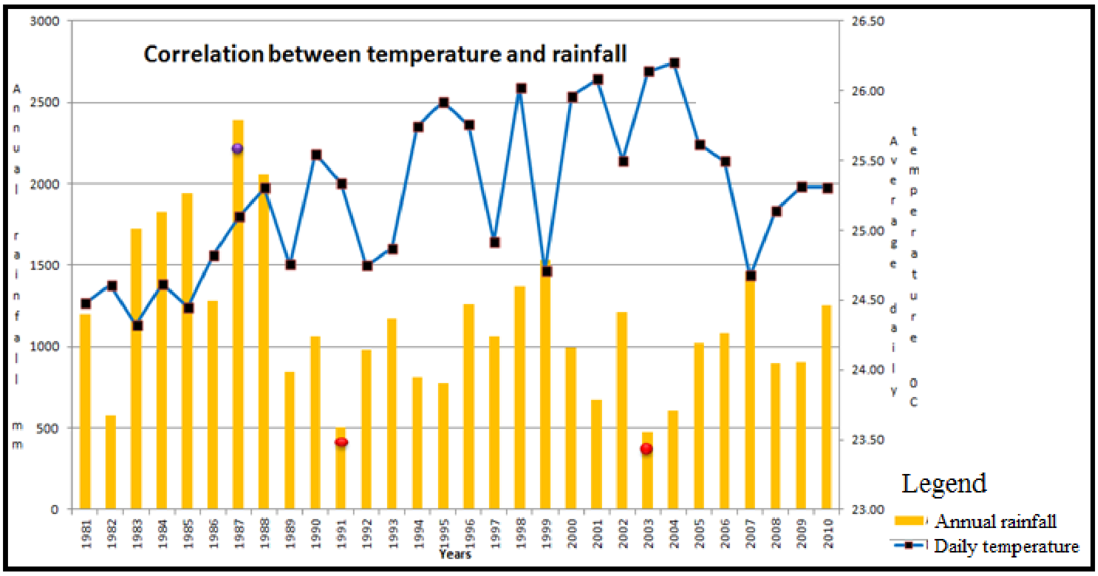

Figure 1: Annual Temperature and Rainfall in Mahottari

3.1.3 Demography

There are 111316 households in this district which comprises 682769 populations. Based on this, there are five constituencies in this district. Total male population was 349472 and female was 333297. The population density of this district was 552.4 per sq km and birth rate was 1.96. The average family size was 6.13, urban population 96,145, and rural population 586624 (CBS, 2011).

3.2 Research Sites

The study sites selection was based on the requirement of research objectives. There were two types of study sites; they were for biophysical data and socioeconomic data.

3.2.1 Studied Site for Biophysical Data

There are 3 collaborative forests, 73 community forests, 15 community planted forest and 11 public plantations in Mahottari district. Altogether 12 community managed forests were selected for the study areas. They are 3 collaborative forests, 3 community forests, 3 community planted forests and 3 public plantations. The community forests selected using the lottery method while all collaborative forests were selected for the studies because these forests are natural but management systems are different. The main species of these forests are Sal (*Shorea robusta*) and other species are Saj (*Terminalia tomentosa*), Botdhairo (*Lagerstroemia parviflora*), Harro (*Terminalia chebula*) and Barro (*Terminalia belerica*). Similarly, the community planted forests and public plantations were selected using same method. The major planted species is *Eucalyptus camaldulensis* and other naturally regenerated species were *Cynodon dactylon* and *Mimosa pudica* in all the sites. The detail of study sites are presented here.

3.2.1.1 Collaborative Forests

The selected collaborative forests were Banke-Maraha, Tuteshwarnath and Gadhanta-Bardibash (figure 2). The description of these forests presented below.

Banke-Maraha collabotative forest: The location, soil characteristics and applied silviculture operations provide the condition of the collaborative forest. This forest is located in Khayarmara 3,5 and 7. The social unit of this CFM covers 18 VDCs. There are 18 village development committees managing the forest. They are Khayarmara, Bharatpur, Laxminia, Sahshsula, Khopi, Bisbiti, Sunwal, Gaidhabhetpur, Raghunathpur, Phulkaha, Samshi, Pokharbhinda, Sundarpur, Itharwakati, Parsha Debar, Sonama, Khayarbani and Laxminia Barginia. Soil is generally loamy and suitable for tropical and subtropical species, some of them are *Shorea robusta*, *terminalia tomentosa* and *Lagerstroemia parviflora*. However, sandy loam and sandy soils are found near to Banke and Maraha streams which is suitable for *Acacia catechu* and *Dalbergia sissoo*.

Total area of the forest was 2006 ha. The green trees had not harvested from the forest but the fallen logs were collected and sold annually. No any silvicultural operations are applied in this forest. The patrolling is regular in day time. Though the detail schemes has emphasized on practice of silvicultural operations and selection felling according to sub compartment, they are not implemented yet. The forest has disturbed because of local pressure. Sometimes local people of Khayarmara VDC illegally collect the timber and firewood so the condition of this forest is low compared to others.

Tuteshwarnath CFM: The description of Tuteshwarnath CFM includes location, soil characteristics and applied silviculture operations. The location of this CFM is ward number 8 of Maisthan village development committee. The social unit of this CFM covers 20 VDCs. They are Maisthan, Belgachhi, Hatilet, Ramnagar, Paraul, Nigaul, Badia Banchauri, Parsha Pataili, Meghnath Gorhana, Aurahi, Suga, Gaushala, Banauta, Matihani, Ram Gopalpur, Simardahi, Dhamaura, Mahottari, Phulkaha and Parkauli. There was no difference in soil and vegetation of this CFM and Banke – Maraha CFM. Gadhanta stream is flowing in east of the CFM while Maraha stream is flowing in the west. Indeed, sandy and sandy loam soils are generally found at both bank of the steam so vegetations are mainly *Acacia catechu* and *Dalbergia sissoo*. Total area of the forest was 2006 ha. The green trees had not harvested from the forest but the fallen logs were collected and sold annually. No any silvicultural operations are applied in the forest. The patrolling is regular in day time. Though the detail plan in scheme has emphasized on practice of silvicultural operations and selection felling according to sub compartments, they are not implemented yet.

Gadhanta–Bardibash CFM: The description of location, soil characteristics and applied silviculture operations show the brief status of Gadhanta– Bardibash CFM. The location of this CFM is ward number 1, 2 and 7 of Maisthan village development committee. The social unit of this CFM covers 22 VDCs. They are Bardibash, Gauribas, Kishannagar, Bijalpura, Harinmari, Ratauli, Sahodawa, Pipara, Bhramarpura, Danauli Banauli, Ekrahiya, Dhirapur, Hatisarawa, Maihaura, Bishanpur, Khutta piparari, Loharpati, Singhyahi, Sitapur, Damhi Madai, Gonarpura and Bagada. Loamy soil and rich in organic matter show the good vegetation in the most of the part of forest. However, there is sandy loam soil at the edge of Bhapashi and Gadhanta streams in east and west boundaries respectively. Total area of this forest is 1450ha. This forest is dominated by *Shorea robusta* and *Terminalia tomentosa* however; there is few trees of *Acacia catechu* at the edge of the streams. The status of this forest is better than other collaborative forests. Though the forest management scheme has included the silvicultural operation according to subcompartment, it has not applied yet. So, the timber collection and firewood collection were focused only on fallen or felled trees.

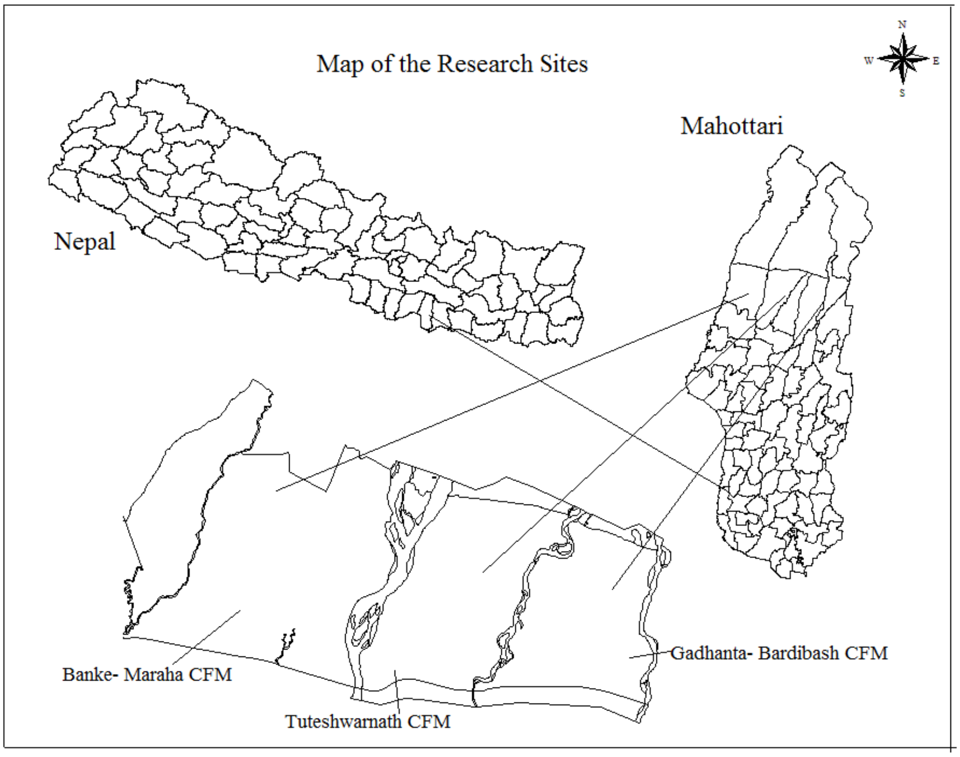

Figure 2: Maps of collaborative forests

3.2.1.2 Community Forests

The selected community forests are Baudh, Chure- Parwati and Chyandanda (Figure 3).

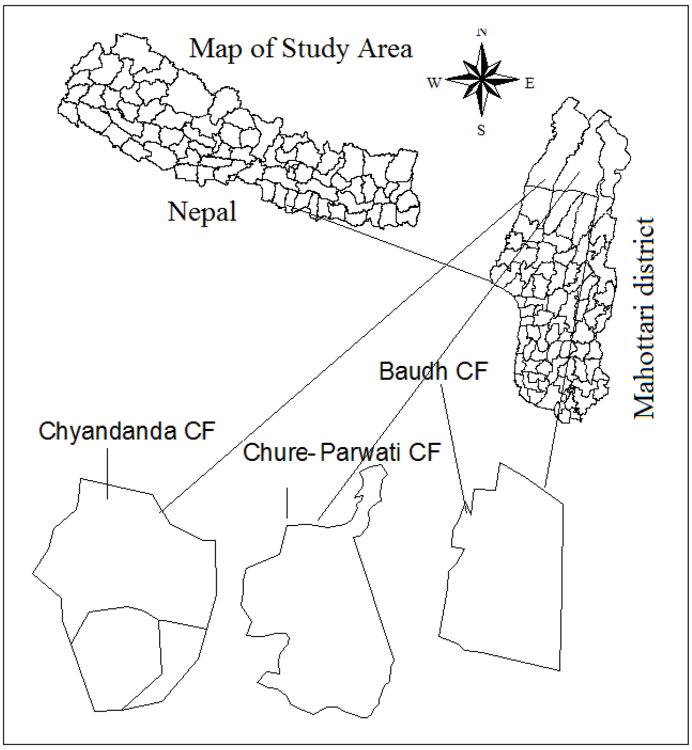

Figure 3: Maps of community forests

***Bauddha community forest*:** It is situated at ward number 5 of Khairmara VDC and users belong to same ward. About 55 households were users of this community forest. They are also member of Banke – Maraha collaborative forest. Total forest area is about 69.73ha. The forest soil is loamy so the dominant species is *Shorea robusta* and associate species are *Terminalia tomentosa, terminalia belerica, Adina cardifolia* and *Lagerstroemia parviflora*. The selection felling of mature and over mature trees have already done in 2010. The silvicultural operations like clearing, pruning, cleaning, weeding, replanting and lastly thinning of pole are applied. In addition, the users are very instant. Since this forest is attached with Banke-Maraha collaborative forest sometimes the pressure of illegal activities was observed in the collaborative forest.

***Chure Parwati community forests*:** It is situated at ward number 8 of Maisthan village development committee and users belong to same wards of same village development committee. About 324 households were the users of this community forest and the area of this forest was 441.70 ha. The soil was fragile and loamy sand because this lies in Churia region and consequences are soil erosion and landslide. The users are very active to manage this forest so they implemented their operation plan and applied silvicultural operations specifically clearing, pruning, cleaning, weeding, replanting and lastly thinning of pole. They harvested selectively mature and over mature tees and sold them. Thus, the status of the forest is satisfactory.

Chyandanda community forest: It is situated in ward number 1,3 and 7 of Bardibash village development committee and users belong to same village. The area of this forest is about 41.35 ha. About 124 households were managing this forest. Since this community forest is situated at the foothills of Churia, there was silt loam soil. The users have implementing the forest operational plan and applying the silviculural practices like clearing, pruning, cleaning, weeding, replanting and thinning. There was no mature and over mature tree but the forest is dominated by the pole staged stem. This forest was affected by the suburbanization of Bardibash market. In the past, this forest was easy site for illegal logging and firewood to meet the demand. In reality, this is the main reason of absent of mature and over mature trees in this community forest.

3.2.1.3 Community Planted Forests and Public Plantations

The selected community planted forests were Sita, Ramnagar and Jogikuti while public plantations were Shreepur, Banuata and Bisbitty (figure 4).

Sita community plantation**:** It is situated at ward number 5 of Khayarmmara and users are of also from same ward number of the village development committee. About 28 households have been managing this community plantation. The forest covers about 5.42 ha. The plantation was done in 2005. The forest soil is very rich organic matter and loamy. Main species was *Eucalyptus camaldulensis* and other naturally regenerated species were *Shorea robusta* and *Terminalia tomentosa*. The users are very active to carry out silvicultural operation like clearing, pruning, cleaning, weeding, replanting and thinning. This plantation site is very close to Banke-Maraha collaborative forest. Thus users have easy access to collect and use the forest products.

Ramnagar community planted forest**:** The location of the site is at ward number 7 of Ramnagar village development committee. The users were from ward number 7 and 8 from same VDC. This covers about 4.92 ha and about there were 102 households managing this forest. The plantation was done in 2007. The *Eucalyptus camaldulensis* is planted in open area but the natural regenerations of *Shorea robusta* and *Terminalia tomentosa* were rejuvenating the site because of nearby natural forest. However, the grazing is main problem here. The users have easy access to carry out the forest products. The status of the plantation is not so good because the users are not so active.

Jogikuti community planted forest**:** This plantation was done at ward number 7 of Belgachhi village development committee in 2006. It covers 8.60 ha and there were about 45 households managing the forest. The users are not so active because they meet their demand of forest products from nearest natural forests and Sagarnath Forest Development Project. The grazing is the main problem of this site.

Shreepur public plantation**:** This plantation is located at ward number 4 of Shreepur VDC. The plantation was done at the bank of Sansari Thakur pond. The users of this plantation are from ward number 4, 5 and 6 of same VDC. The area of this plantation is about 10.5 ha the plantation was done in 2005. There were about 65 users and they were very active to manage the plantation. There is no any natural forest except private plantation. The status of this plantation was very good. The *Eucalyptus camaldulensis* was the planted species. The users adopted the agroforestry in this site so the growth of the plantation was very healthy. The soil was loamy and suitable for this species. The users collect the litters for cooking their food.

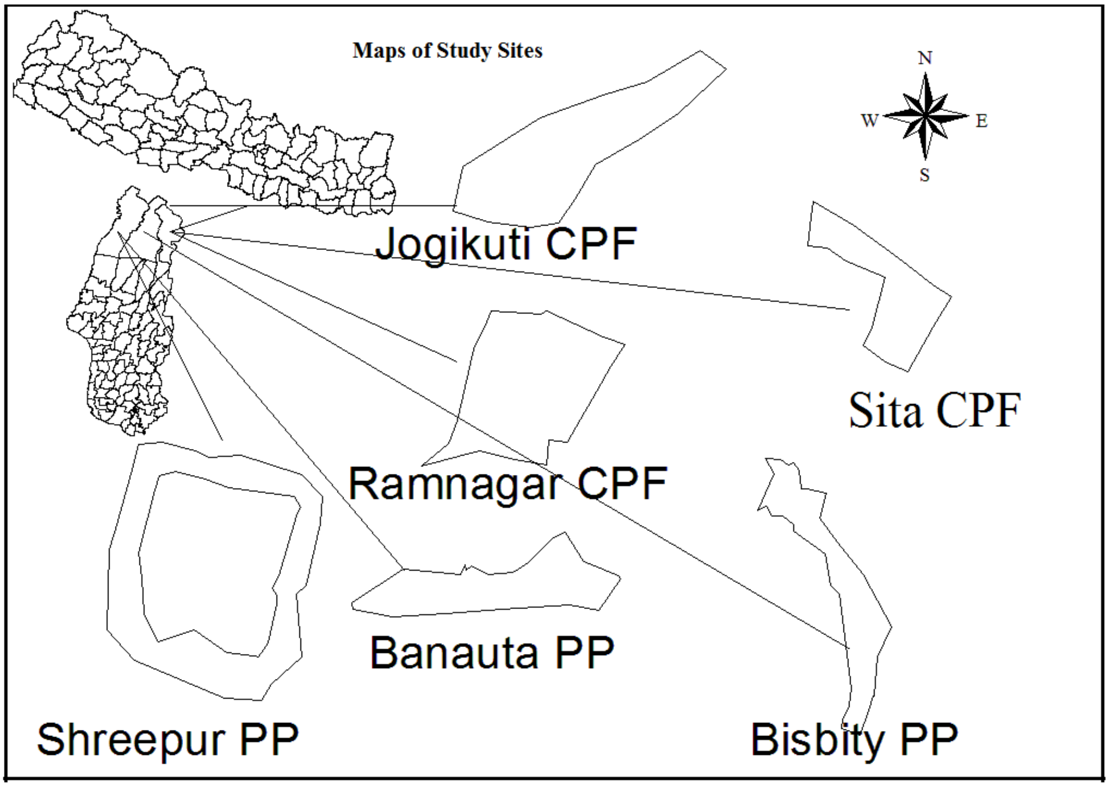

Figure 4: Maps of public plantations and community planted forests

Banauta public plantation**:** This is situated at ward number 4 of Banauta village development committee. The plantation was 8.8 ha and done in 2007 on the bank of the Ratua river specifically Ankashi stream. About 55 housholds managing this plantation and users were from same wards and same village. The soil is sandy loamy but the annual flood carried by Ratu river fertile soil favour the growth of the plantation. The *Eucalyptus camaldulensis* was planted species while natural grasses were *Cynourodon dactylon* and *Mimosa pudica.*

Bisbity public plantation**:** The plantation is situated at ward number 7 of Bisbity village development committee and users were from same location. The plantation was done on the bank of Jangaha stream in 7.6 ha in 2006. The soil was sandy loam and growth was poor because of disturbance of grazing. The planted species is *Eucalyptus camaldulensis* and other naturally regenerated species were *Cynodon dactylon* and *Mimosa pudica* in all the sites. The users were adopted the agroforestry. About 67 households were managing this plantation.

3.2.2 Study Site for Socio-Economic Data

The socio-economic data were used to assess the drivers of deforestation and forest degradation, study of domestic emission and exploration of opportunity and challenges in REDD+ programme.

In case of appraisal of drivers of deforestation and forest degradation the stakeholders' consultations and workshops were organized particularly with staff working to the forest offices and users of related research sites (Annex 3). Apart from this, the short meetings were organized with experts working in this field for exploration of opportunity and challenges.

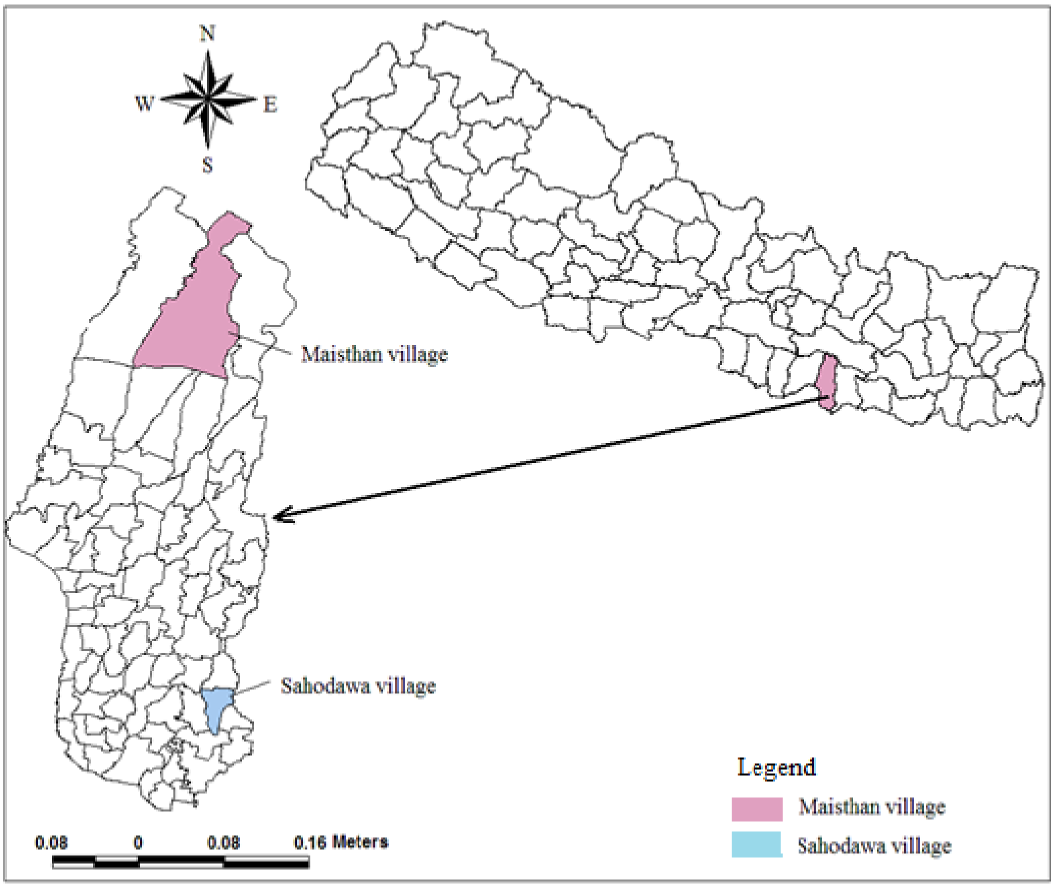

Figure 5: Studied site for domestic emission

In addition, one village near to the forest i.e. Maisthan village and another village i.e. Sahodwa village, which is distant from forest were selected using lottery method in order to compare the domestic emission emitted from the households (figure 5). A brief description of the villages is presented below.

Maisthan village: This village is situated 5-10 km north of the E-W high way. The small villages are connected with feeder road through the forest. There were 11 community forests in this village. There is a contiguous block of forest between village and N-W high ways. The other contiguous block of forests is in Churia and the villages are settled at the foot hills. Most of the community forests are situated in Churia and local communities are users of the community forest. They have migrated from Sindhuli, Makwanpur, Ramechhap, Sindhupalchok and Kabhreplanchok districts. They meet their demand of forest resource from these forests and sometime from Tuteshwarnath collaborative forest too because they are users of this collaborative forest. There are 1130 households in Maisthan village. The dominant populations are Brmahan and Kshetri but some of them are Magar and Gurung. The main occupation of the households is agriculture and they also keep mainly cows, buffalo and goats while Magar and Gurung communities keep pigs, goats and chicken including cows and buffalo. The people have handsome income from Parwal vegetable (*Trichosanthes dioica*).

Sahodawa village: It is situated 10 km west from Janakpur market. The villages is settled both sides of Janakpur – Jalaeshwar road. There were 1500 households in this village. The main occupation of the households is agriculture but there are no irrigation facilities they have to rely on seasonal rainfall. The population dominated by Yadav, Sah, Brahman, Kshettri, Mushar and Chamar. The other occupation of the population is buffalo, cow and goat keeping. Most of the young generation depend up on the abroad income mostly Qatar, Malaysia and Dubai. Some people are relying on the labour work in Janakpur. Infact, there is no any national and community forest to meet their daily need of forest products. The Gadhanta– Bardibash CFM is situated 20-25 km north from this village, though they are distant users of this CFM. They get fire wood and timber occasionally when there is natural disaster like fire and flood. They rely on their own resources for forest products. Most of the rich and medium category families have their own private forest which is dominated by *Mangifera indica, Eucalyptus camaldulensis, Dalbergia sissoo, Tectona grandis.* However poor families have no options of forest products so they rely on dung cake and sticks, litter and straw for cooking.

3.3 Method of Data Collection and Analysis

Primary data were collected directly from the field while secondary data were collected from the records of district forest office, users and other relevant institutions. The secondary data includes the record of timber and firewood, which were also gathered from the annual report of collaborative and community forests. However, there was no any record of collection of forest products from public plantation and community planted forests (figure 6).

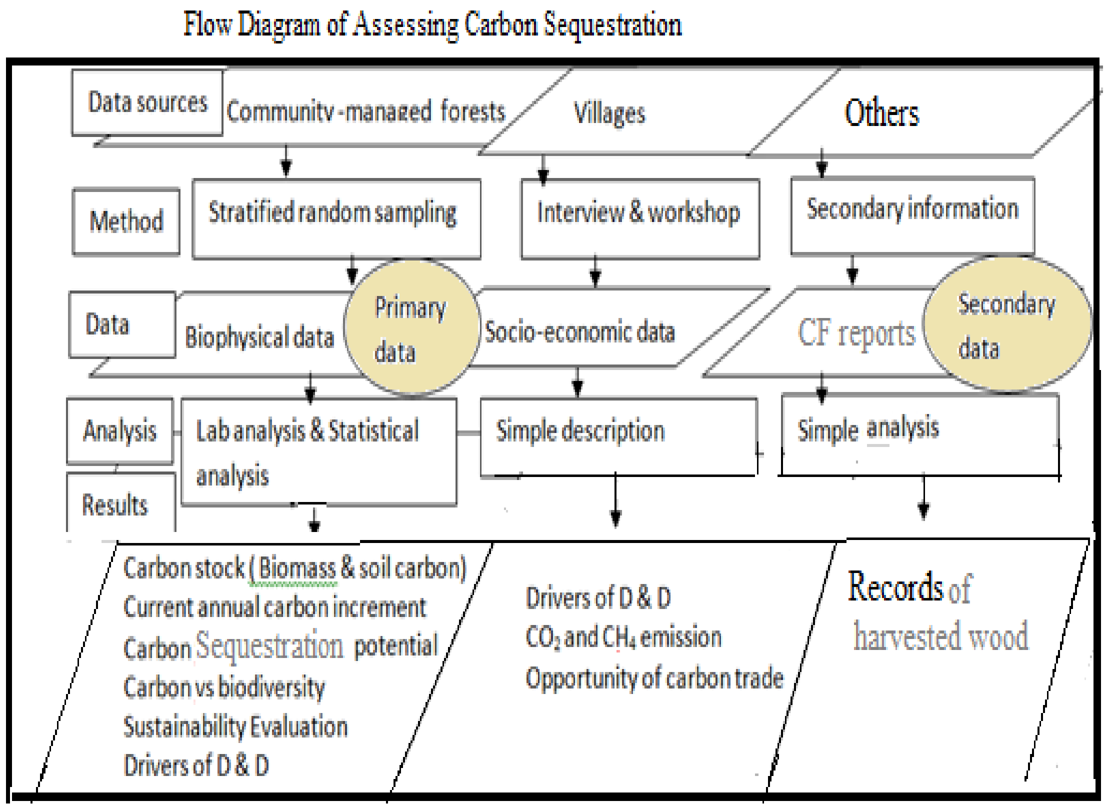

Figure 6: Flow diagram of research method

Mainly, two types of data were collected and analyzed to conduct this research based on Good Practice Guidance for National Greenhouse Gas Inventory (IPCC, 2006). They were biophysical and socio-economic data. Specifically, the biophysical data were collected applying stratified random sampling as well as simple random sampling. Additionaly, the socioeconomic data were collected applying open questionnaire interview and organizing workshop. Then, the collected data were analyzed to assess the forest carbon, biodiversity, diameter distribution, current annual carbon increment and mean annual carbon increment (IPCC, 2006). Simultaneously, the statistical analysis was carried out separately to present the inference precisely.

3.3.1 Biophysical Data Collection and Analysis

The research method consists of four basic steps to collect the biophysical data. They were mapping and stratification, setting the experimental design, sampling process and sampling method of data collection and data analysis. These data were used for assessment of the carbon sequestration; exploration of the opportunity and challenges for carbon trade; evaluation of carbon stock for the sustainability in forest management regimes; appraisal of the biodiversity status and its relationship with the carbon stock; effects of drivers of deforestation and forest degradation on carbon stock and demonstration of CO_2 and CH_4 emission from domestic fuel and cattle keeping.

3.3.1.1 Mapping, Stratification and Experimental Design

The map of forest area was prepared in ArcGIS software using the coordinates taken by GPS Garmin 12. Then the stratification was done in the map. The basic method of forest carbon estimation was same but due to heterogeneous nature of collaborative and community forests and homogeneous character of public plantation and community planted forests, the sampling steps were quite differed. The community and collaborative forests were divided into three major strata particularly tree, pole and regeneration. Each stratum was considered as block and the replicates (samples) were distributed randomly on each stratum following the basic principle of randomized block design (RBD) (Gupta & Kapoor, 1984) so stratified random sampling was applied. The age of the plantation was considered as basic criteria for stratification of public plantation and community planted forests and the plantation area is considered as whole population and samples were taken randomly based on complete randomized design (CRD) and hence the simple random sampling was used.

3.3.1.2 Sampling Process

Sampling process includes the determination of number of sample plots and steps followed to collect the data and measurement. Mainly two methods were applied to determine the number of sample plots. They are based on the pilot sampling and based on fixed sample intensity.

Determination of sample plots applying pilot sampling: The pilot sampling was carried out to fix the number of sample plots based on the optimum allocation method in order to carry out the sampling in community and collaborative forests. For this upto 15 samples were randomly collected from each stratum (MacDicken, 1997). Then biomass was collected which was latter used to determine the required number of sample plots. Following formula was applied to determine the number of sample plots. The number of sample plots determination was based on the variation in population, the number of sampling units measured and associated probability (Husch *et al.*, 2003).

Required number of sample plots (N) = $(CV^{*}t/E)^{2}$

Where, CV is the coefficient of variation of biomass, CV =$S/\bar{x}$

Standard deviation, $S = \sqrt{\sum(x - \bar{x})^2/(n-1)}$

Whereas x is the biomass of trees

t = Value of Student's t-distribution table at n-1 degree of freedom (df) at 10% probability but in (n-1), n denotes number of sample plots taken as pilot sample that is 10-15.

$E = \frac{S}{\sqrt{n}}$; Where, E is the sampling error at 10%, S is the standard deviation (Moore & McCabe, 2003).

Altogether 96 permanent sample plots were fixed to carry out the sampling in collaborative forests. Out of this; 32 plots were fixed for Banke-Maraha CFM, 33 plots for Tuteshwarnath CFM and 31 plots for Gadhanta- Bardibash CFM (as shown in figures 7, 8 and 9).

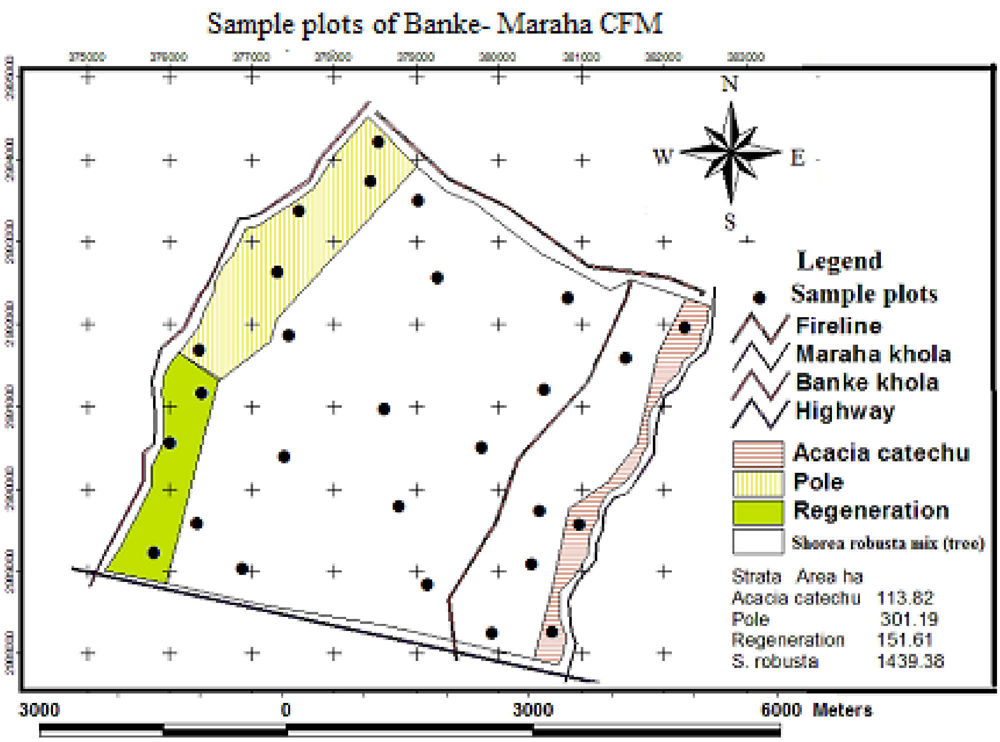

Figure 7: Sample plots distribution on Banke-Maraha CFM

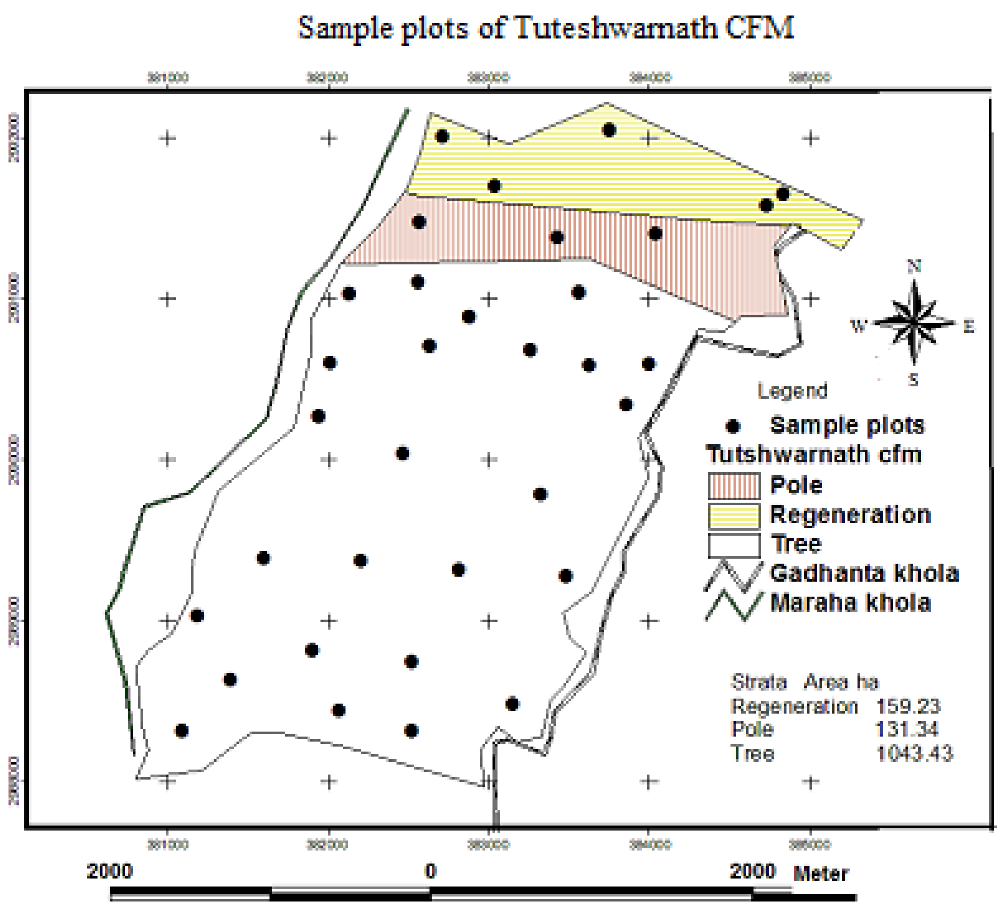

Figure 8: Sample plots distribution on Tuteshwanath CFM

Sample plots of Gadhanta- Bardibash CFM

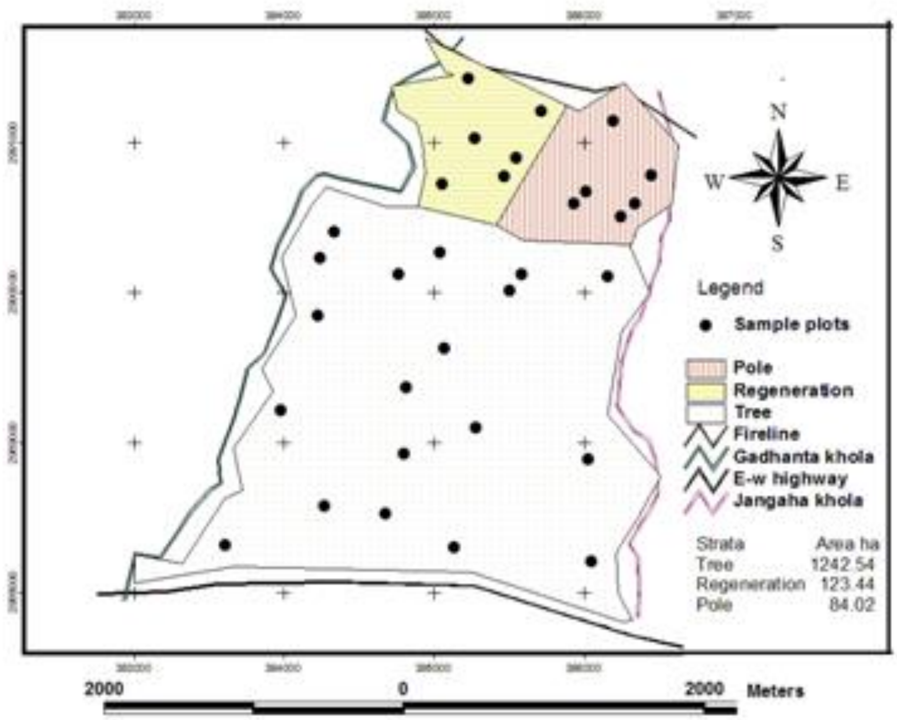

Figure 9: Sample plots distribution on Gadhanta- Bardibash CFM

Similarly, total 80 samples were determined to carry out the sampling in community forests. Among them 25 sample plots were fixed for Baudh CF 30 plots for Chure-Parwati CF and 22 for Chyandanda CF (as shown in figure 10,11 and 12).

Sample plots of Baudh CF

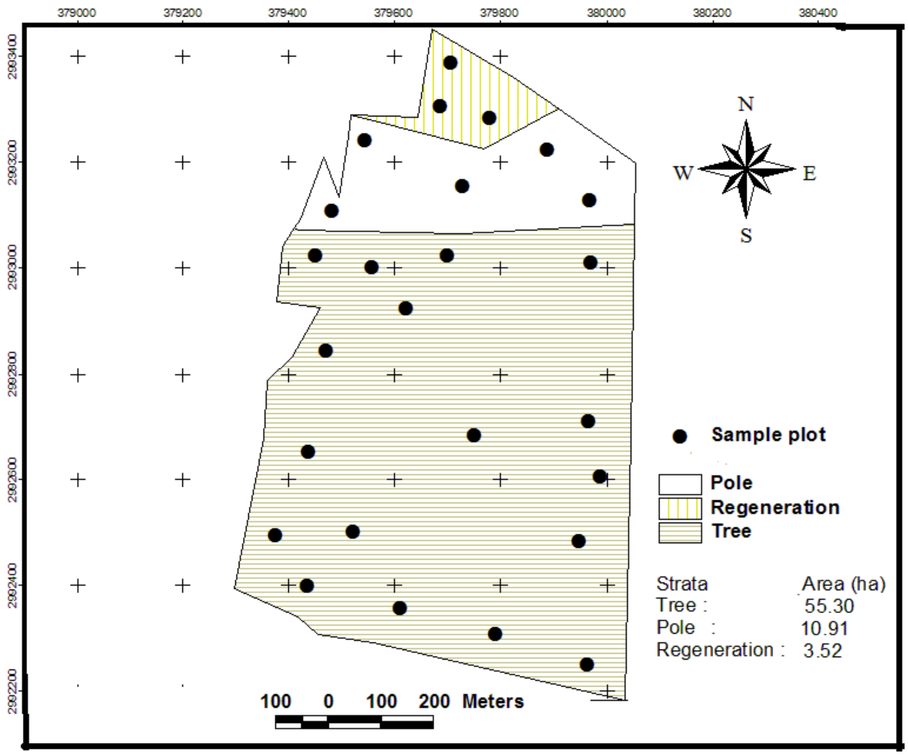

Figure 10: Sample plots distribution on Baudh CF

Sample plots of Chure- Parwati CF

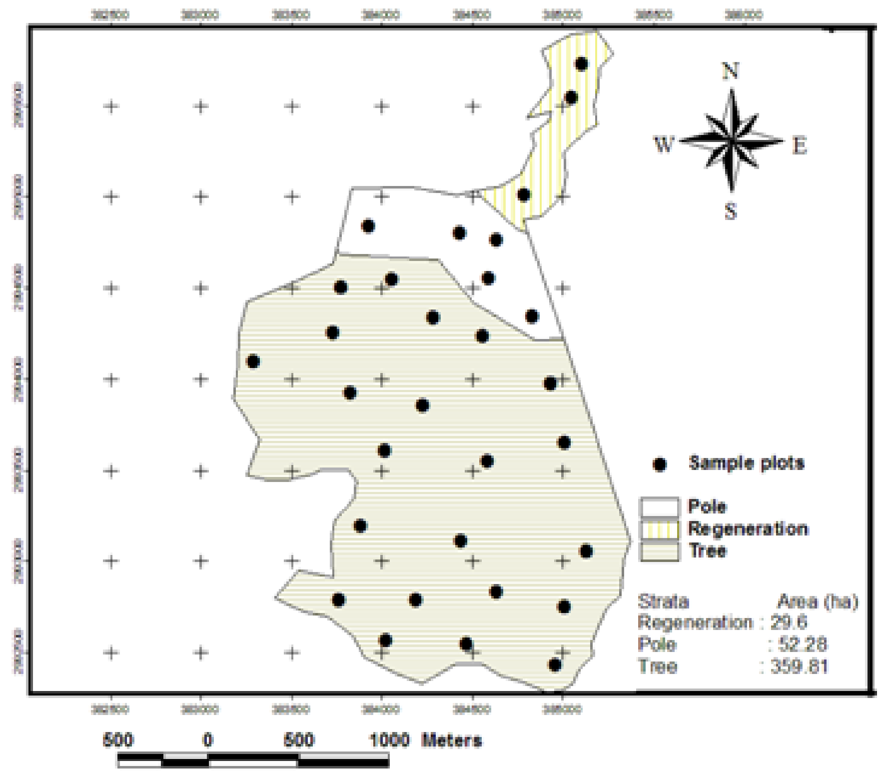

Figure 11: Sample plots distribution on Chure Parwati CF

Sample plots of Chyandanda CF

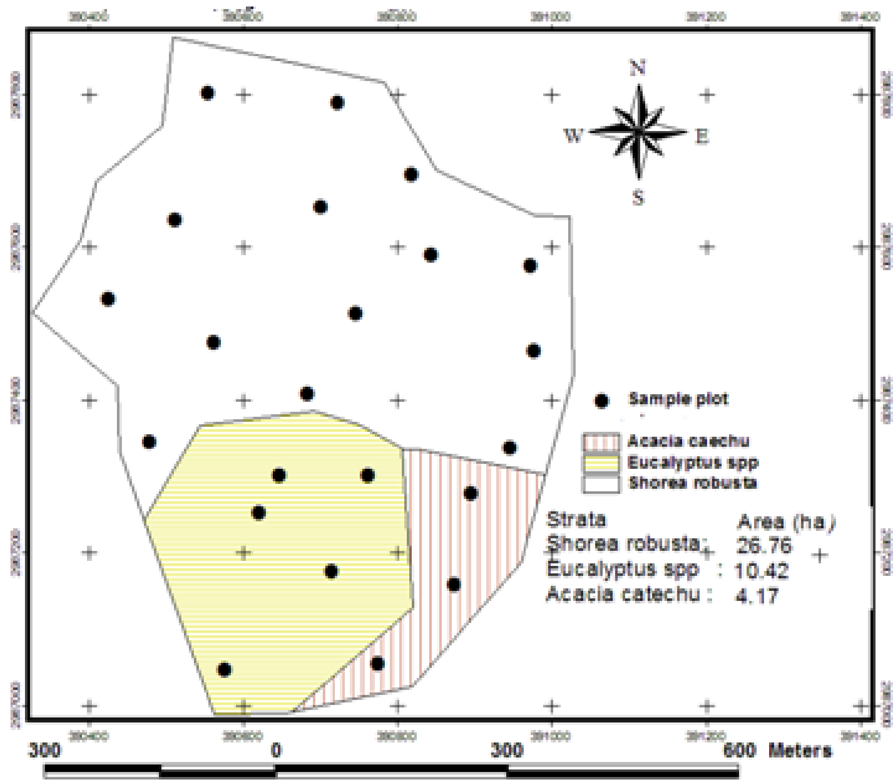

Figure 12: Sample plots distribution on Chyandanda CF

Determination of sample plots based on fixed sample intensity: In case of public plantation and community planted forests, the number of sample plot was fixed based on setting the sample intensity 1%. In case of plantation sites; total 28 sample plots for public plantations (9, 8 and 11 sample plots from Banauta, Bisbitty and Shreepur plantation sites, respectively) were collected applying simple random sampling (as shown in figure 13.14 and 15).

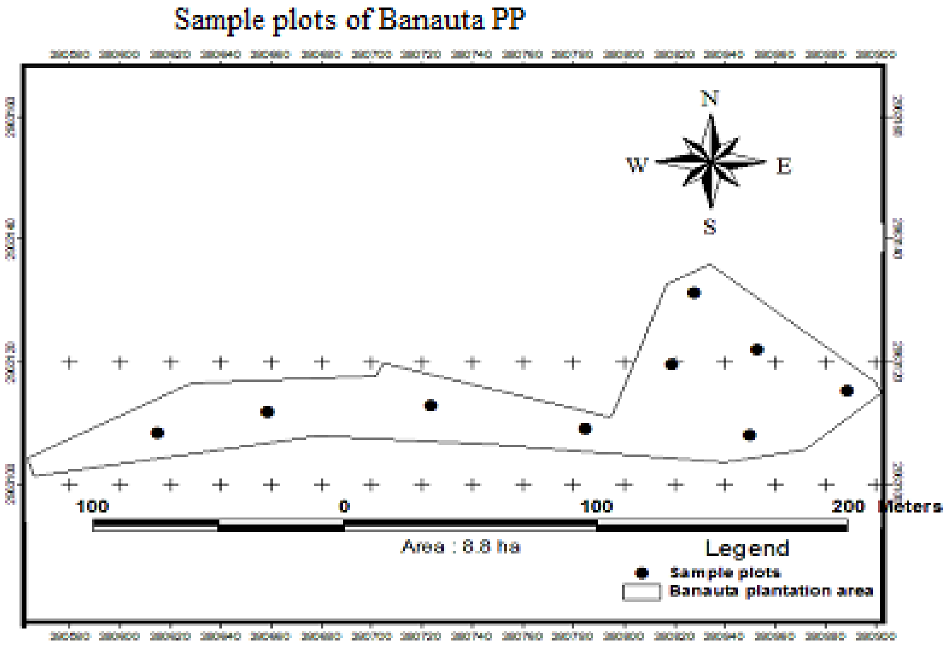

Figure 13: Sample plots distribution on Banauta PP

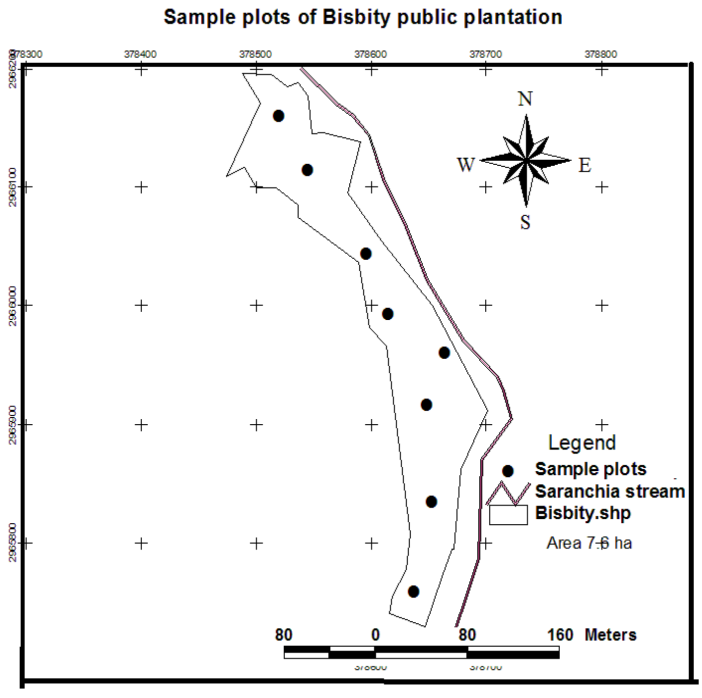

Figure 14: Sample plots distribution on Bisbity PP

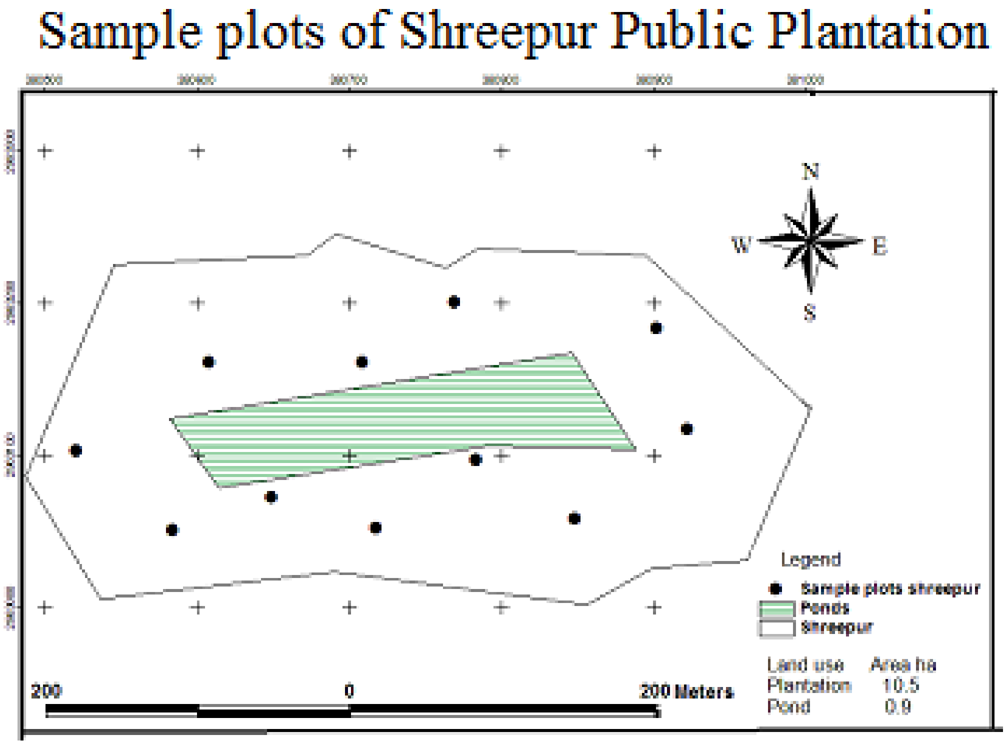

Figure 15: Sample plots distribution on Shreepur PP

Similarly, total 24 plots were collected from community planted forests (6, 7 and 11 sample plots from Sita, Jogikuti and Ramnagar community planted forests respectively). The sample plots were distributed randomly on the map using following formula (as shown in figure 16, 17 and 18).

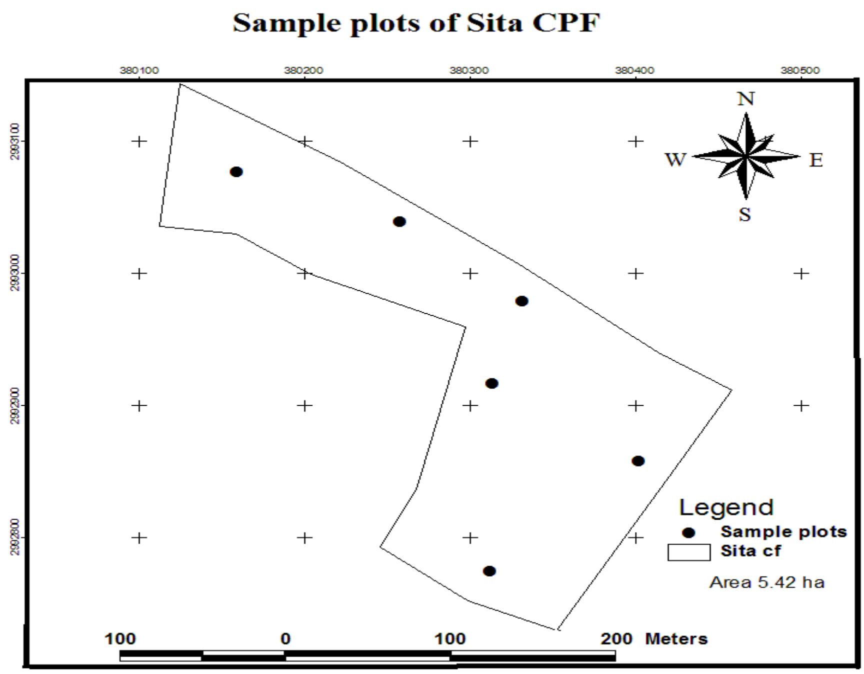

Figure 16: Sample plots distribution on Sita CPF

Sample plots of Jogikuti CPF

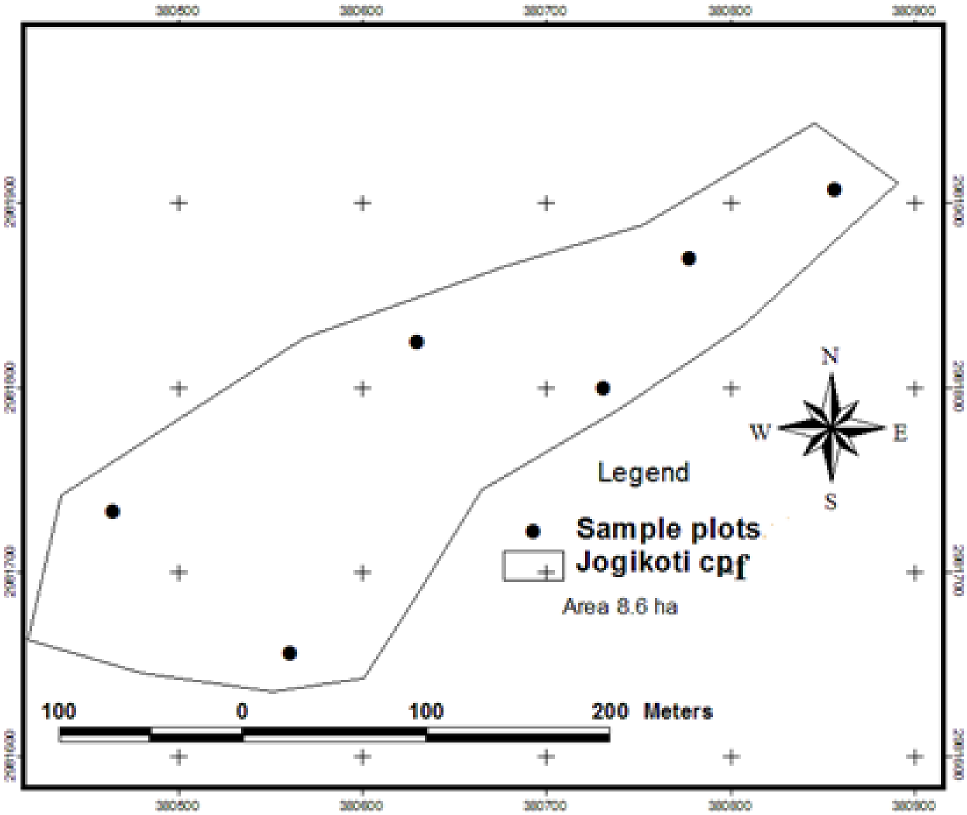

Figure 17: Sample plots distribution on Jogikuti CPF

Sample plots of Ramnagar CPF

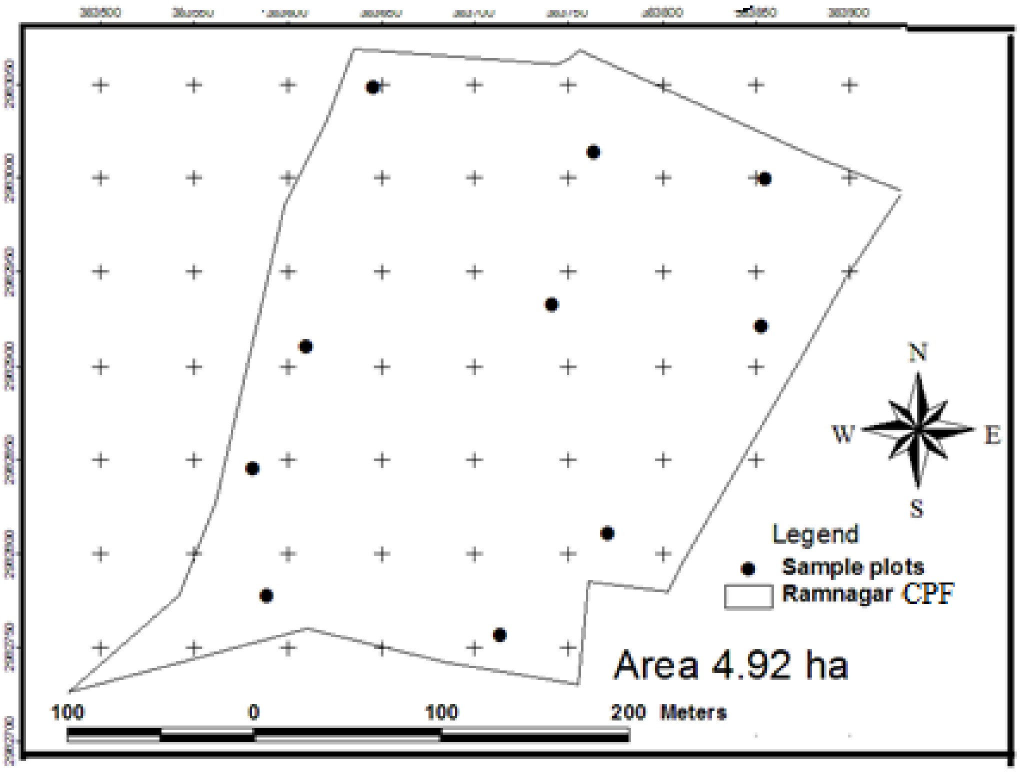

Figure 18: Sample plots distribution on Ramnagar CPF

Then the centre point coordinates of each sample plots were uploaded in the GPS receiver. The formulae used to find the centre point coordinates are described below.

Formula for Coordinates of Sample Plots distribution

$X = x\min + (x\max - x\min) * RN$ and $Y = y\min + (y\max - y\min) * RN$

X = x coordinate point of sample plot

$x\min$ = minimum x-coordinate

$x\max$ = maximum x coordinate

Y = y coordinates of sample plot

$y\min$ = minimum y coordinate

$y\max$ = maximum y coordinate

RN = computer generated random number

Determination of sample plots using the graph: The number of sample plots for determination of biodiversity calculation was done using the typical species curve method. The sampling is continued until the graph of number of species shows the constant (figure 19). This graph was applied to collect data regarding biodiversity (Harper, 1987).

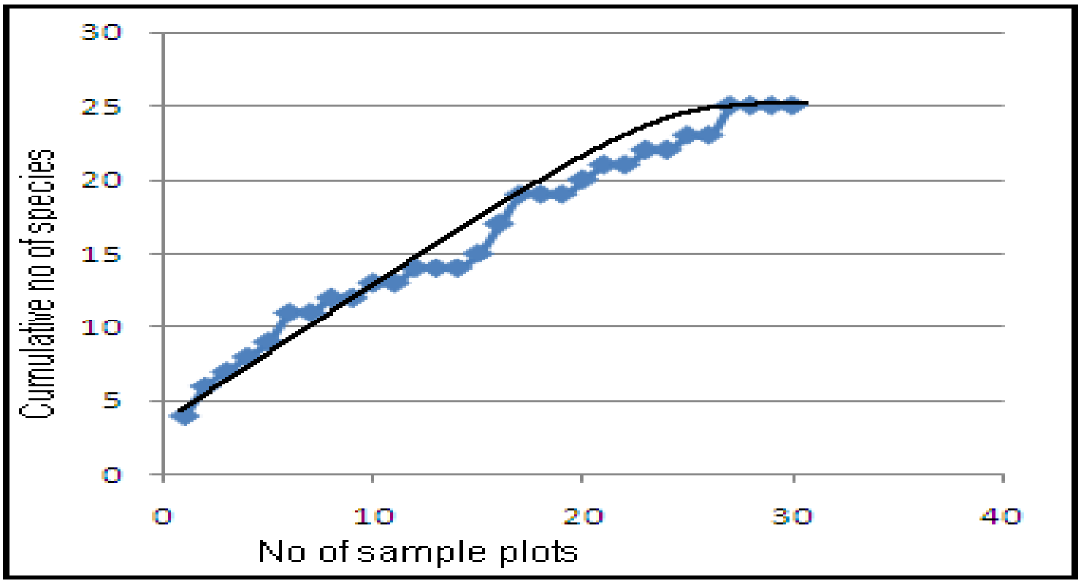

Figure 16: Graph showing maximum required number of sample plots

Sample plots establishment: The nested permanent sample plots were established by navigating the coordinate in the field. For, tree stratum 20m x 25m sample plot was established and nested plots for poles (10m x 10m), sapling (5m x 5m), seedling (5m x 2m) and litter, herbs and grasses (1m x 1m) were established simultaneously (IPCC, 2006, DoF, 2003). Meanwhile, the soil sample plot was established in the centre of the nested plot. There was no any tree staged plants in public plantation and community planted forests.

3.3.1.3 Data Collection

The collection of biophysical data was grouped into two main categories. They are data collection for forest carbon and plant biodiversity calculation.

Data collection for forest carbon and biodiversity: Data collection was started with the measurement of plants in the sample plots. The height and diameter at breast height (DBH) of poles and sapling (DBH > 5cm) were measured but the samples of sapling (DBH <5cm), grasses, litter and soil were packed to carry out for laboratory analysis. Soil samples were collected from three different depths (0-0.1m, 0.1-0.3m and 0.3-0.6m) using soil auger (IPCC, 2006). The photographs of field work and lab work are included in Annex 4. Same plots were used for field data collection from the selected forests for biodiversity estimation too so the species lists were prepared.

The season of data collection is also very significant because most of the plants have leaf shading in March and April, which can affect the litter carbon. Considering this, the data were collected from permanent sample plots in December to January, for 3 consecutive years in between 2011 to 2013 in order to know annual carbon stock change. Moreover, the forest carbon data were also used for evaluation of sustainability of the forest management.

3.3.1.4 Data Analysis

The biophysical data were analyzed applying the Microsoft Excel and Statistical Package of Social Science (SPSS) software version IBM SPSS 20. It covers the calculation of carbon sequestration, biodiversity estimation and evaluation of sustainability in the forests.

3.3.1.4.1 Calculation of Forest Carbon Stock

The forest carbon calculation comprises the choice of biomass calculation equations, biomass estimation, carbon calculation, soil carbon calculation, Mean Annual Carbon

Increment (MACI), Current Annual Carbon Increment (CACI) and carbon sequestration potential.

i. Choice of biomass equation: There are three major equations available for calculation of the wood biomass in Nepal.

a. Volume equation by Sharma and Pukala: This equation is used for volume estimation. Here stem biomass can be calculated multiplying stem volume with the wood density. Moreover, the biomass of branches and leaves can be estimated using 45% and 11% of the stem biomass respectively (Sharma & Pukkla, 1990). The biomass equation is

ln (v) = a+b*ln(d) +c*ln (h), whereas v = volume of the stem, d = diameter of the tree at breast height, h = height of the trees

ln = natural logarithms and parameters a, b and c are the constants

Here, Stem biomass (kg) = Stem Volume (m^3)*Stem Density (kg/m^3)

So, the default values should be used to calculate the biomass of other pools except stem.

b. Biomass equations compiled by Tamrakar (2000): This was compiled for biomass calculation of plant species. Though the equations give the fresh weight of stem, branch and foliage separately based on DBH, these equations do not calculate the dry biomass. Besides, these equations are suitable for biomass calculation of certain DBH only.

Biomass equation, Ln w= a+b ln (DBH), whereas w stands separately for fresh weight of stem, fresh branch and foliage, a and b are constants for each equation and DBH is the diameter at breast height. So, using this equation, the conversion factors of each parts of plant are essential to calculate the dry biomass (Tamrakar, 2000).

c. Equations by Chave *et al.* (2005): These equations are categorized according to annual rainfall and these were prepared using the data of permanent sample plots of most of the tropical country in the world. Sample plots were established in India too. The biomass equations include variable like species wise wood density, DBH and height. These equations should not be used for DBH>5cm, this is the limitation of the equation (Chave *et al.*, 2005).

In this context, most of the REDD+ pilot projects have been employing biomass equation given by Chave *et al.* (2005). The forest biomass experts in Nepal believed that this equation can give more reliable results than other equations. So, this equation is applied to calculate the biomass for the research work. The researcher tested this equation with biomass equation developed by Mandal *et al.* (2013) for *Eucalyptus camaldulensis*, the estimated biomass was not so significantly differed (Mandal *et al.*, 2013).

ii. Biomass calculation: The Above Ground Tree dry Biomass having DBH>5cm, was estimated using the equation of Chave *et al.* (2005) because, this equation is only suitable for DBH> 5cm. $AGTB = 0.0509 * \rho D^2H$ for DBH (sapling, poles and tree)> 5cm.

Where ρ is the wood specific gravity in g cm^{-3} (the wood density of species was included in annex 1); D is diameter at breast height in cm measured at 1.3 m from ground level and H is tree height in m.

Above ground sapling biomass having DBH <5cm was calculated by applying the formula compiled by Tamrakar (2000) and its sample was taken to get dry biomass as this allometric equation provide only the fresh weight. Samples of sapling (DBH <5cm), seedling, leaf litter, herbs and grass (LHG) together were carried out to dry in the laboratory and their dry biomass was calculated using unitary method.

Moisture content of plant samples (seedling, shrubs, herbs and litter) was determined in the lab by drying them at 105^0C. The constant weight was recorded and following formula was applied to calculate the moisture content. The root biomass was calculated by using root shoot ratio 0.125 (MacDicken, 1997).

Moisture content (%) = (Fresh Weight – Dry Weight) of sample x100 /Fresh weight

iii. Carbon calculation: It includes the carbon of biomass (tree + pole + sapling + seedling + seedling + herbs + litter). Then, wood carbon was calculated by multiplying with 0.47 of dry biomass (IPCC, 2006).

iv. Soil carbon analysis: Carbon content in the soil was analyzed by using dry combustion method (Walkley & Black, 1958).

Bulk Density (BD g/cc) = (oven dry weight of soil)/ (volume of soil in the core)

The detail method and calculation of SOC are described below. This includes the reagent used, process and calculation.

Reagents used : Following reagents were used to prepare the chemical for soil carbon analysis. Preparation of chemical for lab analysis for soil carbon is given below.

FAS = Ferrous Ammonium sulphate

VF = volumetric flask

AR grade = standard grade suitable for use

N = Normal

Sodium Fluoride (NaF): AR grade sodium fluoride powdered was used.

Firstly, 1N $K_2Cr_2O_7$ solution: 49.04 gm of $K_2Cr_2O_7$ was kept at 105^0C in hot air oven for 1 hour. As it cools down, it was diluted to 1000 ml volumetric flask (VF). Then, 0.5 N FAS (Ammonium ferrous sulphate): 196 gm of FAS was dissolved in 800 ml of distilled water and added 20 ml of conc. sulfuric acid, cooled and diluted to 1000 ml volumetric flask. Later, approximately 0.5 gm of diphenylamine was dissolved in 20 ml of distilled water and added 100 ml of concentrate (conc) sulfuric acid.

Procedure: Soil sample was sieved in order to remove the stones and roots. For this, 1 gm of 0.2 mm sieved sample was weighed and placed in 500 ml conical flask. Then, 10 ml of 1N $K_2Cr_2O_7$ solution and 20 ml of conc H_2SO_4 was added and mixed with gentle rotation for one minute. Next, the mixture was heated at 150^0 C in hot oven for 30 minutes. Meanwhile, the blank was run in the same manner. After 30 minutes 200 ml of distilled water and 2 ml of diphenylamine indicator was added in it and 0.2 gm of NaF was also added. Later, the $K_2Cr_2O_7$ left and the 0.5 N FAS solution was titrated from burette. Then the volume of FAS consumed for titration and the brilliant green end point was noted down.

Calculation of soil organic matter: following formulae were used to calculate soil organic carbon.

$$\% \text{ Organic Matter} = \frac{0.67 * \text{Normality of FAS} * \text{Volume of FAS consumed}}{\text{Weight of soil sample}}$$

Where,

Volume of FAS consumed= volume of FAS consumed by blank (chemical) – volume of FAS consumed by sample

When, molarity is converted into normality, 0.67 was used as a conversion factor.

$$\text{Normality of FAS} = \frac{\text{Volume of potassium dichromate taken* Normality of dichromate}}{\text{Volume of FAS consumed by blank}}$$

$$\text{\% Organic Carbon} = \frac{\text{Soil organic matter}}{1.724}$$

Here, 58% soil organic matter = 100% organic carbon, 1.724 was used as a constant factor.

SOC = Organic Carbon Content % x Soil Bulk Density (Kg/cc) x thickness of horizon.
(Walkley & Black, 1958)

Total Carbon= Total biomass carbon + Soil carbon

v. Mean Annual Carbon Increment, Current Annual Carbon Increment and carbon sequestration: The removal of CO_2 from atmosphere and its potential were calculated using following formulae.

Mean Annual Carbon Increment (MACI) = Sum of Carbon stock of Pole and Sapling/age of plantation or average age of plants.

Current Annual Carbon Increment (CACI) = Carbon stock of year (n) - Carbon stock of year (n-1) (Lal, 2007).

Carbon sequestration potential and its valuation: Then, the value was changed into equivalent to removal of CO_2 or carbon sequestration, which was estimated using the multiplying conversion factor 44/12. The carbon sequestration potential was calculated for 2 years, 3 years, 4 years, 5 years and 10 years multiplying with 2,3,4,5 and 10 respectively. Later the monetary value of carbon sequestration potential was estimated by multiplying with the rate of US$ 5 CO_2 t^{-1} (Molly *et al.*, 2012). At the same time, the cost for management and protection of these forests was considered as US$ 3 ha^{-1} (Karky & Baskota, 2009). Thus, the estimated net value of carbon sequestration was calculated by deducting the total management and protection cost from total value of carbon sequestration.

3.3.1.4.2 Calculation of IVI and Forest Biodiversity

Calculation of IVI: The IVI was calculated applying formulae given by Curtis & McIntosh, (1950)

IVI = relative density+ relative frequency + relative basal area

$$\text{Density} = \frac{\text{Total number of individuals of a species in all sample plots}}{\text{Total number of sample plots studied}}$$

$$\text{Frequency} = \frac{\text{Number of sample plots in which the species occured}}{\text{Total number of sample plots studied}}$$

$$\text{Basal Area} = \frac{\pi D^2}{4}$$

Besides, the relative density, relative frequency and relative basal area were calculated in percentage. Thus, the total value of IVI was 300. Latter, rank was calculated for each species based on IVI, carbon and Mix (carbon % + IVI%). The carbon stocks of some valuable species were compared among collaborative and community forests. At the same time the rank of plant species based especially on Mix and carbon was compared to evaluate the effect of carbon stock on ranking. This was not applied for public plantations and community planted forests because the plantations were monoculture and this was only *Eucalyptus camaldulensis*.

Calculation of plant species biodiversity: The plant biodiversity was calculated using following formulae (Guy and Stephen 2003).

Species richness S: is $E = \frac{D}{S}$ the number of species in the community or sample

Simpson's evenness $E = \frac{D}{S}$, Where *D* is the Simpson's diversity index, *S* is the species richness.

Shannon-Weiner Biodiversity Index, $H = -\sum_{i=1}^{s}(\text{pi})(\ln \text{pi})$, where pi is the total individuals in a species community

3.3.1.4.3 Evaluation of Carbon Stock for Sustainability

The Meyer's (1943) simplification of De Liocourt's law was applied to check the diameter distribution of the stems. Meanwhile sustainability was evaluated using the Biolley's Check Method" - Method du-Control (Meyer, 1943).

i. De Liocourt's law

Number of stems in Diameter interval (Y)= Ke^{-ax} (Prakash, 2001)

Where, K is relative stand density based on site quality,

e= 2.72 the base of Naperierian logarithms

x= diameter at breast height

ii. Biolley's "Check Method" - Method du-Control which has focused on the volume ratio of DBH<30cm: DBH =30-50cm: DBH >50 cm to 20:30:50 (Meyer, 1943; Prakash, 2001). This was modified to evaluate the carbon stock ratio instead of volume ratio.

3.3.2 Socio-Economic Data Collection and Analysis

Socio-economic data were used to know about the impacts of climate change, drivers of deforestation and forest degradation, CO_2 and CH_4 emission as well as opportunity and challenges of forest carbon trade under REDD+ programme. Thus, the data were collected accordingly. Latter the collected data were analyzed based on the requirement of research objectives.

3.3.2.1 Data Collection

The sampling process and data collection were presented according to the research objectives. This includes the sampling process of i. assessing drivers of deforestation and forest degradation; ii. firewood consumption and cattle keeping and iii. exploration of opportunity and challenges in forest carbon trade.

3.3.2.1.1 Sampling Process of Assessing Drivers of Deforestation and Forest Degradation

Socio-economic data includes information regarding drivers of deforestation and forest degradation and their underlying causes as well as effects of forest management and protection units on forest carbon stock. So, the key informants interview and workshops were organized to gather the data.

Firstly, the brief questionnaires were developed (Annex 2) to list out the main drivers and underlying causes of deforestation and forest degradation discussing with forest expert team. These questionnaires were tested in small group interview with staff of district forest offices to finalize them. Secondly, the interview was carried out with selected key informants to prepare the draft list of drivers of deforestation and forest degradation. In reality, the list of key informants was prepared in short meeting with staff of district forest offices (DFO) and user's committee members. There were about 11 key informants representing from user's committee, teachers, political leaders, DFO staff. Thirdly, another workshop was organized with users of the collaborative forests and executive members to know the variations in drivers and underlying causes of deforestation and degradation as well as how these agents affect in each collaborative forest.

In addition, information regarding effect of grazing, fire, logging, encroachment and invasive species were noted through field observation. The site observation was especially focused on to list out the marks of illegal logging like stump, grazing effects, foot marks of animals and their excreta, list of invasive species and damage due to fire. In addition, the encroachment record was gathered from district forest office, Mahottari.

Similarly, data regarding the forest management and protection units were gathered from questionnaire survey organizing informal interaction in the field. It was focused on how the management and protection institutions were functioning in minimizing the rate of deforestation and forest degradation.

Same process was applied to collect the data regarding drivers of deforestation and forest degradation from selected community forests. However, only short meetings were organized with users of public plantation and community planted forests to collect these data.

3.3.2.1.2 Sampling Process to Collect Firewood Consumption and Cattle Keeping

In the beginning, the record of total household were collected from Centre Bureau of Statistics (CBS, 2011) and village profile, there were 1130 households in Maisthan village and 1500 households in Sahodawa village. Next, household in villages was categorized into three groups explicitly rich, medium and poor applying the participatory well being ranking process. The criteria has focused on types of house, employment, land holding, cattle keeping, education, income source (business) and food security (Chapagain & Banjade, 2009). If household has annual income of about US$ 1000- 2000, Khapada (roofing burnt clay tile), 1 employee, 1 ox and 1 cow and educational qualification class 10 pass are categorized under medium family while having more than that grouped under rich and less than that are kept under poor household (hh). The number of households fall under rich, medium and poor was 404, 424 and 303 respectively in Maisthan village while they were 420, 540 and 540 respectively in Sahodawa village. Number of household was considered as sample unit and 5% sample intensity was taken. Lastly, 138 households were selected randomly from these villages for sampling. Out of this, 60 samples including 22 rich, 22 medium and 16 poor households were taken from Maisthan village while 78 samples (24 rich, 27 medium and 27 poor households) from Sahodawa village but only 56 and 76 samples were used for analysis since one sample appeared as outlier.

The data collection was categorized into two groups anmely i. fuel consumption and ii. Cattle keeping.

a. Data collection of fuel consumption: The fuel consumption varied according to the season, generally, people use more fuels in winter than summer. So, record of fuel was taken in April (summer) and January (winter) from selected families. Then, fuels used by each family were weighted in the morning and evening for 7 days in summer and 7 days in winter to determine the daily consumption.

b. *Data collection of cattle keeping*: At the same time records of cattle keeping like number of oxen, cows, goats, buffalos, pigs and chicken were taken from selected households using participatory rural appraisal (PRA) technique.

A part from that, a short meeting was organized to find the best management options of CH_4 emission targeting to reduce CO_2 sources, simultaneously.

3.3.2.1.3 Sampling Process for Scope and Challenges of Forest Carbon Trade

Firstly, a short meeting was organized to prepare the draft questionnaires about the opportunities and challenges associated with the forest carbon trade. Then, the interview was carried out with selected key informants to prepare the draft list. Next, a workshop was organized to share the draft documents and to collect the comments regarding the opportunities and challenges. Lastly, the final report of the opportunities and challenges were prepared incorporating the participants' comments.

3.3.2.2 Data Analysis

The description of analysis of collected socio-economic data is presented below. This includes the analysis of drivers of deforestation and forest degradation, CO_2 and CH_4 emission, exploration of opportunity and challenges for carbon trade.

3.3.2.2.1 Analysis of Firewood Consumption and CO_2 Emission

Nepal proposed tier 2 approach, so the factors suggested by IPCC (2006) are used to calculate CO_2 and CH_4 emissions. Practically, Nepal has 4 months of winter and 8 months of summer season. Hence, this variation is considered for calculation of CO_2 emission from fuel burning (Bhattrai, 2005). The conversion factor of CO_2 emission from Carbon of different types fuel given by IPCC (2006) was used (Table 7).

Table 7: Conversion factor into C and CO_2 emission

Types of Fuels	Conversion factor to Carbon content	CO_2 emission
Wood	Dry fuel*0.47	Actual C emissions were multiplied by the molecular-to-atomic weight ratio of CO_2 to C (44/12) to obtain total CO_2 emitted from fuel
Bamboo	Dry fuel*0.46	
Dung cake and stick	Dry fuel*0.39	
Straw and leaves	Dry fuel*0.32	

Source: (IPCC, 2006)

Calculation of CO_2 emission: The fuel biomass were not completely dried so about 100 gram samples of different fuel types were weighted and were dried in the laboratory at 105^0C until the samples showed their constant weight (Akagi *et al.*, 2011). Then, following conversion factors were used to determine the CO_2 emission from fuel (table 7) (IPCC, 2006).

3.3.2.2.2 Calculation of CH_4 Emission

Following factor was used to calculate CH_4 emission (table 8) from domestic animals and the factor for transformation is $1CH_4$ equivalent to $21CO_2$ was applied (IPCC, 2006). Calculation of CH_4 emission was done by the estimation of enteric fermentation and manure management of the domestic cattle, presented in table 8.

CH_4 emission= (enteric fermentation + manure management) * number of domestic cattle

Table 8: CH_4 emission factor

CH_4 emission kg head^{-1} yr^{-1}	**Cow / ox**	**Buffalo**	**Goat**	**Pig**	**Chicken**
Enteric fermentation	47	55	5	1	0.00
Manure management	1	2	0.22	7	0.02

(Source: IPCC, 2006)

3.3.2.2.3 Determination of CO_2 Saving Through Biogas Plant

The biogas plant installation can save the CO_2 emission. Technically, BSP (2009) stated that about 4 m^3 biogas plant is considered as sufficient size to meet the cooking, heating and lighting needs for a family sized 5 persons.

Thus,

$$\text{Number of biogas plant (volume 4 m}^3\text{ size) potential} = \frac{\text{No. of cows or buffaloes}}{2}$$

$$= \frac{\text{No. of pigs}}{7}$$

Saving of CO_2 equivalent yr^{-1}= 2.56 t of 1 biogas plant (volume 4 m^3 size)

(BSP, 2009)

3.3.3 Statistical Analysis

The statistical test was carried out to compare the variables. Therefore, parametric tests and nonparametric tests were applied. For these tests, the data were prepared and examined for normality using Kolmogorov-Smirnov and Shapiro-Wilk test, test of homogeneity of data set and box plot analysis were carried out and outliers were removed to prepare the data for parametric test. The independent samples t-test was applied to compare two sets of mean while the one way ANOVA and Tukey's Honestly Significant Difference (HSD) were used to compare mean of three sets of data. At the same time non- parametric tests like Kruskal Wallis and Multiple comparison were carried out for non normal data (Unger *et al.*, 2012). The Statistical Package of Social Science (SPSS) software version IBM SPSS 20 was used to compare these data.

i. Independent samples t-test was applied to compare a. CO_2 and CH_4 emission on household basis in Maisthan and Sahodawa villages; b. annual carbon sequestration (Collaborative forest verses community forests and public plantation verses community planted forests)

ii. One way ANOVA (analysis of variance) and Tuky HSD test were applied to compare a. the carbon stocks among community forests, collaborative forests, public plantations and community planted forests; b. CO_2 and CH_4 emission by family categories; c. carbon stocks in collaborative forests

iii. Z test was applied to compare the carbon stock of collaborative and community forests

$$Z = \frac{\overline{x_1} - \overline{\overline{x_2}}}{\sqrt{(\frac{{S_1}^2}{n_1} + \frac{{S_2}^2}{n_2})}}$$

iv. The species wise mean carbon stocks in collaborative forests and in community forests were carried out using either ANOVA and Tuky HSD if the data were normal or Kruskal Wallis test and Multiple comparison whether the data are not normal.

v. Moreover, the Microsoft EXCEL was applied to carry out the regression analysis. Moreover, this software was also used to determine the value of correlation coefficient, R^2 and draw the curve showing the relationship between two variables specifically biodiversity and carbon stocks.

CHAPTER 4

4. RESULTS AND DISCUSSION

The results are presented in three parts according to the research objectives. They are: i. carbon sequestration potential, which includes carbon stock, current annual carbon increment, carbon sequestration potentials and their opportunities and challenges under REDD+ programme; ii. sustainable management of forest and carbon stocks and iii. drivers of deforestation and forest degradation and their effects on forest carbon and CO_2 and CH_4 emission at local level.

Since, the carbon assessment especially of large plants which dominantly contribute in whole biomass is based on the species, their diameter, height and wood density. However, the biodiversity indexes are only concern to the available species and their dominance in localities. Thus the list of main species, carbon stock and their ecological values are also essential.

4.1 Plant Specieswise Carbon Stock and Their Ecological Values

The specieswise carbon stocks were differed in these forests as well as the ecological values of plant species was also differed. Thus the plant species which have significant contribution in carbon stocks are described in the beginning with highlighting the list of plant species.

Besides the species wise carbon stocks, the above ground and below ground carbon stocks have also significant important in total carbon stock. The carbon stocks varied in different management regimes like collaborative forest, community forests, public plantation and community planted forests. It is essential first to categorize the comparable carbon stocks based on the condition of the forest. The selected community forests and collaborative forests are natural forests so these are statistically compared with each other while the public plantations and community planted forests are afforested areas. Other important consideration was the age of the forests and plantations.

4.1.1 List of Plant Species Found in Community Managed Forests

Followings are the species found in different forest management regimes (Table 9).

Table 9: Species found in community managed forests

SN	Family	Botanical name	CFMs	CFs	PPs	CPF
1	Dipterocarpaceae	*Shorea robusta*	+	+	-	-
2	Combretaceae	*Terminalia tomentosa*	+	+	-	-
3		*Anogeisus latifolia*	+	+	-	-
4		*Terminalia belerica*	+	+	-	-
5		*Terminalia chebula*	+	+	-	-
6	Lythraceae	*Lagerstroemia parviflora*	+	+	-	-
7	Euphorbiaceae	*Sapium insigne*	+	+	-	-
8		*Mallotus philipinensis*	+	+	-	-
9		*Croton roxburghii*	+	+	-	-
10		*Bridelia retusa*	+	+	-	-
11	Fabaceae	*Dalbergia latifolia*	+	+	-	-
12		*Cassia fistula*	+	+	-	-
13		*Dalbergia sissoo*	+	+	-	-
14		*Desmodium oojeinense*	+	+	-	-
15	Myrtaceae	*Eugenia jambolana*	+	+	-	-
16	Myrtaceae	*Eucalyptus camaldulensis*	-	-	+	+
17	Leguminosae-Mimosaceae	*Albizzia procera*	+	+	-	-
18		*Acacia catechu*	+	+	-	-
19	Malvaceae	*Sterculia villosa*	+	+	-	-
20		*Bombax ceiba*	+	+	-	-
21	Sapindaceae	*Schleichera trijuga*	+	+	-	-
22	Phyllanthaceae	*Phyllanthus embelica*	+	+	-	-
23	Dilleniaceae	*Dillenia pantaguana*	+	+	-	-
24	Rubiaceae	*Anthocephalus chinensis*	+	+	-	-
25		*Adina cordifolia*	+	+	-	-
26	Apocynaceae	*Alstonia scholaris*	+	-	-	-
27	Vervenaceae	*Gmelina arborea*	+	+	-	-
28	Anacardiaceae	*Semecarpus onacardium*	+	+	-	-
29	Rutaceae	*Aegle marmelous*	+	+	-	-
30	Oleaceae	*Nyctanthes arbor-tristis*	+	+	-	-

Note: + indicates the presence of species and **-** shows the absence of species.

Most of the species were about to similar in community and collaborative forests because they are natural forests but there was only *Eucalyptus camaldulensis* in public plantation and community planted forests. Altogether, there were 17 plant families and 29 species found in these forests. However dominant species were *Shorea robusta, Terminalia tomentosa, Lagerstroemia parviflora, Sapium insigne* and *Mallotus philipinensis* while dominated species were *Bridelia retusa, Anthocephalus chinensis* and *Aegle marmelous* in community and collaborative forests. Some species were varied among community forests too. For example, *Dalbergia sissoo* and *Acacia catechu*, *Eucalyptus camaldulensis* were not found in Chure- Parwati CF because, these were not planted here (table 9).

In addition, herbs and shrubs species were also very common in these community managed forests. Some examples are Kans grass (*Saccharum spontaneum*), Bhanti (*Ardisia solanacea*), Dhaiyaro (*Woodfordia fruticosa*), Mothe (*Cyperus rotundus*), Kalo Musli (*Curculigo orchioides*), Karipata (*Murraya koenigii*). *Woodfordia fruticosa* (Asuro). *Cynodon dactylon* (Dubo)**,** Elephant grass (*Pennisetum purpureum*) and Tapre (*Cassia Tora*) are some of them.

4.1.2 Specieswise Carbon Stock and IVI in Collaborative Forests

Generally the higher the carbon stock the higher was the IVI of the plant species. However, ranking them based on mix (IVI + carbon) showed there was some effect of carbon stock on the species ranking.

Species wise carbon stocks in collaborative forests: Species wise carbon stocks varied in collaborative forests. Generally highest carbon stock was found in *Shorea robusta* in all forests. Similarly, species like *Terminalia tomentosa, Lagerstroemia parviflora, Sapium insigne, Anogeisus latifolia, Mallotus philipinensis* and *Eugenia jambolana* showed high quantity of carbon stocks in these forests while some species particularly, *Cassia fistula, Adina cordifolia, Albizzia procera, Terminalia belerica* had showed less quantity of carbon stock in these forests. However, some species namely *Bridelia retusa, Alstonia scholaris* and *Aegle marmelous* showed very less carbon stocks in these forests.

Table 10: Carbon stock of plant species in collaborative forests

Species	Banke-Maraha ($t\ ha^{-1}$)	Tuteshwarnath ($t\ ha^{-1}$)	Gadhant-Bardibash ($t\ ha^{-1}$)
Shorea robusta	35.93±0.32	44.87±0.42	50.43±0.43
Terminalia tomentosa	25.50 ±0.28	34.49±0.38	36.79±0.38
Lagerstroemia parviflora	11.37±0.21	18.72±0.32	19.87±0.32
Sapium insigne	3.27±0.06	2.44±0.02	1.87±0.02
Anogeisus latifolia	9.80±0.17	11.28±0.28	15.40±0.28
Dalbergia latifolia	0.84	0.68±0.01	0.45±0.01
Mallotus philipinensis	2.55±0.04	0.87±0.06	2.36±0.06
Eugenia jambolana	7.40±0.21	10.14±0.29	13.66±0.29
Cassia fistula	0.32	1.40±0.03	0.59
Adina cordifolia	0.16	2.26±0.20	7.34±0.20
Croton roxburghii	0.15	0.21	0.15
Terminalia belerica	4.37±0.15	1.83±0.22	7.54±0.21
Phyllanthus embelica	0.20	0.23	0.88
Dalbergia sissoo	0.07	0.00	0.17
Nyctanthes arbor-tristis	0.07	0.07	0.07
Bombax ceiba	0.13	1.27±0.18	3.87±0.18
Terminalia chebula	3.42±0.16	1.47±0.16	5.35±0.16
Albizzia procera	1.65±0.10	2.13±0.17	4.06±0.17
Semecarpus onacardium	0.62	0.12	0.10
Dillenia pantaguana	0.83	0.43	0.23
Sterculia villosa	0.12	0.02	0.03
Acacia catechu	0.28	0.02	0.02
Anthocephalus chinensis	0.28	0.02	0.37
Gmelina arborea	0.02	0.02	0.02
Desmodium oojeinense	0.13	0.24	0.01
Schleichera trijuga	0.06	0.79	0.49
Alstonia scholaris	0.09	0.09	0.00
Aegle marmelous	0.02	0.02	0.00
Bridelia retusa	0.00	0.00	0.02
Eucalyptus camaldulensis	0.36	0.18	1.21
Dillenia indica	0.13	0.13	0.14

Note: 0 value showed absent of the species in the forests.

The species wise carbon stock was varied in the collaborative forests because the total carbon stock was also not same in these forests. The estimated total carbon stock in all species was 110.14±0.42 t ha^{-1} in Banke-Maraha CFM, 136.44±0.46 t ha^{-1} in Tuteshwarnath CFM and 173.49±0.33 t ha^{-1} in Gadhant-Bardibash (table 10).

Specifically, the highest carbon stock was found 50.43±0.43 t ha^{-1} in *Shorea robusta* in Gadhanta- Bardibash CFM. Other higher values were recorded in this species was 44.87± 0.24 t ha^{-1} in Tuteshwarnath CFM, 35.93 ±0.32 t ha^{-1} in Banke-Maraha CFM. On the other hand, the lowest value was about 0.01 t ha^{-1} in *Desmodium oojeinense* in Gadhanta- Bardibash CFM. The estimated carbon stock of *Mallotus philipinensis* were 2.55 ±0.04 and 2.36±0.06 t ha^{-1} in Banke-Maraha and Gadhanta- Bardibash CFMs (table 10). The higher value of carbon stock was due to the dominance of *Shorea robusta* in these forests. The report of Tarai published by FRA/DFRS (2014) showed that the estimated carbon stock of *Shorea robusta* was 52.31 t ha^{-1}, which value is quite similar to the estimated carbon stock of *Shorea robusta* in Gadhanta-Bardibash CFM. The carbon stock *Mallotus philipinensis* was 2.45 t ha^{-1} in Tarai (FRA/DFRS, 2014), this value was also close to the value of carbon stock of Banke-Maraha and Gadhanta- Bardibash CFMs.

Specieswise IVI in collaborative forests: Generally, there was some similarity and differences in specieswise carbon stock and IVI. For instance the species like *Shorea robusta, Terminalia tomentosa* and *Lagerstroemia parviflora* showed high carbon stock and high IVI too. However, this principle was differed for *Sapium insigne* which showed less carbon stock about 3.27 t ha^{-1} and the estimated IVI was 18.35 in Banke-Maraha CFM. Similarly, the estimated carbon stock was only 2.44 t ha^{-1} but the IVIs was 8.27 in Tuteshwarnath CFM and it was 1.87 t ha^{-1} but this showed 7.98 in Gadhanta- Bardibash CFM. Same complexity was observed for carbon stock and IVI of *Eugenia jambolana and Terminalia belerica.* The IVI estimate is based on relative BA which includes only the DBH of the plant, relative species density and frequency but carbon estimate also includes height and wood density of the plants. High value species have high IVI and normally they have high biomass (Chandran *et al.*, 2010, Chaubey, 2012). However, the prioritization of the species based on IVI may create the biased perception for climate change worker who is especially functioning for forests enhancement.

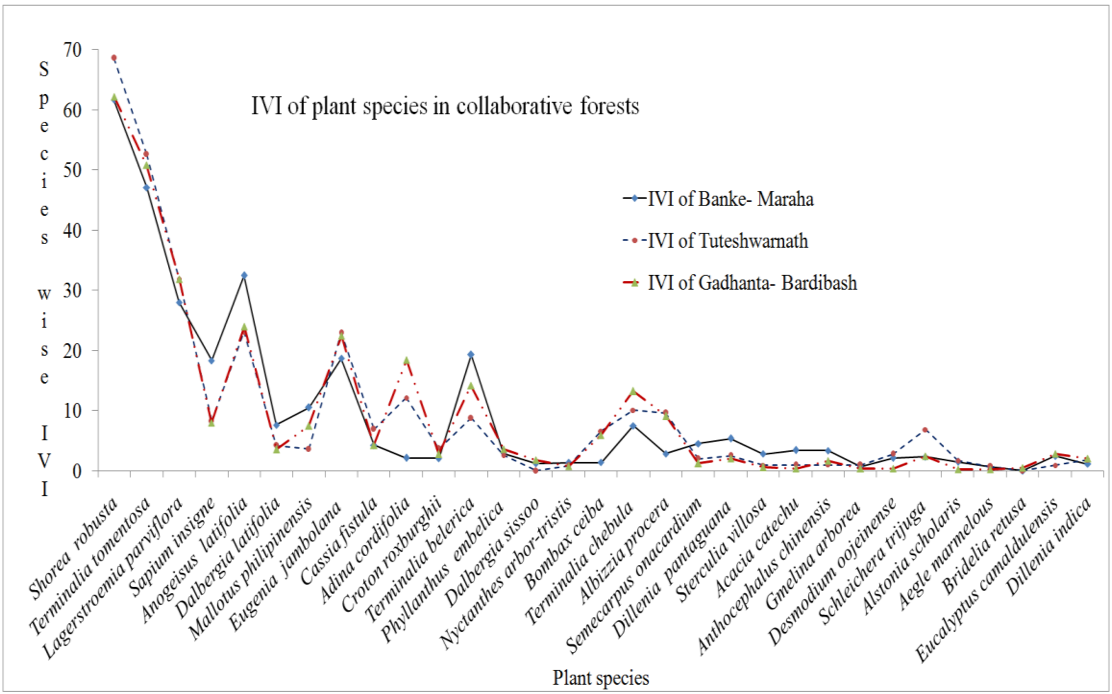

Figure 17: IVI of different species in collaborative forests

Comparison of carbon stocks of major species in collaborative forests: There was not too much variation in carbon stock of major species in these forests. Since the P values were greater than 0.05, the ANOVA (parametric test) and Kruskal Wallis (non parametric one way ANOVA) test showed there was no significant differences in specieswise carbon stock in these forests at 5% level of significant except *Lagerstroemia parviflora*. (table 11). The reason of not variation of species wise carbon may be due to site quality, dominance of more or less same aged plants. It was interesting to show how the rank of these important species varied.

Table 11: Comparison of carbon of major species

Plant Spp	**Parametric test (p-value)**		**Non- parametric (p-value)**	
	ANOVA	**Tukey's test**	**Kruskal Wallis**	**Multiple comparison**
Shorea robusta	0.21	NA		
Terminalia tomentosa			0.43	NA
Lagerstroemia parviflora			0.03	All differed
Sapium insigne			0.93	NA
Anogeisus latifolia			0.80	NA
Dalbergia latifolia			0.66	NA
Mallotus philipinensis			0.21	NA
Eugenia jambolana			0.21	NA
Terminalia belerica			0.44	NA
Terminalia chebula			0.34	NA

Species ranking based on Mix, IVI and carbon in collaborative forests: Some species showed same rank prioritizing based on the carbon, IVI and mix (carbon +IVI) but some species showed different results too. Specifically, *Shorea robusta* and *Terminalia tomentosa* showed same rank 1 and 2 respectively based on all criteria. The other examples of the same ranks were found for *Gmelina arborea, Bridelia retusa* and *Aegle marmelous* in Banke-Maraha and Tuteshwarnath CFMs. However, the ranking of some important species were differed too. For instances, the ranks of *Terminalia chebula* were 9, 10 and 7 in Banke-Maraha CFM based on Mix, IVI and carbon respectively which were 9,7 and 10 in Tuteshwarnath CFM. Same variations in ranking were found in *Dalbergia latifolia, Albizzia procera, Acacia catechu, Anthocephalus chinensis* and so on (table 12).

These create the uncertainty whether the species prioritized based on IVI or based on carbon stock. For instance, *Sapium insigne* was ranked 7 based on IVI but ranked 8 based on carbon in Banke-Maraha CFM; ranked 10 based on IVI but ranked 6 based on carbon in Tuteshwarnath CFM while ranked 10 based on IVI and 12 based on carbon in Gadhanta- Bardibash CFM (table 12).

Similar complexities were observed for *Mallotus philipinensis, Terminalia belerica, Dillenia pantaguana, Albizzia procera* and *Semecarpus onacardium.* These obscurities were challenging to work for biodiversity as well as carbon as a climate change mitigation measure. Thus the mix criterion was proposed to prioritize especially valuing the record of carbon stock.

Table 12: Ranking of plant species in collaborative forests

Species/ Rank base	Banke-Maraha CFM			Tuteshwarnath CFM			Gadhanta-Bardibash CFM		
	Mix	**IVI**	**C**	**Mix**	**IVI**	**C**	**Mix**	**IVI**	**C**
Shorea robusta	1	1	1	1	1	1	1	1	1
Terminalia tomentosa	2	2	2	2	2	2	2	2	2
Anogeisus latifolia	3	3	4	3	3	3	4	4	4
Lagerstroemia parviflora	4	4	3	4	4	4	3	3	3
Eugenia jambolana	5	6	5	5	5	5	5	5	5
Terminalia belerica	6	5	6	10	9	9	7	7	6
Sapium insigne	7	7	8	8	10	6	12	10	12
Mallotus philipinensis	8	8	9	15	16	13	11	11	11
Terminalia chebula	9	10	7	9	7	10	8	8	8
Dalbergia latifolia	10	9	11	14	14	15	16	15	17
Dillenia pantaguana	11	11	12	17	19	16	19	20	19
Albizzia procera	12	17	10	7	8	8	9	9	9
Semecarpus onacardium	13	12	13	20	20	22	23	23	23
Cassia fistula	14	13	15	11	11	11	13	13	15
Acacia catechu	15	14	16	24	23	26	27	27	26
Anthocephalus chinensis	16	15	17	25	24	27	21	22	18
Phyllanthus embelica	17	16	18	19	18	18	14	14	14
Eucalyptus camaldulensis	18	19	14	23	26	20	15	16	13
Sterculia villosa	19	18	24	28	27	25	25	25	25
Adina cordifolia	20	21	19	6	6	7	6	6	7
Schleichera trijuga	21	20	28	13	12	14	17	18	16
Croton roxburghii	22	23	20	16	15	19	18	17	21
Desmodium oojeinense	23	22	22	18	17	17	29	29	29
Bombax ceiba	24	26	21	12	13	12	10	12	10
Alstonia scholaris	25	24	25	22	22	23	30	30	30
Nyctanthes arbor-tristis	26	25	27	27	28	24	24	24	24
Dillenia indica	27	28	23	21	21	21	20	19	22
Dalbergia sissoo	28	27	26	30	30	29	22	21	20
Gmelina arborea	29	29	29	26	25	28	28	28	27
Aegle marmelous	30	30	30	29	29	30	31	31	31
Bridelia retusa	31	31	31	31	31	31	26	26	28

Comparison of IVI in collaborative forests: The values of IVI of same species were also differed in collaborative forests. The IVI of *Shorea robusta* was 62.22 in Gadhanta-Bardibash which was the highest 68.59 and it was the lowest 61.65 in

Banke-Maraha CFM. In case of IVI of *Terminalia tomentosa*, this value was 50.85 in Gadhanta-Bardibash CFM which was the highest about 52.56 in Tuteshwarnath CFM and it was the lowest about 47.09 in Banke-Maraha CFM. The IVI of *Lagerstroemia parviflora* was about 31.9 in Tuteshwarnath CFM, which was the highest about 31.92 in Gadhanta -Bardibash CFM and it was the lowest 27.99 in Banke-Maraha CFM. *Bridelia retusa* was absent in Banke-Maraha and Tuteshwarnath CFMs. Similarly, *Dalbergia sissoo* was absent in Tuteshwarnath CFM (table 12).

Evaluation of effects of carbon on plant species ranking: The Mix based criteria show three types of situations in prioritization of these species. They were a. same rank based either on excluding or including carbon b. promotion of rank and c. demotion of rank of the species.

a. Same rank based either on excluding or including carbon: The prioritization of species based on Mix showed no any differences for some species in these forests. They were altogether 7 species in Banke-Maraha CFM and 17 species in G. Bardibash CFM. Explicitly, the most common species were *Shorea robusta*, *Terminalia tomentosa*, *Anogeisus latifolia*, *Lagerstroemia parviflora* and *Eugenia jambolana* and their contributions to carbon were 32.89, 25.28, 8.27, 13.72 and 7.43% respectively in Tuteshwarnath CFM (table 13).

b. Promotion of rank: Total number of promoted species were 11 each in Tuteshwarnath and G.- Bardibash CFMs which was 12 in Banke-Maraha CFM. They were contributed nearly 16.91, 5.72 and 6.14% carbon in Banke-Maraha, Tuteshwarnath and G.- Bardibash CFMs respectively. Some examples of species promoted their rank based on Mix than carbon were *Dalbergia latifolia*, *Schleichera trijuga*, *Croton roxburghii* and *Acacia catechu*. Specifically, *Dalbergia latifolia* was ranked to 10 based on Mix from 11 based on carbon in Banke- Marha CFM; ranked to 14 from 15 in Tuteshwarnath CFM; ranked to 16 from 17 in Gadhanta- Bardibash CFM. Moreover, *Schleichera trijuga* was switched to rank 21 from 28 in Banke-Maraha and rank 13 from 14 in Tuteshwarnath CFM. Similarly, *Croton roxburghii* was promoted to rank 16 from 19 in Tuteshwarnath and rank 18 from 21 in Gadhanta-Bardibash CFM; *Acacia catechu* was shifted to rank 15 from 16 in Banke- Marha CFM and ranked to rank 24 from 26 in Tuteshwarnath CFM (table 13).

c. Demotion of species rank: The rank of some species was recorded decreasing in Mix rank compared to rank based on carbon. They were 5 species in Gadhanta-Bardibash and 10 species each in Banke-Maraha and Tuteshwarnath CFMs. Some of them were commonly *Eucalyptus camaldulensis, Dillenia indica, Dalbergia sissoo, Alstonia scholaris* and *Nyctanthes arbor-tristis.* The contribution of carbon of these species 15.96% in Banke-Maraha CFM, 4.63% in Tuteshwarnath CFM and 5.55% in Gadhanta- Bardibash CFM. Here, some particular illustrations were i. *Dalbergia sissoo* was promoted to rank 28 from 26 in Banke- Marha CFM, rank 29 from 30 in Tuteshwarnath CFM and rank 22 from 20 in Gadhanta- Bardibash CFM and ii. *Eucalyptus camaldulensis* demoted to 18 from 14 in Banke- Marha CFM, rank 23 from 20 in Tuteshwarnath CFM and 15 from 13 in Gadhanta- Bardibash CFM (table13).

Table 13: Effect of carbon on mix ranking in collaborative forests

Category	**Details**	**Banke-Maraha**	**Tuteshwarnath**	**Gadhanta-Bardibash**
Unaffected spp	N	7	8	17
	% carbon contribution	67.14	89.65	89.31
Promoted spp.	N of spp	12	11	11
	% carbon contribution	16.91	5.72	5.14
Demoted spp	N	10	10	5
	% carbon contribution	15.96	4.63	5.55

4.1.3 Specieswise Carbon Stock and IVI in Community Forests

Species wise carbon stocks in community forests: The species wise carbon stock was also varied in community forests. Total carbon stocks were 85.12±0.54, 93.47±0.24 and 23.87±0.19 t ha^{-1} in Baudh, Chure- Parwati and Chyandanda CFs respectively. Out of them, the highest carbon stock was recorded in *Shorea robusta* in all community forests. They were 28.33±0.34, 26.59±0.24 and 7.97±0.14 t ha^{-1}in Baudh, Chure- Parwati and Chyandanda CFs respectively. Similarly, the second highest record of carbon stock was in *Terminalia tomentosa* in these community forests.

Table 14: Specieswise carbon stock in community forests

Species	Baudh CF ($Ct\ ha^{-1}$)	Chure-Parwati CF ($Ct\ ha^{-1}$)	Chyan Danda CF ($Ct\ ha^{-1}$)
Shorea robusta	28.33±0.34	26.59±0.24	7.97±0.14
Terminalia tomentosa	17.7±0.30	20±0.17	4.63±0.10
Lagerstroemia parviflora	12.75±0.25	11.66±0.16	2.59±0.09
Sapium insigne	0.65±0.02	1.39±0.02	0.64
Anogeisus latifolia	5.4±0.17	9.11±0.15	2.07±0.08
Dalbergia latifolia	1.15±0.05	0.44	0.36
Mallotus philipinensis	1±0.04	0.7	0.29
Eugenia jambolana	6.17±0.11	6.89±0.13	0.92±0.06
Cassia fistula	1.9±0.10	0.26	0.15
Adina cordifolia	1.91±0.11	3.26±0.11	0.79
Croton roxburghii	0.07	0.05	0.06
Terminalia belerica	3.03±0.13	4.1±0.10	0.65
Phyllanthus embelica	0.21	0.11	0.1
Dalbergia sissoo	0.48		0.24
Nyctanthes arbor-tristis	0.04		0.05
Bombax ceiba	0.56	2.81±0.11	0.17
Terminalia chebula	1.62±0.09	2.78±0.07	0.47
Albizzia procera	0.34	1.23±0.06	0.58
Semecarpus onacardium	0.06	0.14	0.12
Dillenia pantaguana	0.13	0.12	0.27
Sterculia villosa	0.05	0.03	0.02
Acacia catechu	0.08	0.06	0.03
Anthocephalus chinensis	0.1	0.17	0.02
Gmelina arborea	0.1	0.02	0.02
Desmodium oojeinense	0.21		0.02
Schleichera trijuga	0.9	0.52	0.52
Alstonia scholaris	0.01		0.05
Aegle marmelous	0.01	0.05	0.04
Bridelia retusa	0.06	0.02	0.02
Eucalyptus camaldulensis		0.77	
Dillenia indica	0.1	0.19	0.01
Total	85.12±0.54	93.47±0.24	23.87±0.19

On the other hand, the lowest record of carbon stock was only 0.01 t ha^{-1} in *Alstonia scholaris* and *Aegle marmelous* in Baudh CF. Same record of carbon stock was found in *Dillenia indica* in Chyandanda CF (table 14). The carbon stock was the highest in *Shorea robusta* because this species is dominant and most preferable for users. Infact, this species is used for the production of high quality timber so the users emphasize the silvicultural operations especially to improve the quality of *Shorea robusta* stand and remove the unwanted species like *Sterculia villosa* and *Bridelia retusa*. Therefore, there was high carbon stock in *Shorea robusta* and very less carbon stock in *Sterculia villosa* and *Bridelia retusa* (table 14).

Species wise IVI in community forests: The variation was also noted in IVI of plant species in community forests. The highest IVIs were recorded in *Shorea robusta* which were 82.03, 71.64 and 66.38 respectively in Chure- Parwati, Baudh and Chyandanda CF. Same trend was found in *Terminalia tomentosa* too. The very less IVIs were estimated in Chure- Parwati CF. They were least 0.38 in *Gmelina arborea* as well as very less 0.43 and 0.63 in *Sterculia villosa* and *Bridelia retusa* respectively (figure 21). The reason of high value of IVIs in *Shorea robusta* and *Terminalia tomentosa* were found because of high dominancy of these species in the community forests.

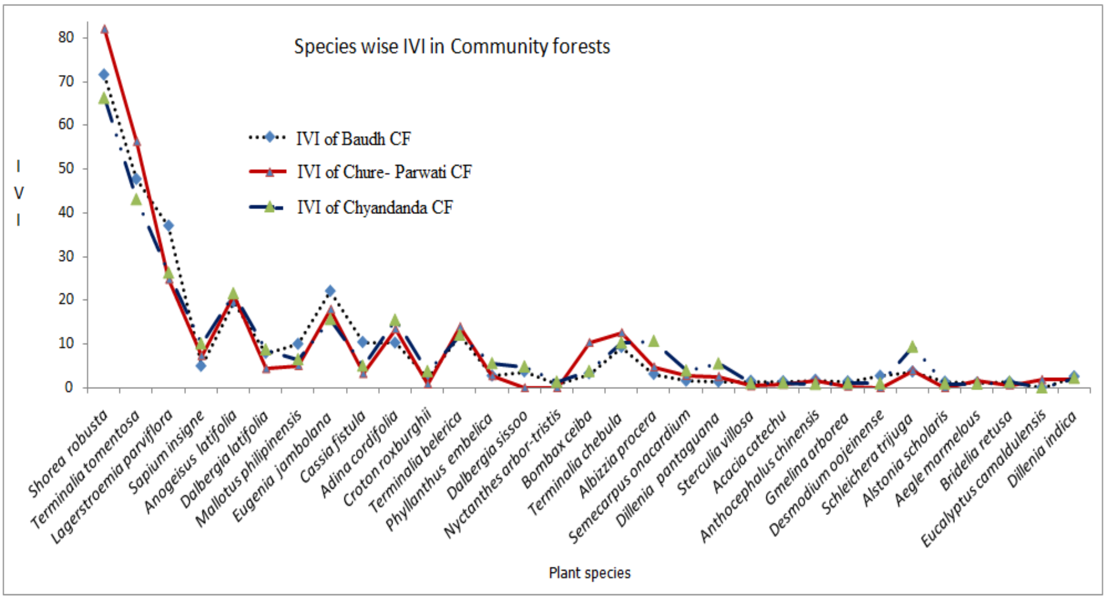

Figure 18: IVI of plant species in community forests

Indeed, the main target of community forest users is to produce good quality timber and *Shorea robusta* is the main quality timber species in Tarai. They thinned the unwanted species like *Sterculia villosa* and *Bridelia retusa* applying silvicultural operations, hence these species have less IVI. The higher the dominance of species the higher is the IVI as well as the opposite of this idea is also true (Dangol & Shivakoti, 2001, Pandya *et al.*, 2013). A study done in Chitwan showed the IVI of *Shorea robusta* was 39.71 the highest in the forest but this was not matching with the IVI of *Shorea robusta* of this research (Dangol & Shivakoti, 2001). The IVI of *Anogeissus latifolia* was recorded 24.10 (Devagiri *et al.*, 2012) which was matching with the estimated IVI of this species of present research. Generally, high dominant species have high IVI (Meng *et al.*, 2011).

Comparison of carbon stocks of major species in community forests: Since No any records carbon stock of the major 10 species showed normality. Thus non-parametric Kruskal Wallis test and Multiple comparison were applied. In case of *Shorea robusta*, *Terminalia tomentosa* and *Lagerstroemia parviflora*, there was significant differences in carbon stocks among these community forests at 5% level of significance. Despite these, there was no significance differences recorded in carbon stocks at 5% level of significant in other species like *Anogeisus latifolia*, *Dalbergia latifolia*, *Mallotus philipinensis*, *Eugenia jambolana*, *Terminalia belerica* and *Terminalia chebula* (table 15).

Table 15: Statistical comparison of specieswise carbon stock

Plant Spp	**Parametric test (p-value)**		**Non-parametric (p-value)**	
	ANOVA	**Tukey's test**	**Kruskal Wallis**	**Multiple comparison**
Shorea robusta	The data are not normal so this test was not applied.		0.001	Differed each other
Terminalia tomentosa			0.001	Differed each other
Lagerstroemia parviflora			0.04	Differed each other
Sapium insigne			0.43	Not Applicable (NA)
Anogeisus latifolia			0.13	NA
Dalbergia latifolia			0.94	NA
Mallotus philipinensis			0.46	NA
Eugenia jambolana			0.06	NA
Terminalia belerica			0.39	NA
Terminalia chebula			0.41	NA

Species ranking based on Mix, IVI and carbon in community forests: Different plant species showed different rank of carbon stocks in community forests. Some examples are the ranks of *Semecarpus onacardium* were 23, 22 and 25 in Baudh CF in, 17, 16 and 19 in Chure- Parwati and 19,18 and in Chyandanda CF based on mix, IVI and C criteria.

Table 16: Ranking of plant species

Species/ Rank base	Baudh CF			Chure Parwati CF			Chyandanda CF		
	Mix	IVI	C	Mix	IVI	C	Mix	IVI	C
Shorea robusta	1	1	1	1	1	1	1	1	1
Terminalia tomentosa	2	2	2	2	2	2	2	2	2
Anogeisus latifolia	5	5	5	4	4	4	4	4	4
Lagerstroemia parviflora	3	3	3	3	3	3	3	3	3
Eugenia jambolana	4	4	4	5	5	5	5	5	5
Terminalia belerica	6	6	6	6	6	6	7	7	7
Sapium insigne	12	12	13	10	10	10	8	10	8
Mallotus philipinensis	10	9	11	12	11	13	13	13	13
Terminalia chebula	9	10	9	8	8	9	10	9	11
Dalbergia latifolia	11	11	10	13	13	15	12	12	12
Dillenia pantaguana	22	26	19	19	18	20	14	15	14
Albizzia procera	16	16	16	11	12	11	9	8	9
Semecarpus onacardium	23	22	25	17	16	19	19	18	18
Cassia fistula	7	7	7	16	15	16	16	16	17
Acacia catechu	25	24	23	24	24	22	24	24	24
Anthocephalus chinensis	21	21	20	21	21	18	30	30	25
Phyllanthus embelica	17	17	18	18	17	21	17	14	19
Eucalyptus camaldulensis	-	-	-	15	20	12	-	-	-
Sterculia villosa	26	23	27	26	26	25	28	26	28
Adina cordifolia	8	8	8	7	7	7	6	6	6
Schleichera trijuga	13	14	12	14	14	14	11	11	10
Croton roxburghii	20	20	24	23	23	24	20	20	20
Desmodium oojeinense	18	18	17	-	-	-	29	27	29
Bombax ceiba	15	15	14	9	9	8	18	19	16
Alstonia scholaris	28	27	29	-	-	-	25	28	22
Nyctanthes arbor-tristis	30	30	28	-	-	-	22	22	21
Dillenia indica	19	19	22	20	19	17	21	21	30
Dalbergia sissoo	14	13	15	-	-	-	15	17	15
Gmelina arborea	24	25	21	27	27	26	26	25	26
Aegle marmelous	29	29	30	22	22	23	27	29	23
Bridelia retusa	27	28	26	25	25	27	23	23	27

Note: the sign **-** denotes absent of the species

Other rank differences were found in *Dillenia pantaguana* too. However most common ranks were 1,2 and 3 of *Shorea robusta*, *Terminalia tomentosa* and *Lagerstroemia parviflora* respectively in these community forests (Table16). No any studies were found related to species ranking based on IVI and carbon together.

Evaluation of effects of carbon on plant species ranking: The mix rank was also evaluated to check the effect of carbon stock on ranking of plant species. The result showed three types of circumstances of species ranking. They are unaffected rank, promoted rank and demoted rank of plant species. There were no any studies done on effect of carbon on ranking of the species in Nepal. The ranking of the species depends up on the frequency, density and dominancy.

Comparison of IVI in community forests: The IVI values of same species were differed in the community forests. Specifically, the IVI value of *Shorea robusta* was 72.64 in Baudh CF which was the highest about 82.03 in Chure- Parwati CF and nearly 66.38 in Chyandanda CF. In addition The IVI of *Terminalia tomentosa* was about 47.74 in Baudh CF. The highest value was 56.33 and lowest value was 43.12 in Chure- Parwati and Chyandanda CFs respectively. Inaddition, the IVI of *Lagerstroemia parviflora* was 26.3 in Chyandanda CF which was the highest about 37.05 and the lowest nearly 24.81in Baudh and Chure- Parwati CFs respectively. The *Eucalyptus camaldulensis* was the absent in Baudh CF and Chyandanda CFs. The species like *Dalbergia sissoo*, *Desmodium oojeinense*, *Alstonia scholaris* and *Nyctanthes arbor-tristis* are absent in Chure- Parwati CF (table 16).

a. Rank unaffected species: The result showed that the rank of 10 species was not affected due to carbon stock in both Baudh and Chure- Parwati CFs which was 18 species in Chyandanda CF. The contributions of carbon of rank unaffected species were 92.99, 89.5 and 90.11% in Baudh, Chure- Parwati and Chyandanda CFs respectively. Indeed, very common examples of the circumstances are *Shorea robusta*, *Terminalia tomentosa* and *Lagerstroemia parviflora* in these community forests.

b. Rank promoted species: It was found that rank of some species was promoted in these community forests. Infact, 10 species were promoted their rank in Baudh CF, 10 species in Chure- Parwati CF and 5 species in Chyandanda CF. Some examples are rank of *Sapium insigne*, *Mallotus philipinensis* and *Terminalia chebula*. Indeed, the ranks of *Sapium insigne* and *Mallotus philipinensis* was promoted to 12 from 13 and 10 from 11 respectively in Baudh CF. Meanwhile the rank of *Mallotus philipinensis* was promoted to 12 from 13 in Chure- Parwati CF. Moreover, the rank of *Terminalia chebula* was promoted to 10 from 11 in Chyandanda CF.

c. Rank demoted species: However, ranks of some species were demoted due to effect of carbon. Such species were listed 10, 7 and 7 in Baudh, Chure- Parwati and

Chyandanda CFs respectively. Some examples are: the rank of *Bombax ceiba* was demoted to 15 from 14 in Baudh CF, 9 from 8 in Chure- Parwati CF and 18 from 19 in Chyandanda CF. Moreover, rank of *Gmelina arborea* was also shifted down to 24 from 21 and 27 from 26 in Baudh CF and Chure- Parwati CF respectively. Same way the rank of *Nyctanthes arbor-tristis* was devaluated to 30 from 28 in Baudh CF and 22 from 21 Chyandanda CF (table 17).

Table 17: Effect of carbon on mix ranking in community forests

Category	Status	Baudh CF	Chure-Parwati CF	Chyandanda CF
Unaffected species	N	10	10	18
	% carbon	92.99	89.5	90.11
Promoted species	N	10	10	5
	% carbon	3.1	6.21	5.83
Demoted species	N	10	7	7
	% carbon	3.91	4.33	4.06

4.1.4 Specieswise Carbon Stock and IVI in Public Plantation and Community Planted Forests

There was only one plantation of *Eucalyptus camaldulensis* in public plantations and community planted forests. Thus the IVI estimation was not essential.

4.2 Carbon Stock in Community Managed Forests

The carbon stock in community managed forests includes carbon in collaborative forests, community forests, public plantations and community planted forests. The above ground carbons are quite significant in tree and pole pools than in seedling, sapling, litter, herbs and grasses pools. Same way, soil carbon is more than root carbon in below ground carbon pools. These carbon pools together contribute in total carbon stock.

The total carbon comprises of above ground and below ground carbon stocks. The above ground carbon includes the carbon in tree, pole, LHG and regeneration (seedling and sapling) while the below ground carbon stocks are carbon in root and soil. The estimated mean carbon stock is affected by the standard deviation and standard error too.

4.2.1 Carbon Stock in Collaborative Forests

The total estimated carbon stock was varied in the collaborative forest because of several reasons. The highest carbon stock was found (274.67±3.59 t ha^{-1}) in Gadhanta- Bardibash CFM and the lowest (197.11± 5.76 t ha^{-1}) in Banke-Maraha CFM and (222.58 ± 3.76 t ha^{-1}) in Tuteshwarnath CFM. The main cause behind the highest estimated carbon stock was due to large number of tree and pole in Gadhanta- Bardibash CFM than other CFMs. Obviously, people used the timber prepared from logs of tree and pole staged plants for construction work and smugglers supply these logs accordingly. The consequences were large variation in carbon stock of pole and tree biomass in these collaborative forests.

No any study was carried out about the carbon stocks in collaborative forest management regime. Thus, the results were compared with the carbon stocks of other forest management regimes. The pilot study done in community forests of Kairkhola watershed, Chitwan, Nepal showed that 276.5 C t ha^{-1} (Bhattarai *et al.*, 2011), other inventory done in protected forests of Tarai Arc Landscape recorded 274.58 C t ha^{-1} (Manandhar, 2010), which are very close to the carbon stock of Gadhanta- Bardibash collaborative forests. Other research study showed that the estimated carbon stock of Bhaiyadevi CF was 193.30 t ha^{-1} (Adhikari, 2010), which value is quite similar to the value of carbon stock of Banke-Maraha CFM. The research signified by Dutta *et al.* (2011), which showed that, the carbon stock of forest biomass was 199.69 t ha^{-1} at *Shorea robusta* stratum in Newar Danda Kamidanda CF (Dutta *et al.*, 2011). The carbon stock variations depend upon the stage of stems present in the forest, biotic and abiotic factors and drivers of deforestation and forest degradation (Kissinger & Herold, 2012).

4.2.1.1 Above Ground Carbon Stock

The above ground carbon stock includes the carbon stock of pole and tree, regeneration as well as herbs, grass and litter. Total estimated above ground carbon stock was 120.93, 143.40 and 185.21 t ha^{-1} in Banke-Maraha, Tuteshwarnath and Gadhanta- Bardibash CFMs respectively (figure 22).

a. Carbon stock of pole and tree: The carbon stock of pole was the highest 63.27t ha^{-1} in Gadhanta- Bardibash CFM, which was followed by the carbon stock 48.13 and

23.53 t ha^{-1} in Tuteshwarnath and Banke-Maraha CFMs respectively. Similarly, the carbon stock of tree in Gadhanta- Bardibash CFM (103.02 t ha^{-1}) was the highest and it was followed by Tuteshwarnath CFM (81.96 t) and least was in Banke-Maraha (79.38 t) CFM. These two pools have major contribution in total carbon stock. In case of tree, they were recorded about 37.57, 40.27 and 36.82% in total carbon of Gadhanta- Bardibash, Banke-Maraha and Tuteshwarnath CFM respectively while for pole, they were 23.03, 11.94 and 21.62% in total carbon of Gadhanta- Bardibash, Banke-Maraha and Tuteshwarnath CFMs respectively (figure 22).

There were more logging problems in Banke-Maraha CFM than other CFMs so there was less carbon stock of pole and tree in this CFM than others. Other important point is, the loggers like to remove the tree and pole staged plants, which have the highest total carbon stocks in comparison to other forest carbon pools. The carbon stocks were noticeably varied in the collaborative forests because of varying density of poles and trees. The study done by WWF, Nepal showed that there was 71.64 t ha^{-1} carbons in pilot area if the canopy cover is 10-40%, this value was quite matching with the carbon quantity of tree in Tuteshwarnath CFM. Another value of recorded C stock was 113.97 t ha^{-1} of forest having 41-70% canopy cover (Manandhar, 2010). Some carbon values of collaborative forests and piloting were matching, reason behind this may be due to similar geographical condition, the piloting site is western Tarai of Nepal, same species composition and dominance of having about to same diameter distribution.

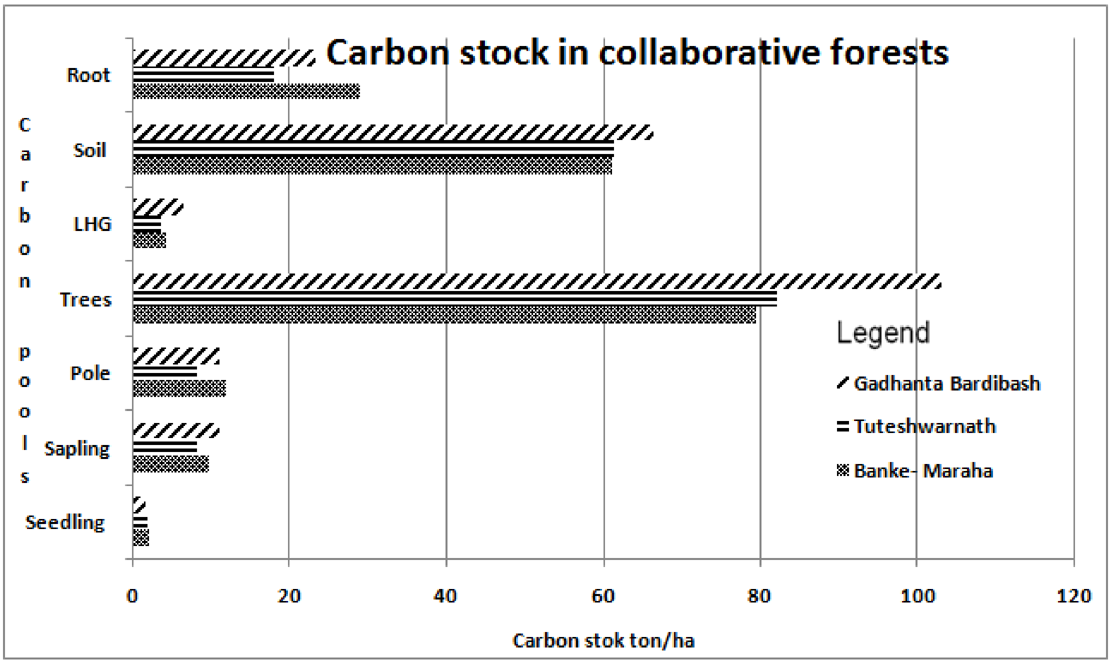

Figure 19: Forest Carbon Stock (C t ha^{-1}) in CFMs

b. Carbon stock of Litter, Herbs and Grasses (*LHG*)*:* There were very less contribution of carbon stock of Litter, Herbs and Grasses (LHG) in total carbon stock because of less contribution of biomass. Here, the carbon stock of LHG was found to be the highest 6.325 t ha^{-1} in Gadhanta- Bardibash CFM but it was the least 3.60 t ha^{-1} in Banke-Maraha and the similar 3.6 t ha^{-1} in Tuteshwarnath CFM. Contribution of carbon stock of Litter, Herbs and Grasses (LHG) were 2.30, 2.14 and 1.62 % only of total carbon stock in Gadhanta- Bardibash, Banke-Maraha and Tuteshwarnath CFMs respectively (figure 22). The carbon stock variation of LHG was mainly due to their high or low presence on the ground surface. So the record of carbon stock of LHG was the highest in Gadhanta- Bardibash and followed by Banke-Maraha and Tuteshwarnath CFMs respectively.

The study done by Lama (2012) showed 2.46 t ha^{-1} carbon in Srijana leasehold forest (Lama, 2012) and the piloting done by WWF showed carbon stock of LHG was 2.95 t ha^{-1} in the forest having 41-70% canopy cover of Tarai Arc Landscape (TAL) (Manandhar, 2010). Similarly, the piloting of watershed showed the carbon stock of LHG was 0.92 t ha^{-1} in dense strata of Kairkhola, Chitwan while it was 1.79 t ha^{-1} in sparse strata of Charnawati, Dolkha (Bhattarai *et al.*, 2011). These values are not matching with the value of carbon stock of LHG in these CFMs but these values indicate their contributions were very less in total carbon stock. The piloting done in TAL area showed that the contribution of carbon stock of LHG recorded 0.76 to 1.79 % (Bhattarai *et al.*, 2011), here the upper value was matching with the record of LHG in total carbon stock of Tuteshwarnath CFM.

c. Carbon stock of Seedling and Sapling: The contributions of carbon stock of seedling and sapling were differed in the collaborative forests. The contribution of seedling in Banke-Maraha, Tuteshwarnath and Gadhanta - Bardibash CFMs were about 1.05, 0.75 and 0.59 % respectively which were 2.07, 1.66 and 1.63 t ha^{-1} correspondingly. However, contribution of sapling in Banke-Maraha, Tuteshwarnath and Gadhanta- Bardibash CFMs were about 5.95, 3.65 and 3.99 % respectively which were 11.73, 8.12 and 10.95 t ha^{-1} correspondingly (figure 22). Their contributions are also very less like carbon stock of LHG but their value has high importance for forest management purpose. Infact, the contributions of carbon of regeneration were 4.58, 7.01 and 4.36% of total carbon in Gadhanta- Bardibash, Banke-Maraha and Tuteshwarnath CFM respectively. The reason of high carbon stock of regeneration (seedling and sapling) in Banke-Maraha CFM may be due to canopy openness and low carbon stock of regeneration in Tuteshwarnath CFM was due to dense canopy which was unfavorable for regeneration establishment. Other reason of this low regeneration was the presence of bushes and effect of grazing, lopping and fire too which disturb the regeneration. The supportive study showed that, the contribution of carbon stock of regeneration was 8.19 t ha^{-1} in undisturbed block of community forests of Bardia, Tarai district of Nepal (KC, 2013), this result was very close to the value of the estimated carbon stock of regeneration of Banke-Maraha CFM (9.7 t ha^{-1}). Moreover, the contribution of carbon by regeneration was recorded about 3.81 % in piloting areas of TAL, somehow these percentage are close with the lowest value of present research (Manandhar, 2010).

4.2.1.2 Below Ground Carbon Stocks

The below ground carbon stocks are root and soil carbon. They were varied according to collaborative forests. Total estimated below carbon stock was 76.18, 79.18 and 89.46 t ha^{-1} in Banke-Maraha, Tuteshwarnath and Gadhanta- Bardibash CFMs respectively.

a. Root carbon: The estimated root carbon was found to be highest 23.15 t ha^{-1} in Gadhanta- Bardibash CFM and followed by 17.92 t ha^{-1} and 15.12 t ha^{-1} in Banke-Maraha and Tuteshwarnath CFM respectively, these records contribute about 8.43, 7.67 and 8.05% of total carbon stock in Gadhanta- Bardibash, Banke-Maraha and Tuteshwarnath CFMs respectively (figure 22).

The root carbon depends up on the above ground carbon stock. The above ground carbon stock was the highest in Gadhanta- Bardibash in comparison to others. The study done in pilot site of dense strata of Charnawati watershed, Dolkha district showed that there was 15.53 t ha^{-1} root carbon which is close to the record of Tuteshwarnath CFM. In the same report, it was also indicated that, about 18.59 t ha^{-1} carbon in dense strata of Kairkhola watershed, Chitwan district (Bhattrai *et al.*, 2011) which is close to the value of root carbon of Banke-Maraha CFM. Meanwhile, the research done by KC (2013) showed, the root carbon was 23.96 t ha^{-1} in of undisturbed block of community forest of Bardia Tarai district (KC, 2013), which was also matching with the record of root carbon of Gadhanta- Bardibash CFM. Other important factors affecting the root carbon is species variation, characteristics of root, its soil penetrating characteristics and suitable soil condition for easy growth.

b. Soil carbon: Moreover, the quantities of soil carbon were quite similar in all collaborative forests having values with 66.31, 61.26 and 61.06 t ha^{-1}, which contribute about 24.14, 30.98 and 27.52% of total carbon stock in Gadhanta-Bardibash, Tutesharnath and Banke-Maraha CFMs respectively (figure 22). This similarity in soil carbon may be because of the same altitude and same nature of the site quality. These all collaborative forests are situated along the north of the East-West highway and they have same types of loamy soil. These findings were also supported by Sah (2014), he recorded 60.32, 62.48 and 63.5 t ha^{-1} in Galtar, Indrakali and Ratu Mahila CFs respectively of Mahottari district. This similarity is due to same nature of climate, vegetation cover and same soil (Sah, 2014).

c. Soil carbon stocks at different depths in collaborative forests: Generally, there were highest quantity of carbon stock at 0-10 cm depth and they were decreased according to the increasing depth. They were 32.5, 28.79 and 29.31 t ha^{-1} in Gadhanta-Bardibash, Tuteshwarnath and Banke-Maraha CFMs respectively at 0-10 cm depth. Meanwhile they were less 22.54, 23.89 and 23.20 t ha^{-1} in Gadhanta- Bardibash, Tuteshwarnath and Banke-Maraha CFMs respectively at 10-30 cm and least 11.27, 8.58 and 8.55 t ha^{-1} in Gadhanta- Bardibash, Tuteshwarnath and Banke-Maraha CFMs respectively at 30-60 cm depth (figure 23).

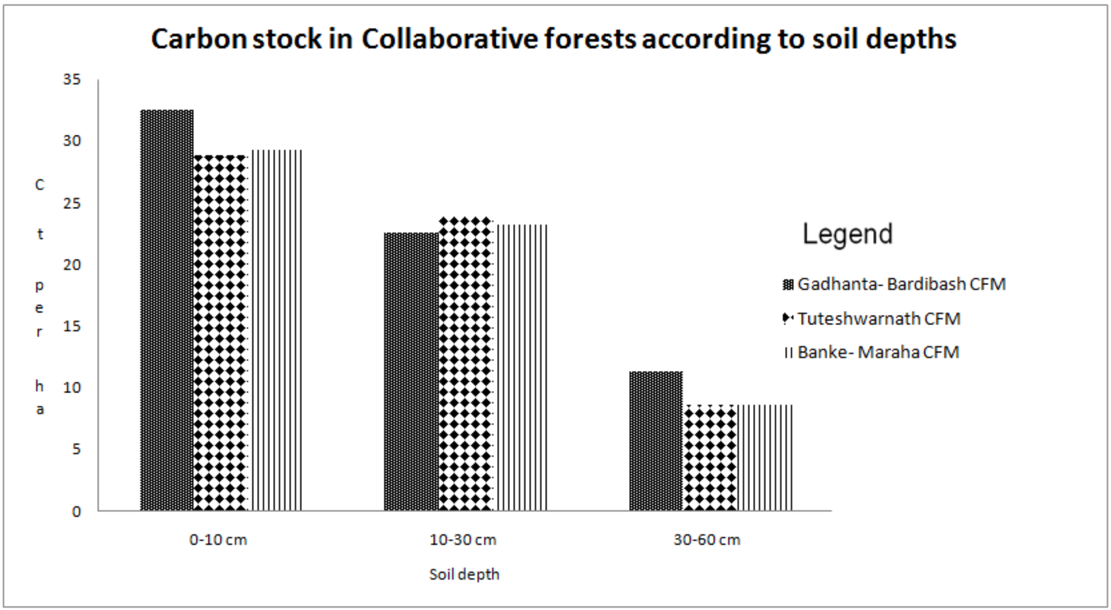

Figure 20: Soil carbon according to depth

The reason of high carbon at upper layer of the soil was due to the high microbial activities and high nutrients in upper depth and they are decreased according to the depth of the soil. Other important reason of high soil carbon was due to decaying of leaf litter at upper layer and that was less in deeper layer (Dutta *et al.*, 2011).

The soil carbon of Jagdol community forest was 32.01 at 0-10 cm depth (Bahandari, 2013), which is matching with the value of soil carbon of Gadhanta- Bardibash CFM. The soil carbon of Newardanda Kamidanda CF was 23.58 t ha^{-1} at 0-10 cm depth which is close to the value of soil carbon of Tuteshwarnath CFM. In addition, the soil carbon of Kali Damar community forest was about 12.88 t ha^{-1} (Dutta *et al.*, 2011), which is very close to the value of soil carbon of Gadhanta- Bardibash CFM at 30-60 cm depth.

4.2.1.3 Statistical Analysis of Carbon Stock

Based on carbon stock t ha^{-1}, the standard error and standard deviation were 1.76 and 9.94 respectively in Banke-Maraha CFM; they were 2.83 and 16.25 respectively in Tuteshwarnath CFM and they were 1.84 and 10.24 respectively in Gadhanta – Bardibash CFM. Similarly, minimum and maximum carbon stocks were also differed, they were 187.22 and 209.33 t ha^{-1} respectively in Banke-Maraha CFM; 214.55 and 230.33 t ha^{-1} respectively in Tuteshwarnath CFM and they were 264.12 and 289.77 t ha^{-1} respectively in Gadhanta- Bardbash CFM. The values of confidence level at 95.0% were 3.59, 5.76 and 3.76 in Banke-Maraha, Tuteshwarnath and Gadhanta-Bardbash CFMs respectively (table 18).

Table 18: Descriptive analysis of carbon stock in collaborative forests

CFMs	Mean C t ha^{-1}	Std. Deviation	Std. Error	Minimum C t ha^{-1}	Maximum C t ha^{-1}	Confidence Level (95.0%)
Banke-Maraha	197.10	9.94	1.76	187.22	209.33	3.59
Tuteshwarnath	222.58	16.25	2.83	214.55	230.33	5.76
Gadhanta-Bardbash	274.66	10.24	1.84	264.12	289.77	3.76

In addition, the carbon stocks were also compared using ANOVA and Tukey HSD Test. The ANOVA showed that there were significant differences in carbon stocks in collaborative forests (table 19) at 5% level of significant.

Table 19: ANOVA showing differences in carbon stocks in collaborative forests

Variation	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	98188.02	2	49094.01	311.49	0.000
Within Groups	14657.81	93			
Total	112845.83	95			

Here, Tukey HSD was applied for multi comparison, it showed that, they were significantly differed ($p<0.05$) from each other (table 20).

Table 20: Tukey HSD Test showing differences carbon stock in CFM

CFMs	Number of sample plots	Subset for alpha = 0.05		
		1	2	3
Banke-Maraha	32	197.10		
Tuteshwarnath	33		222.58	
Gadhanta- Bardibash	31			274.66

4.2.2 Total Carbon Stock in Community Forests

The sum of carbon stock of different pools like carbon stock of tree and pole, regeneration, LHG and below ground together contribute to total carbon stock. They were varied in the community forests.

Total carbon stocks were differed according to the community forests. The estimated carbon stock was found to be highest (172.05±3.82 t ha^{-1}) in Chure- Parwati CF while it was the lowest (92.08±3.15 t ha^{-1}) in Chyandanda community forest. This was 163.95±2.72 t ha^{-1} in Baudh community forest (figure 24).

Generally, the selective felling was applied to collect the timber from these community forests in order to sell them in market outside the district like Kathmandu, Pokhara and Janakpur. The selective felling was concentrated mainly to the DBH>50 cm and in absence of this DBH class, the people like to harvest trees with DBH>30-50 cm. So, this is the main reason of overall low carbon in these community forests.

Within these community forests, though records of stems were high 1441, 1701 and 1753 stems ha^{-1} in DBH<30 cm, they were low 64, 47 and 0 stems ha^{-1} of DBH=>30-50 cm in Baudh CF, Chure- Parwati CF and Chyandanda CF respectively. The higher the number of stems ha^{-1} of large sized plants, the higher is the carbon stock and opposite of this statement is also true (Magar, 2009). The users shared that, the forest stock was very rich in Chyandanda community forests before the urbanization of

Bardibash market. Within 15-20 years period, this forest was heavily damaged but after handed over to user as community forest since last 8 years, the users are actively participating in restoration of the forests.

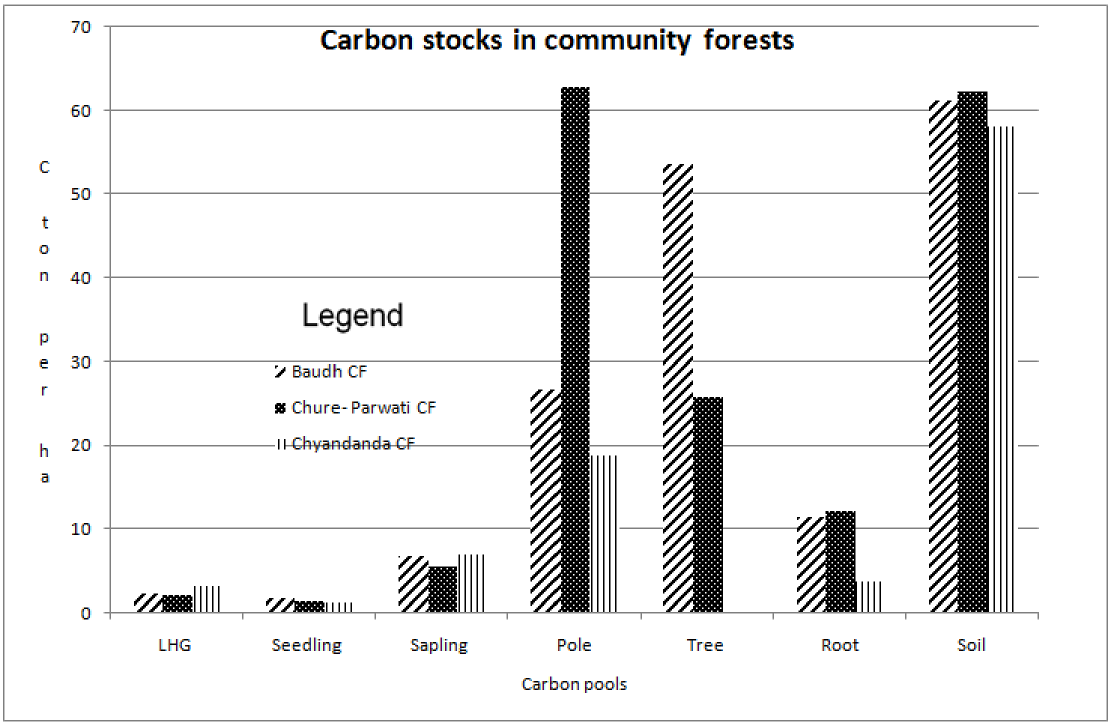

Figure 21: Carbon stocks in community forests

Some studies of different locations also support findings of the present research. The study done by Dutta *et al.* (2011) showed that, the carbon stock of Indrakali CF of Mahottari was 174.36 t ha^{-1} in (Dutta *et al.*, 2011), which value is close to the value of Chure- Parwati CF. In addition, the study done by Lama (2012) showed that, total carbon stock in Janahit leasehold forest was 97.92 t ha^{-1} (Lama, 2012), which is almost similar to the value of Chyandanda CF. These types of similarity in total carbon stock may be due to the similar nature of the forest and forest condition. The Tarai forest contained 123.14 t ha^{-1} of carbon excluding seedlings and saplings of plant species as well as shrub species having DBH<5 cm, climbers, fine roots, grasses (including bamboos) and herbs (FRA/DFRS, 2014), this value was about similar value of carbon stock of Baudh CF excluding soil carbon. The reason of similarity may be due to similar situations because both works carried out in Tarai.

The variation in carbon stocks also depends upon the forest type, age of forest and size of trees (Magar, 2009), density of stems ha^{-1}, the geographical location, plant species, aboveground input received from leaf litter, decomposition of fine roots below ground (soil carbon), management practices and other operating ecological factors (Nautiyal & Singh, 2013). There were very less number of large sized (DBH> 30cm) trees in Chyandanda community forests. Other important part of less carbon in Chyandanda community forest is due to the removal of large sized trees in the past.

4.2.2.1 Above Ground Carbon Stock

Generally, there were tree, pole, sapling, litter, herbs and grass as above ground carbon pools in community forests. Principally, the contribution of these pools in total carbon was varied similar like carbon of collaborative forests.

a. Carbon stocks of tree and pole: The estimated carbon stock of tree and poles were not same in the community forests. Distinctively the carbons stock of tree and pole were 53.70 and 26.79 t ha^{-1} respectively in Baudh CF; they were 25.87 and 62.83 t ha^{-1} respectively in Chure- Parwati CF and they were 0 and 18.88 t ha^{-1} in Chyandanda CF (Figure 24). So, the contributions of carbon of tree pool were 32.75, 15.04 and 0% in total carbon stock of Baudh, Chure- Parwati and Chyandanda CFs respectively. Moreover, the contributions of pole were 16.34, 36.52 and 20.50% in total carbon of Baudh, Chure- Parwati and Chyandanda CFs respectively. These variations in contribution of carbon are due to the presence and absence of stem ha^{-1} and their diameter distribution in the community forests (Dutta *et al.*, 2011). This was also supported by the study done in community forest of Bardia Tarai by KC (2013), the carbon contribution of pole and tree together was 51 to 53%. There were highest numbers of stem ha^{-1} in Chure-Parwati than other, so there was the highest carbon stock in pole and tree together in this community forest among others.

It is remarkable fact that, the carbon stock of tree and pole strata was low due to the selective felling of the plants of these stages in Baudh and Chure- Parwati CFs, while the reason of very low carbon in Chyandanda CF was due to the past records of illegal felling. The study done in Galtar CF in Mahottari, which was one of the affected CF of illegal logging showed that, the carbon stock of tree was 50.25 t ha^{-1}, this value is close to the carbon stock of tree strata of Baudh CF (Sah, 2014). Similarly, the record of tree carbon stock 54.84 t ha^{-1} in sparse forest strata of Lundikhola watershed of Gorkha, REDD+ piloting area done in 2010 (Bhattarai *et al.*, 2011) was also matching with the tree carbon stock of Baudh community forest. The reason behind it may be due to the similar forest condition like same species, age and having presence of similar DBH class.

b. Carbon stocks of LHG, seedling and sapling: The carbon stock of LHG, seedling and sapling were 2.33, 1.79 and 6.72 t ha^{-1} respectively in Baudh CF, they were 2.11, 1.30.and 5.52 t ha^{-1} respectively in Chure- Parwati CF as well as 3.11, 1.22 and 6.89 t ha^{-1} respectively in Chyandanda CF. Undeniably, their contributions were low about 1.09, 0.76 and 1.32% by seedling and 4.10, 3.21 and 7.48 % by sapling in total carbon of Baudh, Chure- Parwati and Chyandanda CFs respectively while the contribution by LHG were very low 1.42, 1.23 and 3.38% only in total carbon of Baudh, Chure- Parwati and Chyandanda CFs respectively. This idea is also supported by the REDD+ piloting done in Kairkhola watershed, Chitwan. Here it was stated that the contribution of other pools like herb, litter, grasses and sapling was very less (Bahandari, 2013). The study done in unmanaged forest block of Bhudkaya community forest also showed that, carbon stock of LHG was 2.57 t ha^{-1} (KC, 2013), which was close to carbon stock of LHG of these community forests. Moreover, the study done by Sah (2014) in Ratu Mahila CF, Mahottari showed that, the carbon stock of regeneration was 7.12 t ha^{-1}, which is close to the carbon stock of these community forests. The reason of the matching carbon stock in these pools of community forest was due to similar species and site quality of these community forests.

4.2.2.2 Carbon Stock of Below Ground

This includes the carbon stock of root and soil. The total soil carbon depends up on the depth wise carbon stock of soil. In reality, the carbon stocks of root were 11.41, 12.20 and 3.76 t ha^{-1} in Baudh, Chure- Parwati and Chyandanda CFs respectively (figure 24) and its contribution was 6.96, 7.09 and 4.08% in total carbon stock of of Baudh, Chure- Parwati and Chyandanda CFs respectively. Meanwhile, the soil carbon was the highest 62.22 t ha^{-1} which was 37.34 % in total carbon of Chure- Parwati CF and it was followed by 61.22 t ha^{-1} that was 36.16 % in total carbon of Baudh CF and the least record was 58.22 t ha^{-1}, which contributed about 63.23% in total carbon stock of Chyandanda CF. Here, supporting evidence was the soil carbon 59.80 t ha^{-1} of Setidevi leasehold forest (Lama, 2012) is quite matching with the value of Chyandanda CF.

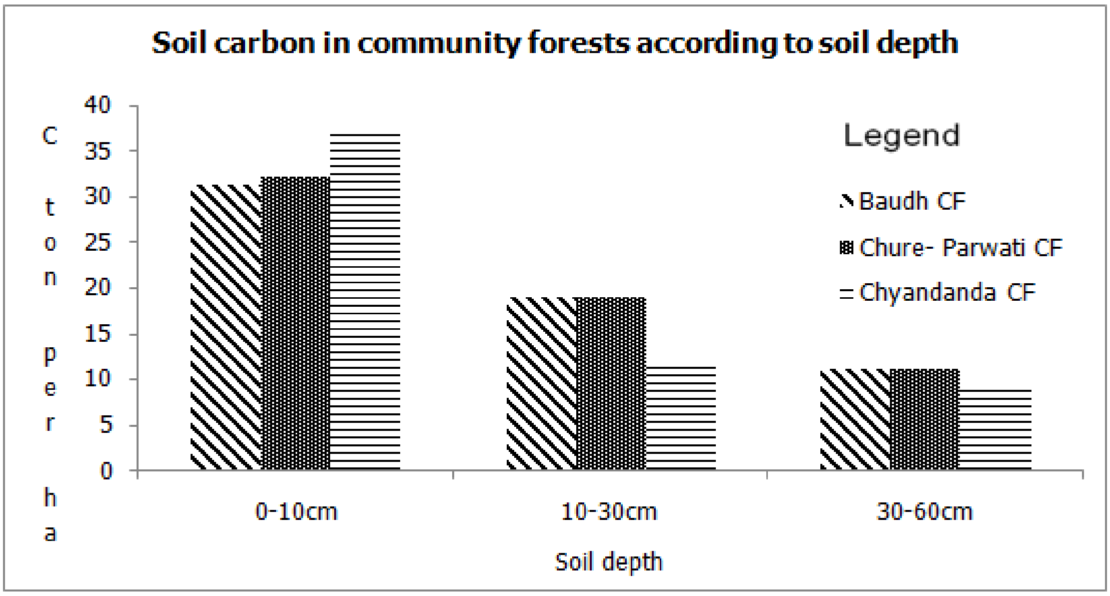

Figure 22: Soil carbon in community forests

The recorded carbon stocks were also varied according to soil depth. They were the highest (37.2 t ha^{-1}) in 0-10 cm and the lowest (9.00 t ha^{-1}) in 30-60 cm (figure 25). The soil carbon is the highest at top most layer and decreased according to the depth of the soil (Ramchandran et al., 2007).

4.2.2.3 StatisticaL Analysis

The statistical analysis includes the carbon stock of community forests showing the standard errors, standard deviation, minimum and maximum values. Based on carbon stock t ha^{-1}, the standard deviation and standard error were 4.33 and 0.79 respectively in carbon stock of Baudh CF; they were 9.25 and 1.85 respectively in Chure- Parwati CF and 7.11 and 1.52 respectively in Chyandanda CF. Similarly, minimum and maximum carbon stocks were 154.22 and 170.88 t ha^{-1} respectively in Baudh CF; they were 162.66 and 179.94 t ha^{-1} respectively in Chure- Parwati CF while they were 84.44 and 98.33 t ha^{-1} respectively in Chyandanda CF. The confidence level at 95.0% were 2.72, 3.82 and 3.15 t ha^{-1} in Baudh, Chure- Parwati and Chyandanda CFs respectively (table 21).

Table 21: Descriptive statistics of catbon stock in CFs

CF	Mean C t ha^{-1}	Std. Deviation	Std. Error	Minimum C t ha^{-1}	Maximum C t ha^{-1}	Confidence Level (95.0%)
Budha	163.95	4.33	0.79	154.22	170.88	2.72
Chure-Parwati	172.05	9.25	1.85	162.66	179.94	3.82
Chyandanda	92.09	7.11	1.52	84.44	98.33	3.15

This variation in carbon stock of community forest was also justified by the statistical analysis. The one way ANOVA showed that, there were significant differences in carbon stocks in community forest at 5% level of significance (table 22).

Table 22: ANOVA of carbon stocks in CFs

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	90581.63	2	45290.82	719.68	0.000
Within Groups	4656.96	74	62.93		
Total	95238.59	76			

Similarly, the multi comparison using the Tukey HSD test also showed that there were significant differences in carbon stock of each community forest at 5% level of significant (table 23).

Table 23: Tukey HSD test in carbon stock variation in CFs

CFs	Number of sample plots	Subset for alpha = 0.05		
		1	2	3
Chyandanda	22	92.08		
Budha	30		163.95	
Chure Parwati	25			172.05

4.2.3 Comparison of Carbon Stock in Collaborative and Community Forests

The average carbon stock of collaborative forest was higher (230.91 t ha^{-1}) than the mean carbon stock (146.05 t ha^{-1}) of community forests. This was also justified by the statistical comparison. Since the Z calculated value (15.85) > Z critical value at 5% level of significance (1.96), so the conclusion can be drawn that, there was significant differences in carbon stock of community forests and collaborative forests (table 24).

There were high carbon stocks in collaborative forests in comparison to community forests. Infact, there were two main reasons behind this. The first one is related to the density of stems ha^{-1} and second one is effect of adopted harvesting practice. There were higher records of stems ha^{-1} in collaborative forests than in community forests in case of DBH> 30 cm. For instance there was 47 and 30 stems ha^{-1} of DBH=30-50cm and DBH>50cm respectively in Gadhanta- Bardibash CFM, which were nil in Chyandanda CF (figure 27). Similarly, there were less number of stems ha^{-1} in Baudh and Chure- Parwati CFs than collaborative community forests. The consequences were low carbon stocks in community forests than collaborative forests. In addition, the lower the DBH class the lower the contribution in total carbon stocks and the higher the DBH class the higher the total carbon stocks (Prakash, 2001). There were not much effects of DBH< 30 cm on carbon stocks variation. Another reason of lower carbon stocks in community forests is due to felling practice of larger DBH>50 cm. The green trees have selectively felled from community forests but not harvested from collaborative forests.

The records of stems ha^{-1} of DBH<30cm were not so differed in both collaborative and community forests. However, total number of stems was differed. It showed overstocked like 1192 and 1753 stems ha^{-1} in Gadhanta- Bardibash CFM and Chyandanda CF respectively (figure 27). This indicated that the thinning operations are lacking in these forests. The silvicultural operations should be concentrated to remove from overstocked and promote the under stocked carbon. Sometimes, there was problem of illegal logging in collaborative forests but regular patrolling efforts by the mobilization of staff and committee members have control the situation satisfactory.

Table 24: Comparison of carbon stock of community and collabrative forests

Comparison of	Number of sample plots	Z calculated value	P-value	Z critical value at 5% level of significance
Carbon stock of community and collaborative forests	n_1-95 and n_2-77	15.85	0.00	1.96

4.2.4 Total Carbon Stocks in Public Plantations and Community Planted Forests

The total carbon stock was varied in public plantation and community planted forests. Explicitly, total carbon stock was the highest (148.89±2.81 t ha^{-1}) in Sita CPF and it was the lowest (30.34 ± 0.86 t ha^{-1}) in Bisbitty PP. Differently, the second highest record of carbon was 140.32 ± 1.58 t ha^{-1} in Shreepur PP. Serially, they were 57.80±1.67, 52.29±0.77 and 30.88±1.93 t ha^{-1} in Ramnagar CPF, Banauta PP and Jogikuti CPF respectively. Based on mean carbon stock, the overall calculated carbon stocks were 1473.33, 807.29, 460.152 and 284.66 t in Shreepur PP, Sita CPF, Ramnagar CPF and Banauta PP respectively. The overall calculated less carbon stocks were recorded 230.60 and 265.61 t in Bisbitty PP and Jogikuti CPF respectively (table 25). One of the main reason of variation overall carbon stock was the area of the plantation while another reason of high carbon stock, was due to the high organic matter in these plantations particularly in Shreepur PP and Sita CPF, because the soil was loamy here. On the other hand, the low carbon stock was in plantation in Bisbitty PP and Jogikuti CPF due to the dominance of sandy soil. Other factors of variation in carbon stock of these plantations were low number of stems per ha and age of the plant (figure 29).

Table 25: Carbon stock in public and community planted forests

Plantation	Pole & Sapling C t ha^{-1}	Root C t ha^{-1}	Grass & litter C t ha^{-1}	Soil C t ha^{-1}	Total C t ha^{-1}	Total C t
Shreepur PP	54.34	6.79	0.06	79.13	140.32	1473.33
Banauta PP	11.48	3.74	0.07	37.00	52.29	460.152
Bisbitty PP	12.03	1.50	0.065	16.74	30.34	230.60
Sita CPF	68.89	8.61	0.06	71.33	148.89	807.29
Ramnagar CPF	22.00	2.75	0.05	33.00	57.80	284.66
Jogikuti CPF	13.65	1.71	0.08	15.44	30.88	265.61

There are many factors affecting the carbon stock in plantations but the dominant one was the number of stems ha^{-1}. Certainly, the highest carbon stock in Sita CPF was due to the large number of stems 2211 ha^{-1}. Other important reason of high carbon stock in this CPF was the implementation of plan properly and regular practice of silvicultural operations. On the other hand, the number of stem ha^{-1} were less 1756 and 1833 in Ramnagar and Jogikuti CPFs respectively, thus the carbon stocks t ha^{-1} were less and vice versa. Since there were also least number only 1733 stems ha^{-1} in Bisbitty public plantation, the result was lowest record of carbon stock. The number of stem is 3618 and 2013 ha^{-1} high in Shreepur and Banauta public plantations respectively (figure 29) and hence the records of carbon stock were high. Other influencing factors of carbon variation were the soil carbon, applied silvicultural operations, age of the plant and effect of drivers of deforestation and forest degradation. Remarkably, there were very less quantity of carbon in grass and litter but this was very high in soil. Considerably, the other significant contribution of carbon stock was due to low age of the plantation.

4.2.4.1 Carbon Stock of Pole and Sapling

The record of carbon stock in pole and sapling pools was the highest (68.89 t ha^{-1})in Sita CPF, while that was the lowest (11.48 t ha^{-1}) in Banauta PP. Another higher carbon stock of pole and sapling together was 54.34 t ha^{-1} in Shreepur PP because there were higher numbers of stem ha^{-1} in these areas. Sequentially, the record carbon stock of pole and sapling together was 22.00 t ha^{-1} in Ramnagar CPF. However, the records of carbon stocks of pole and sapling together were low 12.03 t ha^{-1} in Bisbitty PP and 13.65 t ha^{-1} in Jogikuti CPF. Here, it is essential to remark about the plantation year, specifically, plantation was done in 2007 in Banuata PP and Ramnagar CPF; this was done in 2006 in Bisbitty PP and Jogikuti CPF as well as it planted in 2006 in Shreepur PP and Sita CPF. The age of the plants is one of the major reasons of the variation of carbon stock of these plantations. Moreover, the record of carbon stock of pole was the highest 46.27 % and it was the lowest 21.95 % in total carbon stock of Sita CFP and Banauta PP correspondingly. In addition, the records of this contribution were 38.73, 39.66, 38.06 % and 44.2% in total carbon stock of Shreepur PP, Bisbitty PP, Ramnagar CPF and Jogikuti CPF respectively. The study done in Budhkaya community forest showed that, the record of pole and tree carbon was about 50% in total carbon stock in disturbed forest block (KC, 2013), which was close to the record carbon stock of pole of Sita CPF.

Infact, there were no any studies of carbon assessment done in public plantation and community planted forest in Nepal. However, some researches done on carbon assessment which showed matching results with this research. Here, the research done by Dutta *et al.* (2011) showed that the estimated carbon stock of biomass of 9 years of *Eucalyptus camaldulensis* were 84.07 t ha^{-1} and 87.42 t ha^{-1} in Indrakali and in Newardanda Kamidanda community forests of Mahottari district respectively (Dutta *et al.*, 2011). Based on the mean annual carbon increment, the estimated carbon stock of biomass (pole and sapling) in Indrakali community forest would be 56.01 t ha^{-1} at 6 years, which is close to the carbon stock of the Shreepur public plantation. Similarly, the estimated carbon stock of biomass (pole and sapling) in Newardanda Kamidanda community forest would be 67.99 t ha^{-1} at 6 years, which is close to the carbon stock of Sita community planted forests. Likewise, the carbon stock of Shreepur public plantation may be very close after 10 and 11 years.

The estimated above ground carbon stock of Barkhe community forests in Dolkha district showed 21.83 t ha^{-1} (Shrestha *et al.*, 2012), this value is similar to above ground carbon stock of Ramnagar CPF. Same way, his another study also showed that, the above ground carbon stock of Chyansi CF was 56.6 t ha^{-1}, which is close to above ground carbon stock of Shreepur PP. Likewise, the other study in Dolkha district showed that, the above ground pole carbon stock of Setidevi leasehold forest was found to be 11.48 t ha^{-1} (Lama, 2012), this record is quite similar to the carbon stock of Banauta and Bisbitty PP. Additionally, the study done in Chitwan district showed that, the estimated above ground pole carbon stock of Purbeli leasehold forest was 9.15 t ha^{-1} (Vaidya, 2012) and this is nearly similar to the carbon stock of pole and saplings of Banauta PP. Indeed, these values are close because of the similar number of stem ha^{-1} and these forests are about same aged.

4.2.4.2 Carbon Stock of LHG and Root

As shown in Table 25, the least record of carbon stock was found in LHG carbon and which was less in root stock. The carbon stocks of LHG were 0.06, 0.07, 0.065, 0.06, 0.05 and 0.08 t ha^{-1} respectively in Shreepur PP, Banauta PP Bisbitty PP, Sita CPF, Ramnagar CPF and Jogikuti CPF. Moreover, the carbon stocks of root were 6.79, 3.74, 1.50, 8.61, 2.75 and 1.71 t ha^{-1} in Shreepur PP, Banauta PP, Bisbitty PP, Sita CPF, Ramnagar CPF and Jogikuti CPF respectively. The carbon stock of LHG was very less 0.04, 0.13, 0.21, 0.04, 0.09 and 0.26% in Shreepur PP, Banauta PP, Bisbitty PP, Sita CPF, Ramnagar CPF and Jogikuti CPF respectively. It was also less in root pools particularly 4.84, 7.15, 4.95, 5.78, 4.76 and 5.54 % in Shreepur PP, Banauta PP, Bisbitty PP, Sita CPF, Ramnagar CPF and Jogikuti CPF respectively . Supportive study showed that, the above ground carbon stocks of LHG were 0.08 t ha^{-1} found in undisturbed forest block and 0.07 t ha^{-1} in disturbed forest block of Budhakaya CF the first value is matching with the carbon stock of LHG of Jogikuti CPF and second one is close to the carbon stock of LHG of Banauta PP. Remarkably, the percentage of carbon of LHG was only 0.05%, which is close to the percentage carbon of LHG of Shreepur PP (KC, 2013). Same study showed that, the carbon stock of root was 6.76 t ha^{-1} in disturbed forest block and it was 5.74 t ha^{-1} in undisturbed forest block, here both values are close to value of Shreepur PP.

4.2.4.3 Soil Carbon

Generally, there was higher carbon stock in soil in plantation areas. They were serially 79.13, 71.33, 37.00, 33.00, 16.74 and 15.44 t ha^{-1} in Shreepur PP, Sita CPF, Banauta PP, Ramnagar, Bisbitty PP and Jogikuti CPF respectively (Table 25). It was noticed that, the higher the soil carbon the higher was the total carbon stock in the plantations such as the soil carbons were very high in Shreepur PP and Sita CPF so the total carbon stocks were also too high here. However, the carbon stocks were low in Bisbitty PP and Jogikuti CPF. Specifically, Banauta PP, Bisbitty PP, Ramnagar CPF and Jogukuti CPF are situated on the bank of the river and the soil here is sandy therefore there were less organic matters, this is the major cause behind the less carbon.

The contributions of soil carbon were 70.76, 47.91, 56.39, 55.19, 57.09 and 57.09% in total carbon of Banauta PP, Shreepur PP, Sita CPF, Bisbitty PP, Ramnagar CPF and Jogikuti CPF respectively. This indicates average soil carbon was 56.22%. There was about 44.35% soil carbon in disturbed block of Budhakaya CF (KC, 2013), which record is matching with the percentage carbon of soil of Sita CPF.

The soil carbon was found to be 73.92 t ha^{-1} in Gorkhali leasehold forest, which value is quite similar to the value of Sita CPF. Similarly, the soil carbon of Ratmate leasehold forest was 37.89 t ha^{-1} (Lama, 2012), this value is close to the value of Banauta PP. The carbon stocks depend up on the stage of the plants, species of plantation, practices and silvicultural operations (agroforestry) adopted, site quality and microbial activities in the soil (Oren *et al.*, 2001). The soil carbon of Tarai forest was reported 33.66 t ha^{-1} (FRA/DFRS, 2014), which is about to similar the record of soil carbon of Ramnagar CPF.

As shown in figure 26, the soil carbon was the highest in 0-10 cm depth, this was followed by soil carbon of 10-30 cm and least value was found in 30-60 cm. In fact, the estimated records of soil carbon were 31.46, 15.18, 7.96, 28.36, 13.54 and 7.34 t ha^{-1} in Shreepur PP, Banauta PP, Bisbitty PP, Sita CPF, Ramnagar CPF and Jogikuti CPF respectively in 0-10 cm. They were less 29.39, 14.96, 5.04, 26.49, 13.34 and 4.65 t ha^{-1} in Shreepur PP, Banauta PP, Bisbitty PP, Sita CPF, Ramnagar CPF and Jogikuti CPF respectively in 10-30 cm. Moreover, they were lower 18.28, 6.86, 3.74, 16.47, 6.12 and 3.45 t ha^{-1} in Shreepur PP, Banauta PP, Bisbitty PP, Sita CPF, Ramnagar CPF and Jogikuti CPF respectively in 30-60 cm (Figure 26). Clearly, soil carbon decreses according to increasing soil depth in a profile. This view is supported by other several studies (Harrison *et al.*, 2011).

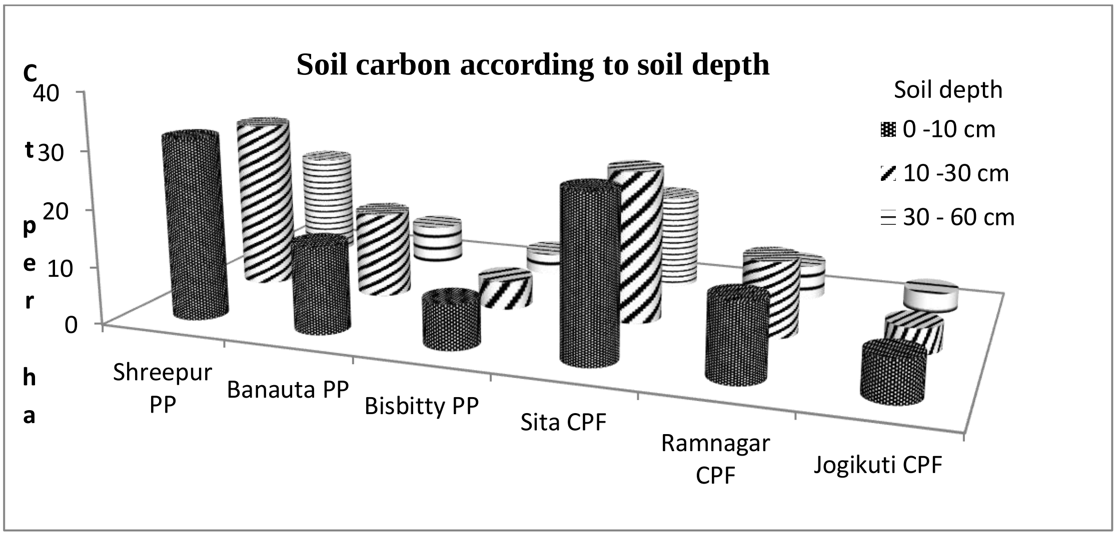

Figure 23: Soil carbon in public plantation and community planted forests

The soil carbon was 14.45 in Kalyankari LHF at 0-10 cm depth (Lama, 2012), which was matching with the soil carbon of Ramnagar CPF, the soil carbon of Sawunepani LHF was 13.54 at 10-30 cm (Vaidya, 2012), which is very close to the value of Ramnagar CPF. However, no records of soil carbon were found at 30-60 cm depth.

4.2.4.4 Statistical Analysis of Carbon Stock

The descriptive statics based on carbon stock t ha^{-1} can provide the simple statistical information about the carbon stock of public plantation and community planted forests. Exclusively, the standard deviations were 1.01, 2.36 and 1.03 in Banauta, Shreepur and Bisbitty PPs respectively while the standard errors were 0.34, 0.71 and 0.36 t ha^{-1} in Banauta, Shreepur and Bisbitty PPs respectively. Moreover, minimum and maximum value of carbon stocks were 48.25 and 56.33 t ha^{-1} respectively in Banauta PP; they were 136.69 and 143.67 t ha^{-1} respectively in Shreepur PP while they were 29.12 and 31.73 t ha^{-1} respectively in Bisbitty PP (table 26).

In case of community planted forest, standard deviations were 2.68, 1.80 and 2.87 t ha^{-1} in Sita, Ramnagar and Jogikuti CPFs respectively. In addition, the standard errors were 1.09, 0.68 and 0.86 t ha^{-1} in Sita, Ramnagar and Jogikuti CPFs respectively. Moreover, the minimum and maximum value of carbon stocks were 145.04 and 152.02 t ha^{-1} respectively in Sita CPF. Besides, they were 55.89 and 60.98 t ha^{-1} respectively in Ramnagar CPF but they were 25.98 and 36.34 t ha^{-1} respectively in

Jogikuti CPF. Here, the confidence levels at 95% were 0.77, 1.58, 0.86, 2.81, 1.67 and 1.93 t ha^{-1} in Banauta, Shreepur, Bisbitty, Sita CPF, Ramnagar and Jogikuti CPFs respectively (table 26).

Table 26: Descriptive statistics of carbon stock in public plantation and community planted forests

PP/PCF	Mean C t ha^{-1}	Std. Error	Std. Deviation	Minimum C t ha^{-1}	Maximum C t ha^{-1}	Confidence level (95.0%)
Banauta	52.29	0.34	1.01	48.25	56.33	0.77
Shreepur	140.32	0.71	2.36	136.69	143.67	1.58
Bisbitty	30.34	0.36	1.03	29.12	31.73	0.86
Sita CPF	148.89	1.09	2.68	145.04	152.02	2.81
Ramnagar CPF	57.80	0.68	1.80	55.89	60.98	1.67
Jogikuti CPF	30.88	0.86	2.87	25.98	36.34	1.93

4.2.4.5 Comparison of Carbon Stock of Same Aged Plantations

The public plantation and community planted forests were afforested in the same year but carbon stocks showed some differences in these areas. Thus, they were statistically tested using the independent samples two tailed t-test statistics to compare the carbon stocks of these plantations. The t-test showed that, there were significant differences in carbon stocks between Banauta public plantation and Jogikuti CPF, Bisbitty PP and Sita CPF as well as Shreepur PP and Ramnagar CPF at 5% level of significance since the p-values were less than 0.05 (table 27).

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There may be many factors behind the carbon stocks variation in plantations but the dominant one was the number of stems ha^{-1}. Specificlly, there was low 2013 stems ha^{-1} in Banauta pulic plantation and 1833 stems ha^{-1} high in Jogikuti CPF; low 1733 stems ha^{-1} in Bisbitty public plantation and 2211 stems ha^{-1} in Sita CPF as well as it was the high 3618 stems ha^{-1} high in Shreepur public plantation and low 1756 stems ha^{-1} in Ramnagar CPF.

Table 27: Comparison of carbon stock between public plantation and community planted forests

PP	CFP	t calculated value	t tabulated value	P(T<=t) two-tail
Banauta PP	Jogikuti CPF	-82.17	2.16	0.00
Bisbitty PP	Sita CPF	-50.2	2.18	0.00
Shreepur PP	Ramnagar CPF	142.49	2.08	0.00

4.3 Carbon Sequestration its Potential

Carbon sequestration potentials is based on the current annual carbon increment (CACI). They were vary according to management of the forests. The value of carbon is determined by the rate of carbon sequestration.

4.3.1 Current Annual Carbon Increment (CACI) in Collaborative and Community Forests

The recorded CACIs were varied in collaborative and community forests. Infact, CACI mainly depends up on the stage of plants. The estimated current annual carbon increment (CACI) was found to be highest (2.85 t ha^{-1}) at second consecutive years in Chyandanda community forest while it was the lowest and negative, -1.18 t ha^{-1} in Banke- Maraha CFM (Table 28) at same consecutive years. The CACIs was 2.30 t ha^{-1} in Chyandanda CF but it decrease in carbon annual i.e. annual carbon loss (ACL) -0.40 in Banke- Maraha CFM respectively at first consecutive years. Generally, the records of CACIs were increased from first consecutive years to second consecutive years for example 0.45 to 0.90 t ha^{-1} in Gadhanta- Bardibash CFM, 1.70 to 2.11 t ha^{-1} in Baudh CF, 1.30 to 1.73 t ha^{-1} in Chure- Parwati CF. However, decreasing trend was noted 0.83 to 0.48 t ha^{-1} in Tuteshwarnath CFM. It was due to the variation in total carbon stocks in first to third year (table 28).

There were increasing trend of total carbon stock in three years. Specific examples of increasing records of carbon stock in year 1, year 2 and year 3 were 222.58, 223.41 and 223.89 t ha^{-1} respectively in Tuteshwarnath CFM and they were 274.67, 275.12 and 276.02 t ha^{-1} in three respective years of Gadhanta- Bardibash CFM. However, the records of carbon stock showed decreasing trend 197.09, 196.69 and 195.51 t ha^{-1} in year 1, year 2 and year 3 respectively in Banke- Maraha CFM. Noticeably, the carbon stocks were highly increased in Chyandanda CF in comparison to others, it was 92.08 t ha^{-1} in 2011, which was reached to 94.38 t ha^{-1} in 2012 and again inclined to 97.23 t ha^{-1} in 2013. Other high increases in carbon stock were 163.95 to 165.65 and to 167.76 t ha^{-1} in 2011, 2012 and 2013 respectively in Baudh CF while they were 172.05 to 173.35 and lastly to 175.08 t ha^{-1} in three mentioned years respectively in Chure- Parwati CF.

Table 28: Current annual carbon increment in collaborative and community forests

CFM/CF	**C stock t ha^{-1}**			**CACI t ha^{-1} (C of yr_2- yr_1)**	**CACI t ha^{-1} (C of yr_3- yr_2)**	**Average t ha^{-1} CACI**
	2011	**2012**	**2013**			
Banke-Maraha CFM	197.09	196.69	195.51	-0.40	-1.18	-0.79
Tuteshwarnath CFM	222.58	223.41	223.89	0.83	0.48	0.65
Gadhanta- Bardibash CFM	274.67	275.12	276.02	0.45	0.90	0.68
Baudh CF	163.95	165.65	167.76	1.70	2.11	1.90
Chure-Parwati CF	172.05	173.35	175.08	1.30	1.73	1.51
Chyandanda CF	92.08	94.38	97.23	2.30	2.85	2.58

The records of CACIs were generally increased from first year to next consecutive years such as in Gadhanta- Bardibash CFM, Baudh CF, Chure- Parwati CF but it showed decreasing trend in Tuteshwarnath CFM. Though there are many factors affecting on variation in current annual carbon increment in these forests, the main reliable reasons were harvesting and illegal logging, stage and age of the available trees in the forests and applied silvicultural practices. Generally, the user groups of community forests have been practicing the silvicultural operation according to the operational plan. The other reason of the highest CACI in Chyandanda community forest was because of the dominance of growing staged plants especially pole and sapling sized stems in comparison to other forests. Thus there were high CACIs in community forests. It is remarkable fact that, the variations in CACIs in community forests were high mainly due to harvesting and thinning activities. However the forest management schemes were not completely followed by the management unit of collaborative forests. There is no practice of thinning and harvesting operations in these collaborative forests. Indeed, the collaborative forest management unit only collects dead fallen trees and logs and it does not harvest even the mature and overmature green trees. So there were low CACIs in collaborative forests. In reality, some permanent sample plots were also disturbed due to illegal felling, fire and grazing in Banke- Maraha CFM. In case of Tuteshwar nath CFM, there was high logging effect than in Gadhanta- Bardibash CFM.

Some studies done on CACIs in Nepal are showing similar results. Remarkably, the study done by Tewari & Karky (2007) showed that CACI in natural *Shorea robusta* forest of Ilam district, Nepal was 3.1 t ha^{-1} which was near to the CACI at second consecutive year of Chyandanda CF. In addition, in same study but at different site, the CACI of CF of Lalitpur district was 1.41 t ha^{-1} (Tewari & Karky, 2007), which was closely matching with CACI of Chure- Parwati CF at first consecutive year. Similar study done by Adhikari (2010) estimated the CACI was 2.21 t ha^{-1} in Bhaiyadevi CF (Adhikari, 2010), which value was near to the CACI at first consecutive year of Chyandanda CF. The study done by Tewari & Karky (2007) showed that there was increasing trend of carbon stock from first year to third year. The above ground carbon stock was 57.94 t ha^{-1} in first year, which was increased to 60.75 t ha^{-1} in second year and then it gradually reached to 64.13 t ha^{-1} in third year in CF of Ilam district while in case of Lamatar CF, Lalitpur district, recorded carbon stocks were 51.19, 52.32 and 54.00 t ha^{-1} in year 1, 2 and 3 respectively. Similar trends were found in carbon stock of CF of Manang too, it was 30.94 in year 1 and reached to 33.19 in year 3 (Tewari & Karky, 2007). Since the carbon stock of year 3 was 128.25 t ha^{-1} of CF of Lamatar, this record is close to the record of carbon stock of third year of Chyandanda CF. The reason of these values may be due to the age and diameter distribution of the stems, density of stem ha^{-1}, species and application and practice of silvicultural system (Prakash, 2001).

4.3.2 Cureent Annual Carbon Increment in Public Plantations and Community Planted Forests

The CACIs of plantation areas were generally showing increasing trend. However, there was exceptional record in Bisbitty PP where the CACIs were 3.87 and 3.57 t ha^{-1} in between 2011 to 2012 and 2012 to 2013 and average CACI was 3.72 t ha^{-1} since the carbon stocks in this plantation were 30.34, 34.21 and 37.78 t ha^{-1} in year 2011, 2012 and 2013 respectively (table 29). Here, the reason of decreasing CACIs in Bisbitty PP was due to removal of sapling from permanent sample plots. Meanwhile, the estimated highest average of CACI was 5.41 t ha^{-1} in Shreepur PP, hence the estimated CACIs were 4.25 t ha^{-1} between 2011 to 2012 and higher 6.56 t ha^{-1} between 2012 to 2013 since the carbon stocks were 140.32, 144.57 and 151.13 t ha^{-1} in year 2011, 2012 and 2013 respectively. Likewise, the records of CACIs highly increased from 3.71 to 6.00 t ha^{-1} in Banauta PP between 2011 to 2012 and 2012 to

2013, so the average CACI was 4.86 t ha^{-1} because the carbon stocks were 52.29, 56.00 and 62.00 t ha^{-1} in year 2011, 2012 and 2013 respectively (table 29). The reason of such increasing trends of CACIs was mainly due to the presence of growing staged plants specially sapling and pole. generally, the plants have high growth in early stage like sapling and pole (young) but they have less when they get maturity this is the main reason of high growth rate in plantation (Prakash, 2001).

Similar trends of CACIs were found in all community planted forests too. They were the highest 2.00 to 4.00 t ha^{-1} in year 2012 - 2011 and 2013 - 2012 respectively in Sita CPF and the average CACI was 3.00 t ha^{-1} since the carbon stocks were 148.89, 150.89 and 154.89 t ha^{-1} respectively (table 29). Though there were increasing trends of CACI also in other CPFs, they were increased slowly than others. Here, the records of CACIs were only 1.02 to 2.33 t ha^{-1} between 2011 to 2012 and 2012 to 2013 correspondingly in Ramnagar CPF and hence the average CACI was 1.68 because the carbon stocks were 57.8, 58.82 and 61.15 t ha^{-1} in 2011, 2012 and 2013 correspondingly. Little higher increased CACIs were recorded from 1.23 to 2.23 t ha^{-1} between 2011 to 2012 and 2012 to 2013 respectively in Jogikuti CPF and therefore average CACI was 1.73 since the carbon stocks were 30.88, 32.11 and 34.34 t ha^{-1} in 2011, 2012 and 2013 respectively.

Actually, the estimated average current annual carbon increment (CACI) was found to be highest in Shreepur public plantation, whereas it was recorded lowest in Ramnagar community planted forest (table 29). The users of Shreepur PP have been practiced agro-forestry and silviculture practices, which comprise the regular weeding and cleaning operations together but user group of Ramnagar community planted forest have not implemented any types of silvicultural practices at all, so the estimated CACI was the highest in previous one and lowest in latter one. Additionally, the CACI also depends up on the age of plant, density of stems, size of the plants, site quality, aboveground input received from leaf litter, decomposition of fine roots below ground, management practices and other ecological factors (Magar, 2009). In this context, forest professionals advocated that forest management activities have great potential effect on above and below ground carbon stock dynamics (Powere *et al.*, 2012).

Table 29: Current Annual Carbon Increment (t ha^{-1}) in plantations

Plantation types	2011 C t ha^{-1}	2012 C t ha^{-1}	2013 C t ha^{-1}	CACI t ha^{-1} (C of yr_2- yr_1)	CACI t ha^{-1} (C of yr_3- yr_2)	Average t ha^{-1} annual C increase
Shreepur PP	140.32	144.57	151.13	4.25	6.56	5.41
Banauta PP	52.29	56	62	3.71	6	4.86
Bisbitty PP	30.34	34.21	37.78	3.87	3.57	3.72
Sita CPF	148.89	150.89	154.89	2	4	3
Ramnagar CPF	57.8	58.82	61.15	1.02	2.33	1.68
Jogikuti CPF	30.88	32.11	34.34	1.23	2.23	1.73

Indeed, no any study was done regarding the CACI in *Eucalyptus camaldulensis* in Nepal but Amatya & Shrestha (2002) observed that the yield table of Sagarnath plantation showed differences in carbon stocks of two consecutive years (year 7 and year 6) up to 4.4 t ha^{-1} (Amatya & Shresth, 2002), which is close to the present finding of average current annual increment of Banauta public plantation. Meanwhile,) biomass table by Tamrakar (2000) showed that, the change of two consecutive years (year 7 and year 6) in carbon stock was 5.78 t ha^{-1} (Tamrakar, 2000), which was almost similar to the CACI of Shreepur public plantation.

The reason behind the variation of carbon stock in plantation areas were interest and need of forest and forest products and their availability for the users. Here, the estimated CACIs in public plantation were very high than those of community planted forests. In this circumstance, the users of public plantation are poor and marginalized households and they have no land to create the forest except the public plantation. Additionaly, they had no any private forest or plantation before. Apart from this, the public plantation also provides the opportunity for user to implement the agro-forestry practices, which are favorable for growth of the plantation. Indeed, where the resources are scarce, their value is very high. In reality, the users of public plantation have managed and adapted well silviculture practice because they have lacking of forest and forest product; they have hope either to use these forest products for building their houses or sell them to generate income. Therefore, they are highly motivated and managing these plantations effectively and sincerely. Nevertheless, users of community planted forest have natural forest and high valuable *Shorea robusta* nearby in their community forests, they are not feeling any shortage of forest and forest products and thus they are less interested and motivated than the users of public plantation for management of plantations. This is the main reason for enthusiasm about the public plantation and applying the operations effectively, which helps for high growth or CACIs in public plantation than community planted forests.

On the other hand, common pools (lands) specifically owned by village development committee, school, college and other institutions are highly potential for public plantations. This is novelty work because common pool is managed by the landless and forestless people to meet their demand of forest products. Other most important significance of the public plantation is the management of common land as plantation, which can guarantee the security of such lands to misuse because there is a great threat to capture of common land generally by the elite in the village. If these lands are managed under the two institutions like public plantation user and owners of institutions such as school or VDC, then there will be less chance of illegal capture of these common lands. This idea is also supported by Karna in his Ph.D. thesis, he emphasized that common property is every body's property but it is nobody property too (Karna, 2008), it is align with the principle of tragedy of commons mentioned by Hardin (1968). So, the collective action theory is working to manage the common pools as plantation. Moreover, this is also potential for forest carbon credit under REDD+ programme and environmental services like protection from river slides, avenues for eco-tourism and biodiversity conservation.

4.3.3 Carbon Sequestration Status in Community and Collaborative Forests

The literal meaning of carbon sequestration is the process of annual removal of CO_2 from the atmosphere sinking it into plants or forests and soil. It is remarkable fact that, the higher the CACIs, the higher is the carbon sequestration and vice versa. So, carbon sequestration also varied in the community managed forests. It differs in natural forests like collaborative and community forests and in plantations as well such as public plantations and community plantation due to different management practices.

The carbon sequestration was varied according to the effective areas and rate of removal of CO_2 t ha^{-1} in collaborative and community forests. In totality, the estimated overall carbon sequestration was 3915.82 t. In this circumstance, the carbon sequestrations in collaborative and community forest showed the reduction of CO_2 from atmosphere annually. Comparatively, the carbon sequestration rates were higher in community forests which were 6.98, 5.56 and 9.45 t ha^{-1} in Baudh, Chure- Parwati and Chyandanda CFs respectively than that of collaborative forests. Basically, the total carbon sequestrations were 385.44, 2338.96 and 275.93 in Baudh, Chure-Parwati and Chyandanda CFs respectively (table 30). The rationale of the higher carbon sequestration in the community forests was primarily due to the under stocking such as less number or lacking of large sized trees (DBH> 30 cm). because there was high competition of large sized crown trees for light and food. On the other hand, there were high rate of carbon sequestration in all community forests because of the under stocking and low competition of small sized crown. The higher carbon sequestration in young aged forests is due to low competition of light (Yadav, 2008).

However, there were lower carbon sequestration 2.40 t ha^{-1} in Tuteshwarnath CFM and 2.48 t ha^{-1} in Gadhanta- Bardibash CFM. Nevertheless, there was larger area of forest and more carbon sequestration rate of Gadhanta- Bardibash CFM than Tuteshwarnath and CFM, therefore, total carbon sequestration was 3056.19 t of former CFM but it was 2934.47 t of the latter CFM. Exceptionally, there was emission too from Banke- Maraha CFM, where there was -2.90 t ha^{-1} CO_2 emission and the total recorded CO_2 emission was -5075.17 t, if the whole study area is assumed as one subnational REDD+ research project (table 30). The reason behind the low carbon sequestration in the collaborative forests was mainly due to the over stocking of large sized trees (DBH> 30 cm) because there was high competition of large sized crown trees for light and food. On the other hand, there were high rate of carbon sequestration in all community forests because of the under stocking and low competition of small sized crown.

Table 30: Carbon sequestration in collaborative and community forests

CFM/CF	Effective area ha*	Carbon sequestration t ha^{-1}	Total carbon sequestration t	Remark
Banke-Maraha CFM	1750	-2.90	-5075.17	Leakage
Tuteshwarnath CFM	1221	2.40	2934.47	
Gadhanta-Bardibash CFM	1231	2.48	3056.19	
Baudh CF	55.22	6.98	385.44	
Chure-Parwati CF	421	5.56	2338.96	
Chyandanda CF	29.21	9.45	275.93	
Total			3915.82	

*Note: effective areas of these forests are net area of the forest deducting open areas, roded area, river and river bed from total forest area and calculation done based on this.

The variation of carbon sequestration was recorded in community and collaborative forests because of differences in CACIs. Supportively, the study done by Yadav (2008) showed that annual carbon sequestration rate was about 2.2 t ha^{-1} in community forest having dominance of *Shorea robusta*, this record was about matching with rate of carbon sequestration of Tuteshwarnath and Gadhanta-Bardibash CFMs. Similar study done by Karky & Baskota (2009) revealed that the estimated annual carbon sequestration was 11.37 t ha^{-1} in *Shorea robusta* forest in CF of Ilam district (Karky & Baskota, 2009) which was almost to the carbon sequestration rate of Chyandanda CF.

The REDD+ pilot project done in three watersheds of Chitwan, Gorkha and Dolkha shown that, many enhancement activities were carried out for carbon increment (Bhattrai *et al.*, 2011). One of the important activities was the promotion of alternative energy for users of community forest despite of use of firewood. Total carbon increment was 27391.6 t, which is equivalent to sequestrate 100435.8 t carbons in the community forests of these watersheds. The annual rate of carbon sequestration ranged from 1.32 to 5.31 t ha^{-1} in these watersheds (Bhattrai *et al.*, 2011). The upper most of carbon sequestration in community forests of these watersheds was matching with the carbon sequestration rate of Chure- Parwati CF.

Noany study has done yet on leakage in Nepal. The lakage was observed in Banke-Maraha CFM. The Hardin's article in science (Hardin, 1968), about "the tragedy of the commons" is fit here in different way. Indeed, community forest users living vicinity of this collaborative forest intentinally and illegally collect and meet their vested interest of the forest products from the collaborative. In reality, the forest resources as commons of the collaborative forests has been illegally used by the most of the community forest users to meet their demand, to trade and damage them but they conserve their community forests. Circumstance is, they have proud to conserve their commons in community forest for what? Have they tragedy to destruct the commons? The answer has double standard, yes to conserve the commons of community forest but no for destruction of collaborative forests. Then, is it tragedy or joy of commons? The hidden fact is tragedy of commons of community forest but not of the collaborative forest. The complexity is, they destroy the commons of the collaborative forest to reach the destination because they believe in the freedom to use the commons. The questions touch our mind and hurt the real nature and environment lover. Is it fair to destroy the commons to conserve the commons? Is there difference in commons of collaborative forest and community forests? The balance answer is, there is no different. Then, the judgement is not fair. The scientist believe, everyone thinks chiefly of his own, hardly at all of the common interest" (Olson, 1965).

4.3.4 Carbon Sequestration Status in Public Plantations and Community Planted Forests

The estimated carbon sequestration was found to be higher in planted forests than in natural forests. It was the highest carbon sequestration 19.82 t ha^{-1} in Shreepur public plantation while it was the lowest only 4.60 t ha^{-1} in Ramnagar CPF among these planted forests (table 31). Reasonably, the users of public plantation were more active to participate in implementation of public plantation operational plan, which was not found in community planted forest except in Sita CPF. The operational plan of public plantation has main focus on practice of silvicultural operations and agroforestry. Over all carbon sequestration was 504.85 t in both public plantation and community planted forests (table 31). In reality, the carbon sequestration depends up on the CACI. The records of the CACI was highest in Shreepur public plantation while it was the lowest in Ramnagar CPF. The total estimated carbon sequestration was 176.38 t in Shreepur PP. In the same trend, the other higher records of carbon sequestration were found 17.80, 13.64 and 11.00 annually in Banauta PP, Bisbitty PP and Sita CPF respectively, so the total carbon sequestration were 131.73, 85.93 and 47.52 in these plantations correspondingly. However, low record of carbon sequestration was found 6.34 t ha^{-1} in Jogikuti CPF so the total carbon sequestration was found 46.22. Lastly, the total carbon sequestration was 17.07 t, which was the lowest in Ramnagar CPF (table 31). Presumably, the carbon sequestration depends up on the CACI (Dutta *et al.*, 2011), the records of the CACIs and areas of the plantation were varied so the estimated carbon sequestration was also varied.

No any study was done in CACI of *Eucalyptus camaldulensis* in Nepal, but the yield table of Sagarnath plantation showed that differences in carbon stocks of two consecutive years (year 7 and year 6) was found 4.4 t ha^{-1} which is equivalent to 16.13 t carbon sequestration (Amatya & Shresth, 2002) and this is closely matching to the present result of average carbon sequestration of Banauta public plantation. Other study done by Dutta *et al.* (2011) showed that annual carbon sequestration was about

4.2 t ha^{-1} in Newardanda Kamidanda community forest (Dutta *et al.*, 2011) especially in 14-year *Eucalyptus camaldulensis* plantation which value is likely to match with the value of Jogikuti CPF.

Table 31: Carbon sequestration in public plantation and community planted forests

Plantation types	Effective area ha	Carbon sequestration (t ha^{-1})	Total Carbon sequestration (t)
Shreepur PP	10.5	19.82	176.38
Banauta PP	8.8	17.80	131.73
Bisbitty PP	7.6	13.64	85.93
Sita CPF	5.42	11.00	47.52
Ramnagar CPF	4.92	4.60	17.07
Jogikuti CPF	8.60	6.34	46.22
Total			504.85

4.3.5 Carbon Sequestration Potential in Collaborative and Community Forests

Total cumulative carbon sequestration projected according to year after years. The estimated cumulative carbon sequestration varied in every year. For instance, the estimated cumulative carbon sequestration potential in collaborative and community forests may be 7821.02 t for 2 years, 11731.5 t for 3 years, 15642 t for 4 years, 19552.6 t for 5 years and 39105.1 t for 10 years (table 32).

Table 32: Cumulative carbon sequestration potential in collaborative and community forests

CFM/CF	Cumulative carbon sequestration potential t					
	2 years	3 years	4 years	5 years	10 years	Remark
Banke-Maraha CFM	-10150	-15225	-20300	-25375	-50750	Leakage
Tuteshwarnath CFM	5860.8	8791.2	11721.6	14652	29304	
Gadhanta- Bardibash CFM	6105.76	9158.64	12211.52	15264.4	30528.8	
Baudh CF	770.8712	1156.307	1541.742	1927.178	3854.356	
Chure-Parwati CF	4681.52	7022.28	9363.04	11703.8	23407.6	
Chyandanda CF	552.069	828.1035	1104.138	1380.173	2760.345	
Total	7821.02	11731.5	15642	19552.6	39105.1	

Similarly, the projection of carbon sequestration for plantations also showed different. Here, the estimated cumulative carbon sequestration potentials in public plantation and community planted forests could be 1210.38 t for 2 years, 1815.57 t for 3 years, 2420.76 t for 4 years, 3025.95 t for 5 years and 6051.9 t for 10 years (table 33).

Table 33: Cumulative carbon sequestration potential

Plantations	Cumulative Carbon sequestration potential (t)				
	2 years	**3 years**	**4 years**	**5 years**	**10 years**
Shreepur PP	416.22	624.33	832.44	1040.55	2081.1
Banauta PP	313.28	469.92	626.56	783.20	1566.4
Bisbitty PP	207.33	310.99	414.66	518.32	1036.64
Sita CPF	119.24	178.86	238.48	298.10	596.2
Ramnagar CPF	45.26	67.89	90.53	113.16	226.32
Jogikuti CPF	109.05	163.57	218.09	272.62	545.24
Total	1210.38	1815.57	2420.76	3025.95	6051.9

The carbon sequestration may not be same for every year and each forests and plantation since several factors such as stage of plant, favorable site, species growth characteristics and other competing factors affect the carbon sequestration (Janssens *et al.*, 2003). Thus the carbon sequestration potential may be differed. The carbon sequestration potential was reported 183736.5, 257890.4 and 60552.25 for 5 years and 367473, 515780.8 and 121104.5 for 10 years from Ludikhola watershed, Gorkha, Charnabati watershed from Dolkha and Kayarkhola watershed from Chitwan respectively (Bhattrai *et al.*, 2011).

4.3.6 Monetary Value of Carbon Sequestration and its Eligibility for Carbon Trade

The carbon stock change was calculated estimating differences in carbon stocks of two consecutive years. Then, the carbon stock change was converted into removal of CO_2 or carbon sequestration, which was estimated using the multiplying conversion factor 44/12. The carbon sequestration potential was calculated for 2 years, 3 years, 4 years, 5 years and 10 years multiplying with 2,3,4,5 and 10 respectively. Later the monetary value of carbon sequestration potential was estimated by multiplying with the rate of US$ 5 CO_2 t^{-1} (Molly *et al.*, 2012). At the same time, the management and protection cost of these forests was considered as US$ 3 ha^{-1} (Karky & Baskota, 2009). Next, the protection and management cost was deducted from total monetary value of carbon sequestration.

The result showed that, the total monetary value of carbon sequestration in natural forests and plantation was US$ 5967.62. Out of this, estimated monetary value of carbon sequestration in the community and collaborative forest deducting the emission due to leakage from Banke- Maraha collaborative forest was US$ 3580.85 whereas the estimated value of carbon sequestration in public plantation and community planted forest was US$ 2386.77. Thus, the estimated values of carbon sequestration ha^{-1} were found higher US$ 83.99 and 74.85 of Shreepur PP and Banauta PP respectively. Meanwhile, the medium values of carbon sequestration ha^{-1} were US$ 33.37, 43.84 and 56.53 of Chyandanda CF, Sita CPF and Bisbity PP respectively. On the other hand, the lower values of carbon sequestration ha^{-1} were recorded US$ 27.64, 26.87 and 26.48 of Baudh CF, Jogikuti CPF and Chure- Parwati CF respectively. Same way, the very lower values of carbon sequestration ha^{-1} were recorded US$ 17.34, 11.00 and 10.54 of Ramnagar CPF, Tuteshwarnath CFM and Gadhanta- Bardibash CFM respectively while the lowest and it means emission as leakage and negative value was recorded US$ -12.64 of Banke- Maraha CFM.

The CACI, carbon sequestration and its monetary value are interrelated to each other. In this circumstance, since there was negative value that is carbon emission by Banke- Maraha CFM. This is the indication of negative monetary valuation from emission by Banke- Maraha CFM. However, there was higher rate of carbon sequestration ha^{-1} of Shreepur PP, thus the monetary value of this was the US$ 83.99 ha^{-1}. In addition, other higher rate of carbon sequestration ha^{-1} were of Banauta PP, Bisbitty PP and Sita CPF hence, the monetary values were higher US $ 74.85, 56.53 and 43.84 respectively while they were lower carbon sequestration ha^{-1} of Chyandanda CF, Baudh CF, Jogikuti CPF and Chure- Parwati CF, hence the monetary values were US$ 33.37, 27.64, 26.87 and 26.48 respectively. Same way, the very low carbon sequestrations ha^{-1} were recorded at Ramnagar CPF, Tuteshwarnath CFM and Gadhanta- Bardibash CFM, so the values were recorded US$ 17.34, 11.00 and 10.54 respectively. In contrary, since the emission was recorded from Banke- Maraha CFM, the monetary value of leakage ha^{-1} may be US$ -12.64 (table 34).

Table 34: Valuation of carbon sequestration

Management types of forests	Protection & Management cost (US $)	Value of carbon sequestration in US$ Per ha value	Total value	Net value	Remark
Gadhanta- Bardibash CFM	4350	10.54	15280.95	10930.95	
Tuteshwarnath CFM	4002	11.00	14672.35	10670.35	
Banke-Maraha CFM	6018	-12.64	-25345.83	-31363.83	Leakage
Baudh CF	209.19	27.64	1927.21	1718.02	
Chure-Parwati CF	1325.1	26.48	11694.82	10369.72	
Chyandanda CF	124.05	33.37	1379.69	1255.64	
Shreepur PP	31.5	83.99	881.92	850.42	
Banauta PP	26.4	74.85	658.66	632.26	
Bisbitty PP	22.8	56.53	429.66	406.86	
Sita CPF	16.26	43.84	237.6	221.34	
Ramnagar CPF	14.76	17.34	85.33	70.57	
Jogikuti CPF	25.8	26.87	231.12	205.32	
Total				5967.62	

Source: (Khatri *et al.*, 2013)

Some studies regarding valuation of carbon sequestration were showed variation in monetary values. The study done by Tewari (2007) showed that the mean annual carbon sequestration rate of some community forests of Uttranchal, India of 13.57 t ha^{-1} and hence the estimated monetary value of this would be US$ 162.84 at the rate of US$ 12 per tonne CO_2, and US$ 67.85 CO_2 ha^{-1} yr^{-1}, even if the prices were as low as US$ 5 per tonne of carbon (Tewari & Karky, 2007), which is close to the monetary value of carbon sequestration of Banauta PP and Bisbitty PP. The value of annual carbon sequestration varied according to the forest condition. It was higher in planted forest than natural forest, if the conditions like site and climatic factors are same (Prakash, 2001).

Some more studies have similar values of carbon sequestration. The carbon sequestration of Kairkhola watershed of Chitwan showed the worth US$ 9.2 ha^{-1}, this value of carbon sequestration ha^{-1} was close to the monetary values of carbon sequestration ha^{-1} of Gadhanta- Bardibash CFM and Tuteshwarnath CFM (table 34). The reason behind it may be due to both Chitwan and Mahottari lie in Tarai, having same geographical region. Moreover, the piloting done by ICIMOD, ANSAB and FECOFUN, Nepal reported that, monetary value of carbon sequestration ha^{-1} were US$ 7.59 and 14.60 ha^{-1} of Charnawati watershed Dolkha and Lundikhola watershed

Gorkha respectively (Bhattarai *et al.*, 2011). Similarly, the value of carbon sequestration ha^{-1} in Ramnagar CPF is quite close to the monetary value of carbon sequestration ha^{-1} of Lundikhola watershed, Gorkha district. The similarity may be due to poor site quality of Ramnagar CPF and that of Lundikhola watershed.

The lower the carbon sequestration, the lower is the monetary value (Tewari *et al.*, 2007). In this context, the study about the estimation of monetary value of carbon sequestration of Lamatar CF, Lalitpur district showed about US$ 25.85 ha^{-1} yr^{-1} at the rate $5/tonne per year (Banskota *et al.*, 2007). Other exciting news was about the cheques worth US$ 44,188, US$ 26,122, and US$ 24,691 handed over to REDD+ networks of the Chanarwati watershed (Dolakha district), Ludhikhola watershed (Gorkha district), and Kayerkhola watershed (Chitwan district) respectively as REDD+ seed grant in the distribution ceremony, Kathmandu, Nepal, which was held on 18 July 2012 (ICIMOD, 2012). These seed grants ended up in the hands of 105 community forest user groups (CFUGs) from the three watersheds. This was the demonstration of carbon payments for contributions to sustainable conservation and management of forests as a part of Norwegian Agency for Development Cooperation (NORAD) funded pilot REDD+ project which began in 2010 (Khatri *et al*., 2013).

4.3.7 Monetary Value of Carbon Sequestration Potential

The expected cumulative monetary net value may be differed every year. However, if all the factors are assumed to be constant, the potential cumulative net value of carbon sequestration potential in collaborative and community forests may be US $ 29690.24 for 2 years, US $ 44535.36 for 3 years, US $ 59380.48 for 4 years, US $ 74225.6 for 5 years and US $ 148451.2 for 10 years (table 35).

Similarly the expected cumulative monetary net value of carbon sequestration potential may also be differed in public and community planted forests for every year. Here, the cumulative net value may be US$ 3362.96 for 2 years, US$ 8940.33 for 3 years, US$ 11920.44 for 4 years, US$ 14900.55 for 5 years and US$ 29801.1 for 10 years as shown in table 36.

Table 35: Expected cumulative monetary net values of carbon sequestration potential in collaborative and community forests

CFM/CF	Cumulative Expected Monetary Value (US $)					Remark
	2years	3years	4 years	5 years	10 years	
Banke-Maraha CFM	-50750	-76125	-101500	-126875	-253750	Leakage
Tuteshwarnath CFM	29304	43956	58608	73260	146520	
Gadhanta- Bardibash CFM	30528.8	45793.2	61057.6	76322	152644	
Baudh CF	3854.36	5781.53	7708.71	9635.89	19271.8	
Chure Parwati CF	23407.6	35111.4	46815.2	58519	117038	
Chyandanda CF	2760.35	4140.52	5520.69	6900.86	13801.7	
Total	39105.1	58657.7	78210.2	97762.8	195526	
Protection & Management cost	9414.86	14122.29	18829.72	23537.15	47074.3	
Net Value	29690.24	44535.36	59380.48	74225.6	148451.2	

There may be different value of carbon sequestration potential since it depends mainly on annual rate of carbon sequestration (Bhattrai *et al.*, 2011). Remarkably, it is exciting information for carbon trade in Nepal since she is potential to bring upto US$ 60 million from carbon fund under the forest carbon partnership facility as the Emission Reduction Plan Idea Note (ER-PIN) got permission to work for REDD+ demonstration activities from REDD+ programme under the World Bank for emission reduction from the forests of Rautahat to Kanchanpur district between 2015 to 2020 (Koirala *et al.*, 2014).

Other news published in Kantipur highlighted that Nepal won the proposal of US$ 60 million for implementation of ER-PIN (Koirala, 2014). Based on this ER-PIN, the emission reduction package will be developed soon which includes the country's REDD+ progress, captures lessons learned, assesses remaining gaps and identifies activities for the way forward to the implementation of performance based activities.

Table 36: Cumulative Expected Monetary Value of Plantations

Plantations	Cumulative Expected Monetary Value (US $)				
	2 years	3 years	4 years	5 years	10 years
Shreepur PP	2081.1	3121.65	4162.2	5202.75	10405.5
Banauta PP	1566.4	2349.6	3132.8	3916	7832
Bisbitty PP	1036.64	1554.96	2073.28	2591.6	5183.2
Sita CPF	596.2	894.3	1192.4	1490.5	2981
Ramnagar CPF	226.32	339.48	452.64	565.8	1131.6
Jogikuti CPF	545.24	817.86	1090.48	1363.1	2726.2
Total	6051.9	9077.85	12103.8	15129.8	30259.5
Protection & Management Cost	9414.86	137.52	183.36	229.2	458.4
Net Value	3362.96	8940.33	11920.44	14900.55	29801.1

In addition, the report of piloting showed that, the expected monetary value of carbon sequestration ha^{-1} were US$ 7.59 and 14.60 ha^{-1} in 5 years and in years of Charnawati watershed Dolkha and Lundikhola watershed Gorkha respectively (Bhattarai *et al.*, 2011).

4.3.8 Criteria for Carbon Trade

Nepal has proposed the hybrid approach. It is the policy will be developed by national REDD+ project and Implementation and preparation will be done by sub-national level, it may be regional level. Thus, the sub-national REDD+ project may be eligible candidate for carbon trading. However, the issues of additionality, development of the reference emission level (baseline), designing the monitoring reporting and verification system (MRV), assurance of social and environmental standard and permanency and leakage should be clearly defined for eligible under the REDD+ programme.

It needs to meet the certain set of criteria to determine the opportunity of the forest carbon trade under the REDD+ programme. They are additionality and monetary value of carbon sequestration and its potential, reference emission level, social and environmental standard, permanency, MRV system and supporting institution and scope of expansion.

Additionality: The certified emissions reduction (CER) proves that emissions reduce from deforestation and forest degradation through performance based positive stock change is additionality. Here, the present study adds the value in opportunity of forest carbon trade under REDD+ in Nepal. Infact, increasing carbon sequestration rate, scope of expansion and other technical back up can assure the additionality, which offers the opportunity of forest carbon trade. Apart from these, the additionality is also related to the value of the carbon sequestration.

The additionality was differed in collaborative and community forests. Infact, the record showed that the average additionality of CO_2 was about 2.38 t ha^{-1} in Tuteshwarnath CFM and 2.49 CO_2 t ha^{-1} in Gadhanta-Bardibash CFM. The estimated average additionality of CO_2 was about 9.46 t ha^{-1} in Chyandanda CF (Table 37). The carbon stock change is considered as the current annual carbon increment. This is base to calculate the carbon sequestration rate which is the additionality on the base line. The estimated CO_2 additionality was the highest 9.46 t ha^{-1} in Chyandanda CF but it was the lowest about in Tuteshwarnath CFM. The current annual carbon increment is the main responsible for CO_2 additionality. The CACI was the highest in CO_2 additionality and lowest in Tuteshwarnath CFM so the additionality was (table 37).

Table 37: CO_2 Additionality in CFMs and CFs

CFM and CF	CO_2 Additionality t ha^{-1}			Remarks
	Years (2011 to 2012)	Years (2012 to 2013)	Average	
Tuteshwarnath CFM	3.04	1.76	2.38	There was leakage in Banke-Maraha CFM
Gadhanta-Bardibash CFM	1.65	3.30	2.49	
Baudh CF	6.23	7.74	6.97	
Chure- Parwati CF	4.77	6.34	5.54	
Chyandanda CF	8.43	10.45	9.46	

The variation of CO_2 was also recorded in public and community planted forests between 2011 and 2013. They showed the additinality in the forest. Specifically, the estimated average CO_2 was the highest about 19.84 t ha^{-1} in Shreepur and lowest 6.16 t ha^{-1} in Ramnagar CPF (table 38).

Some studies showed that the CO_2 additinality in different types of Vanpanchyat in Uttrakhand, India. The records based on three years showed that, the estimated average CO_2 additinality were 12.47, 15.22 and 8.07 t ha^{-1} in Even-aged Banj oak forest, dense mixed Banj oak forest and mixed Banj oak chirpine degraded respectively in Dhaili VP forest (Tewari and Karky, 2007). The CO_2 additionality in mixed Banj oak Chirpine degraded forest was close to the additionality of Chyandanda CF. The same stocks density per ha may be one of the important reason to match this value.

Table 38: CO_2 additionality in Public plantations and Community Planted Forests

Public plantation & Community planted forests	CO_2 additionality t ha^{-1}		
	Years (2011 to 2012)	Years (2012 to 2013)	Average Additionality
Shreepur PP	15.58	24.05	19.84
Banauta PP	13.60	22.00	17.82
Bisbitty PP	14.19	13.09	13.64
Sita CPF	7.33	14.67	11.00
Ramnagar CPF	3.74	8.54	6.16
Jogikuti CPF	4.51	8.18	6.34

The study done by same author in different sites showed that the CO_2 additionality was 14.85, 11.18 and 15.58 t ha^{-1} in young Banj oak with Chirpine forest, Chirpine forest with bushy Banj oak and young pure Chirine forests respectively in Toli Vanpanchayat (Tewari and Karky, 2007). The additionality value of in young pure Chirpine forests was quite close to the mean CO_2 additionality of Bisbitty public plantation. The reliable reason may be the similar growth rate in the forest.

The CO_2 additionality was also estimated in public and community planted forests between 2011 and 2013. Specifically, the estimated average CO_2 additinality was the lowest 6.16 t ha^{-1} in Ramnagar CPF and the highest about 19.84 t ha^{-1} in Shreepur public plantation. The reason may be the good soil and high stock density in Shreepur public plantation in comparison to others.

Emission Level (*Baseline*)*:* It is specified emission of a specific year from where, the country commit to reduce the emission. The past reports showed that, there were some records of growing stock and biomass for instance the master plan for forestry sector (HMGN/ ADB/FINIDA 1988) also emphasizes on the record of the biomass. In this perspective, available analysis of forest based on satellite image (2000) of Tarai area, the records of the present and other studies may be helpful to develop the relevant reference emission level. In reality, the government of Nepal has not fixed the base year for REDD+ programme yet but the general discussion indicated that around 1990 may be suitable reference year (MoFSC, 2010b) for hill area and this was between 2000 to 2005 in Tarai. The other provision of reference emission level showed that these should be connected to the national level REDD+ programme through the hybrid approach.

Monitoring Reporting and Verification: The MRV should be scientific and sound. Designing the sub-national level REDD+ project including such research can support to develop the MRV system. Importantly, the ground based permanent sample plots, availability of satellite image and annual record of carbon stock will be able to assure to design the sound and scientific MRV. However, the users emphasize on the affordable, cost effective and user-friendly MRV system.

Social and Environmental Standard: Other important parameter to link with the REDD+ programme is application of social and environmental standard. Actually, there are eight principles and several criteria set to carry out the REDD+ SES pilot in Nepal. Though this pilot is not started yet in here, some practices of social inclusion, gender equity and equality, good governance etc have been carried out in community managed forests as social safeguards. In addition, the Environmental Impact Assessment (EIA) and Initial Environmental Examination (IEE) are in practice as safeguards for application of environmental standards. The REDD+ programme is functioning here with the regular support of the World Bank. So the country is respecting and applying the basic environmental and social principles of the World Bank too.

Permanency: The permanency is still under discussion for REDD+ programme. Generally, 30 years fixed or 60 years period for 2 additional period, each for 20 years like clean development mechanism is proposed for REDD+ too. Regarding this, it can be possible only for natural forest, slow growing species and long rotation plantation. It is not suitable for short rotation plants and fast growing species like *Eucalyptus camaldulensis*, which has only 7 years rotation and other 2 more consecutive 7-year rotations from coppice system. In totality, it takes altogether 21 years to complete the plantation cycle. So, collaborative and community forests can easily fit in this framework while some more modification will be needed for plantation project to be eligible for carbon credit.

Supporting Institution and Criteria for Payment: Specially in Mahottari district, the collaborative forest district network, federation of community forest users, Nepal (FECOFUN) district level institution, Association of Tarai public forest user-Nepal (APLFUN) district level institution have been working for protection and management of the forests. These institutions may be supportive for carbon trading too under the REDD+ programme. Besides these, there are institutions of REDD+ network in Dolkha, Gorkha and Chitwan which may be model to develop the network to other areas extension of REDD+ programme.

Notably, the pilot work was done by ICIMOD set the payment criteria like 40 % for forest carbon status and enhancement; 25% for ethnic diversity; 15% for sex ratio, and 20% for poor household. This was organized by the REDD+ network which is still in function. These institutions may be candidate to establish the network with REDD+ network or to bundle in one REDD+ project.

Scope of Expansion: This Ph.D. research project covers the total forest area 5388.62 ha. Out of this, there are 4790 ha collaborative forests, 552.78 ha community forests, 26.9 public plantation and 18.94 ha community planted forests. Moreover, there is high scope of expansion of REDD+ project in other forest areas of Mahottari and neighboring districts particularly to Dhanusha, Sarlahi as well because of contiguous block of forests.

There are possibility of areas extension under collaborative and community forest. For instance, there is a Jaladh collaborative forest (2125 ha) in Dhanusha district east of Mahottari and 3 collaborative forests (7530 ha) in west, these are contiguously connected to the forests of Mahottari district. Similarly, there are about 5000 ha community forests in Dhanusha and 7000 ha community forest in Sarlahi district. In addition, Emission reduction plan idea note (ER-PIN) is going to support by carbon fund under the forest carbon partnership facility in order to reduce the emission from deforestation and forest degradation under REDD+ The permanency is still under discussion for REDD+ programme. Generally, 30 years fixed or 60 years period for 2 additional period, each for 20 years like clean development mechanism is proposed for REDD+ too. and boundary covers between Rautahat dsitrict (defragmented adjoining district of Sarlahi) to Kanchanpur district (Koirala, 2014). A total forest area of Tarai from Kanchanpur to Dhanusha district is 1022557 ha. Most of them is managed under participatory management regime, which may be potential for carbon sequestration project under REDD+ project.

Generally, global discussions emphasize on the large blocks of forest areas more than 10000 ha to be eligible for carbon trade under the REDD+ programme because it can reduce the transaction cost and designing the MRV and REL (Angelsen *et al.*, 2009). However, it is difficult to find such block of forest.

4.3.9 Confrontation in Carbon Trade

Technically, assurance of non-permanency and leakage are profound challenges for forest carbon trade under REDD+ programme in Nepal. In addition data consistency and capacity gaps as well as the issues of co-benefits and carbon trade of small scale plantations under the REDD+ programme are the major challenges. Next to these issues are effects of drivers of deforestation and forest degradation on forest carbon stocks.

Leakage: The drivers of deforestation and forest degradation (D & D) as well as underlying causes are the major problems, which result to the leakage. Over exploitation of forest timbers and firewood, encroachment, invasion of unwanted species, unmanaged grazing and seasonal fires are the main causes of leakage in these forests. However, the level of damage is not same to all forests. The negative current annual carbon loss (ACL) in Banke- Maraha collaborative forest is indicator of leakage of forest carbon. Actually, the drivers of deforestation and forest degradation have damaged the community and collaborative forest than plantations in Tarai (Karna, 2008).

There was leakage in different forest carbon pools in the Banke -Maraha CFM. It was found that the highest leakage was recorded due to damage in the tree stage. It was -3.87 t ha^{-1} in between 2011 and 2012 which was -3.00 t ha^{-1} in between 2012 and 2013 (table 39). If the REDD+ programme is started in vicinity of this, the leakage should be addressed at any cost. No any study has done on forest carbon leakage in Nepal.

Table 39: Change in carbon in year 2011 to 2013

Years	Change in carbon	LHG	Seedling	Sapling	Pole	Tree
In 2011 to 2012	C t ha^{-1}	-1.00	-0.95	1.59	3.91	-3.87
	Change types	Negative	Negative	Positive	Positive	Negative
	% change	8.84	8.39	14.02	34.55	34.2
In 2012 to 2013	C t ha^{-1}	-0.18	-0.11	1.01	1.34	-3
	Change types	Positive	Negative	Positive	Positive	Negative
	% change	3.19	1.95	17.91	23.76	53.19

The leakage is the big issue in REDD+ programme. The leakage is categorized under two major categories, they are primary leakage and secondary leakage. The primary leakage is the emissions, which are directly attributable to the deforestation agents while the secondary leakage is the emissions which are not directly attributable to the deforestation agents but rather to other actors through effects on prices and markets (Aukland, Costa, & Brown *et al.*, 2003). Leakage is caused because a forest resource such as timber, fodder or firewood is not available anymore in the protected area without direct substitution. Though there are leakages in other forest areas too, a good example of leakage was noticed in Banke- Maraha CFM because the users in the vicinity of this forest illegally collect the timber, firewood and fodder from here. In addition, the grazing and fire are also big challenges to control.

Co-benefit**:** Mainly biodiversity and livelihood promotion are considered as the co-benefit under the REDD+ programme. However, these points are judicially valuable; any weakness may affect on local biodiversity and livelihood. This is relevant for this finding as well.

It is not an absolute guarantee of biodiversity conservation and promotion applying the REDD+ prohramme under the carbon trade. So, this is associated issues under the REDD+ programme for the carbon trade. Moreover, there is inseparable relationship between agriculture and forestry and it is remarkable facts that most of the poor citizens are reliant on forest resource for their livelihood subsistence. Human development index 2013 showed Nepal is at 157th rank, this indicated the poverty is serious problem, which directly affects on forest resource management (UNDP, 2013). So, the priority should be given for livelihood promotion too. Without dealing with the issues of poverty, the REDD+ programme cannot move smoothly the least development countries like Nepal (Pfaff *et al.*, 2007).

Small scale plantations and concept of bundling**:** The concept of bundling will be one of the better options to link the forest carbon trade. Public plantation and community planted forest are the example of small scale community based forest management while community forests are the block of forests in Tarai and collaborative forests are large block of forest managing users, local district development committee. Here, the single unit may be the candidate for forest carbon trade but it may not be cost effective. Therefore bundling of such types of forest management unit in one network will be efficient way to reduce the transaction costs which is ideally also supported by the REDD+ pilot projects like WWF and ICIMOD (Bhattarai *et al.*, 2011; Manandhar, 2010).

Other importance of bundling approach may be fit for bundling of income generation through environmental services like watershed, biodiversity services, landscape and forest carbon. Thus, this will be new avenue to get the income from forest carbon trade but the questions are how much benefit from this alone? Can such reward alone will be enough for motivation of community people? Answer will be no or very doubtful. Then, bundling of reward in one functional network of different environmental services will be relevant concept so that community participation in forest management will be more effective and this may be new study scope for next research.

The bundling approach is also useful for non-governmental forest institutions. Indeed, there are Federation of Community Forest Users, Nepal (FECOFUN), Association of leasehold forestry, Association of Tarai Public Forest (public plantation) User-Nepal (APLFUN), Association of Collaborative Forest Users, Nepal (ACOFUN) functioning for the issues of forest users. Overall goal of these institutions is to contribute in forest management. Actually, these all institutions have national level separate organization and they are advocating for their own organizations. So, it is national need to formulate a separate national level umbrella organization, which can represent from all these community managed organizations and this can jointly influence for better policy formulation and counter react against the user harm policy. Nevertheless, this may be other place of research.

Data gaps and handling capacity gaps: This research work provides the data only for 3 years from 2010 to 2013. After this there may not be assurance continuity in both data gathering and handling. Although, the data were collected from the community and collaborative forests during the forest inventory process, there is no any permanent sample plot in the field. Therefore, the maintenance of these sample plots may be questionable.

Benefit sharing of carbon: This research project may create the carbon credit, which can provide the benefit to local community and government. However, the confined system of benefit to the users and to government is still unknown. In addition, the livelihood promotion issues always imbedded with the benefit sharing. Exclusively, this includes the national, regional and global network for function to judge the forest carbon benefit sharing, livelihood promotion, carbon right and responsibility together. Since, the carbon benefit and livelihood promotion are the global issues so Nepal has also to include these issues in the emission reduction package (R-Package). This will be important debatable issues for the next research.

The study is still going on the benefit sharing of REDD+ in Nepal. The experts and stakeholder suggested that the benefit sharing in REDD+ can be decided according to the forest management regime. There are different types of existing benefit sharing of distribution of forest products in different community managed forests regime. The existing benefit sharing is 50/50% in collaborative forests (MoFSC, 2012 & 2014) but

100% in community forests and community planted forest (Kanel & Dahal, 2008). In case of public plantation it is based on the agreement policy between users and owners, generally 50/50% is mentioned in agreement. So, it will be better to take the account of these existing policies and practices.

These evidences support to decide the benefit sharing in forest carbon trade too. The benefit sharing should be 50/50% for government and users in collaborative forests while this will be same to owner and users in case of public plantations. Moreover, it will be better to share the 30% benefit to government and 70% to users in community forests and community planted forests (table 40).

The benefit sharing practiced in REDD+ payment project by ICIMOD, ANSAB and FECOFUN showed that 40,25,15 and 20% allocation of total payment for forest carbon status and enhancement; ethnic diversity, sex ratio and poor household respectively (ICIMOD, ANSAB and FECOFUN, 2011).

Table 40: Benefit sharing according to forest management regime

Types of forest management regime	Benefit sharing (%)		Remarks
	Government/owner	Users	
Collaborative forests	50	50	
Community forests	30	70	
Public plantation	50	50	Owner
Community planted forests	30	70	

The distribution of forest products is not so difficult but there is no any clear policy about the forest service distribution in Nepal. Here, the carbon sequestration is a type of environmental services and at the same time this is the main crux concept of reward through REDD programme under the payment of environmental services (Muradian *et al.*, 2010). Neglecting the participation of distant users in carbon benefit will be precarious in collaborative forest management. Therefore, this is new avenue for growing REDD+ programme, where community may be benefitted. Since the contribution of distant users is sometime questionable in collaborative forest management, getting the incentive under REDD+ programme may value add and there may be motivation for distant users to contribute in forest management.

4.4 Sustainability in Carbon Stock of Community Managed Forests

The sustainability in carbon stock is completely related to the growing stock of the forests. So the principle of sustainability is applied for carbon stock too. Technically, the Biolley's "Check Method" - Method du-Control, De Liocourt's Law and Diameter Class Distribution and Mean Annual Carbon Increment (MACI) are the principle tools for forest management.

4.4.1 Sustainability in Carbon Stock of Collaborative and Community Forests

Generally, there are two basic laws applied to check the sustainability in irregular uneven aged forests. They are De Liocourt's law and Biolley's "Check Method" - Method du-Control.

4.4.1.1 De Liocourt's Law and Diameter Class Distribution of CF and CFM

The De Liocourt's law showed that there should be certain number of stems ha^{-1} in different DBH classes to maintain the sustainability in the forest. Based on this law, there should be 550, 275, 138, 69, 34 and 17 stems ha^{-1} of DBH= 0-10 cm, DBH=10-20, DBH=20-30, DBH= 30-40, DBH= 40-50 and DBH>50 cm respectively. Moreover, if the records of stems ha^{-1} are compared in three DBH classes, they should into DBH<30 cm, DBH=30-50 cm and DBH>50 cm and the number of stem should be 963, 103 and 17 stems ha^{-1} respectively based on De Liocourt's law. Infact, records of these forests showed that there were 884, 1244, 1192, 1441, 1701 and 1753 stems ha^{-1} of DBH<30 cm in Banke- Maraha CFM, Tuteshwarnath CFM, Gadhanta-Bardibash CFM, Baudh CF, Chure- Parwati CF and Chyandanda CF respectively. Nonetheless, only the record of Banke- Maraha was close to the record of De Liocourt's law but others showed the overstocked. Looking to the DBH=30-50 cm, there were 46, 58, 47, 64, 47 and 0 stems ha^{-1} of DBH=30-50 cm in Banke- Maraha CFM, Tuteshwarnath CFM, Gadhanta- Bardibash CFM, Baudh CF, Chure- Parwati CF and Chyandanda CF respectively but here no any matching record found with De Liocourt's law. All the records of stems ha^{-1} of these forests were understocked. In case of DBH>50 cm class, there were 29, 27, 30, 15, 3 and 0 in stems ha^{-1} in Banke-Maraha CFM, Tuteshwarnath CFM, Gadhanta- Bardibash CFM, Baudh CF, Chure-Parwati CF and Chyandanda CF respectively. Only the record of Baudh CF showed the close to the record of De Liocourt's law while the records of Banke- Maraha CFM, Tuteshwarnath CFM, Gadhanta- Bardibash CFM were overstocked and others were understocked (figure 27).

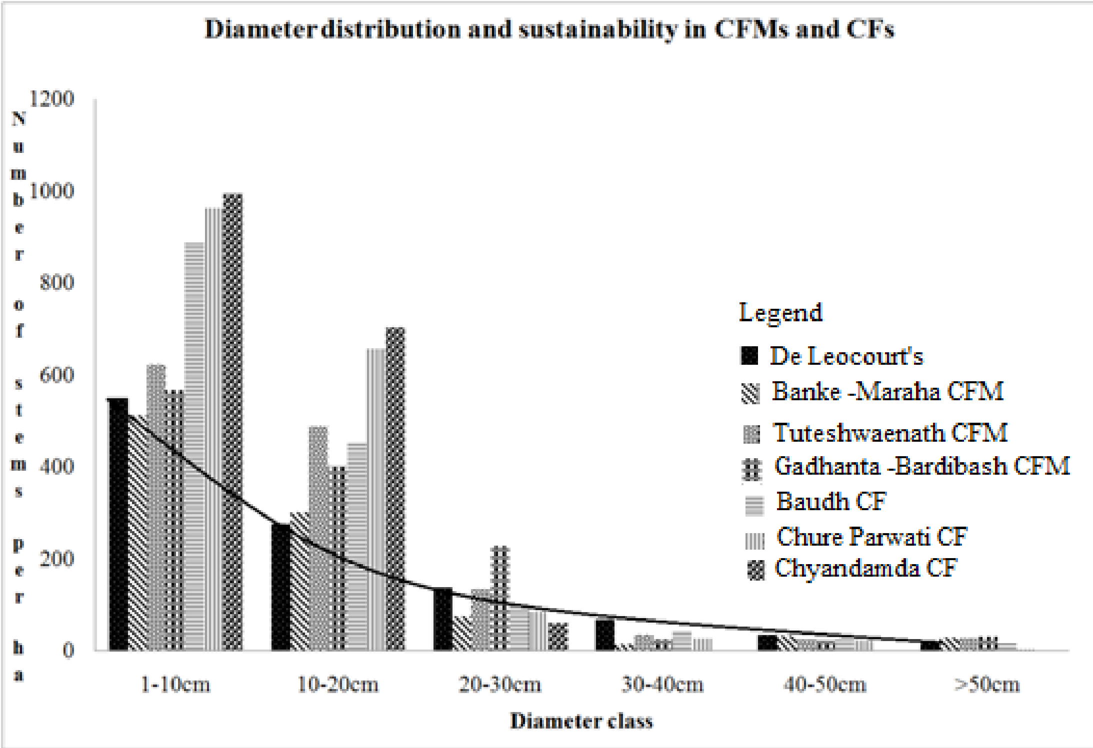

Figure 24: Comparison of diameter distribution of community managed forest with De Liocourt's law

Generally, the users have no idea and forest technicians also not suggested to apply appropriate silvicultural operation to manage the forests sustainably. Essentially, it is point out that the second generation issues of community forest has focus on sustainable management of forest (Kanel, 2004). The De Liocourt's law for diameter distribution is the appropriate tool to plan for choosing the best silvicultural operations for natural irregular forest and it will be helpful to check with Biolley's "Check Method" for stocks. The users of community and collaborative forests and forest technicians are not serious about this principle theory of sustainable forest management. Then, the challenge is, what will be the goal of the Future's of Nepal's Forest 2020 and the main vision of ministry of forests and soil conservation that is "forestry for prosperity".

4.4.1.2 Biolley's "Check Method" — Method Du-control

Neither community forests nor collaborative forest showed sustainability performance based on Biolley's "Check Method" - Method du-Control which has focused on the volume ratio of DBH<30cm: DBH =30-50cm: DBH >50 cm to 20:30:50 (Lal, 2007; Prakash, 2001). This has not included DBH <10 cm, which has less significant contribution in carbon stocks but it has high value in forest enhancement. It is admirable debate whether same principle can be used for carbon stocks based yield regulation.

It is noteworthy to compare the aspects of forest management applying the Biolley's sustainable principle in Nepal's community managed forests. Infact, the community forestry inventory guideline showed that the good quality forests should have the volume> 250 m^3 ha^{-1} for DBH>10 cm (DoF, 2003). Generally, in Tarai (plain area), high value *Shorea robusta* (Sal) is dominant species whose specific gravity is >0.88 g/cc. Allowing the same principle in carbon stock management indicated that, it will be essential matter of discussion to maintain carbon stocks about 20-25, 30-35 and >50 t ha^{-1} in DBH<30 cm, DBH=30-50 cm and DBH>50 cm respectively. So, this will be vital issue to assure the sustainability in irregular forest and address the issues of scientific forest management based on carbon stock.

4.4.1.3 Checking Carbon Stocks with Biolley's (Modified) Principle

According to Biolley's (modified) principle: In this geographical and forest condition the ratio of DBH< 30 cm, DBH= 31-50 cm and DBH>50 cm should be 20:30:50 which means, it should be 22 t ha^{-1} in DBH< 30 cm, 33 t ha^{-1} in DBH= 31-50 cm and 55 t ha^{-1} in DBH>50 cm.

Evaluating the records of carbon stocks and relative carbon percentage in comparison to Bioley's modified carbon stock showed variation in CFMs and CFs according to the DBH class. In case of DBH< 30 cm, the matching carbon stocks were recorded in Banke- Maraha CFM which was about 24.89 t ha^{-1} and its relative percent was 22.63 % to Bioley's modified carbon stock. Another close value of carbon stock was found in Chyandanda CF which was 23.88 t ha^{-1} and the relative percent was 21.71 to the percentage record of Bioley's modified carbon stock. However, other records were 32.32, 26.76, 31.96 and 67.54 t ha^{-1} in Tuteshwarnath CFM, Gadhanta- Bardibash CFM, Baudh CF and Chure- Parwati CF Chyandanda CF respectively which were relatively 29.38, 24.33, 29.05 and 61.40 % respectively to Bioley's modified carbon stock.

Table 41: Evaluation of carbon stock of CF and CFM with Bioley's modified stock

Types	Carbon stock	DBH <30 cm	DBH=30-50 cm	DBH>50 cm
Bioley's modified stock	Carbon stock t ha^{-1}	22.00	33.00	55.00
	Percentage	20.00	30.00	50.00
Banke-Maraha CFM	Carbon stock t ha^{-1}	24.89	17.98	73.85
	Relative % to Bioley's modified	22.63	16.35	67.14
Tuteshwarnath CFM	Carbon stock t ha^{-1}	32.32	38.5	68.98
	Relative % to Bioley's modified	29.38	35.00	62.71
Gadhanta-Bardibash CFM	Carbon stock t ha^{-1}	26.76	55.79	96.33
	Relative % to Bioley's modified	24.33	50.72	87.57
Budha CF	Carbon stock t ha^{-1}	31.96	33.96	19.74
	Relative % to Bioley's modified	29.05	30.87	17.95
Chure-Parwati CF	Carbon stock t ha^{-1}	67.54	23.44	2.43
	Relative % to Bioley's modified	61.40	21.31	2.21
Chyandanda CF	Carbon stock t ha^{-1}	23.88	0.00	0.00
	Relative % to Bioley's modified	21.71	0.00	0.00

In case of carbon stock of DBH= 30- 50 cm, there was only one record of carbon stock that was 33.96 0 t ha^{-1} in Baudh CF which was 30.87% relative to Bioley's modified carbon stock and matching with this modified stock but no any stocks were matching with this stock. They were 17.98, 38.50, 55.79, 23.44 and 0 t ha^{-1} in Banke-Maraha CFM, Tuteshwarnath CFM, Gadhanta- Bardibash CFM, Chure- Parwati CF and Chyandanda CF respectively which were relatively 16.35, 35.00, 50.72, 21.31 and 0 % respectively to Bioley's modified carbon stock.

The evaluation of carbon stock of DBH>50 cm showed there was no any matching carbon stock of CFM and CF with the relative percentage of Bioley's modified carbon stock. Likewise, the carbon stocks were 73.85, 68.98, 96.33, 19.74, 2.43 and 0 t ha^{-1} in Banke- Maraha CFM, Tuteshwarnath CFM, Gadhanta- Bardibash CFM, Baudh CF, Chure- Parwati CF and Chyandanda CF respectively which were 67.14, 62.71, 87.57, 17.95, 2.21 and 0 % relative percent of Bioley's modified carbon stock (table 41).

Conclusively, the evaluation showed that there is no any records of carbon stock of community and collaborative forests which exactly show ratio of 20:30:50 of DBH< 30: DBH= 31-50 cm : DBH>50 cm. Some records of carbon stock showed overstocked and some of them showed under stocked, thus there is no assurance of sustainability of carbon management in these forests. Generally, here the carbon stock of collaborative forests showed overstocked and the community forests showed understocked relative percentage Bioley's modified carbon stock. This is the clear indication of harvesting of green trees from the community forest. So, there was no evidence of sustainability of carbon stock of community forest as well as collaborative forest management. Sustainability is major issue in community based forest management in Nepal (Kanel, 2004) and it had not adopted in the practice yet.

4.4.1.4 Mean Annual Carbon Increment (MACI) in Collaborative and Community Forests

The mean annual carbon increment varied in community and collaborative forests. Infact, the highest MACI was found in Chyandanda CF and the lowest value was found in Banke- Maraha CFM. Here, the trend of MACI was Chyandanda CF> Baudh CF> Chure- Parwati CF> Gadhanta- Bardibash CFM > Tuteshwarnath CFM > Banke-Maraha CFM and their MACI values were 1.76>1.42>1.23>0.56>0.43>0.41 t ha^{-1} respectively (figure 28).

The MACI mainly depends upon the stage of the stems present in the forest (DoF, 2003). It is the fact that, the younger the stage of the stem, the higher is the rate of growth. The study done by Rana, (2011) showed that mean annual carbon increment was 1.40 t ha^{-1} in Torikhet community forest, Jiwanpur-8, Dhading district (Rana, 2011), which is close to the value of Baudh community forest.

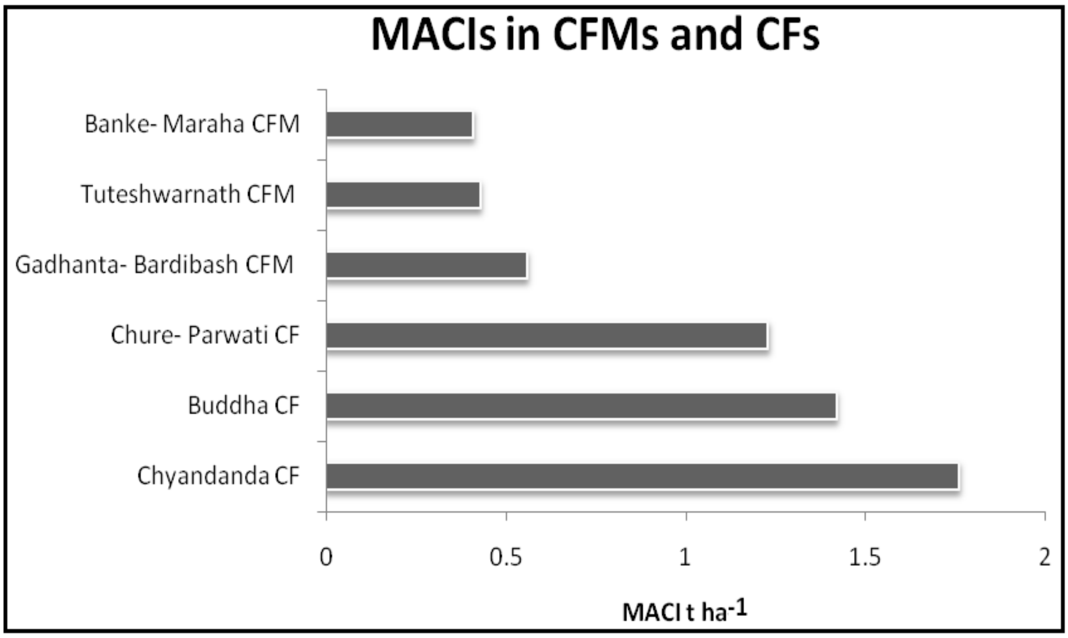

Figure 25: Mean Annual Carbon Increment in CFs and CFMs

The MACI of Phuljor-baba collaborative forest was nearly 0.40 t ha^{-1} (DFO, 2010) which is near to the value of Banke- Maraha and Tuteshwarnath CFM since they have same nature. These are similarity in MACI of collaborative and community forests. Mainly, the MACI is affected by the age of the stem and carbon stock that stem possese. In addition, growing staged plants have high MACI than that of the old and over matured plants (Husch *et al.*, 2003).

4.4.2 Sustainability in Carbon Stock of Public Plantations and Community Planted Forests

The sustainable forest management tools can also be applied in the evaluation of carbon stock of plantations. The areas of public plantation and community planted forests were very small and main species was *Eucalyptus camaldulensis*. The major purpose of these plantations is to produce the pole so that poor community will be able to generate income within short period. In fact, the rotation of these plantations is 7 years and is very good coppicer for second and third rotation periods so entire replanting cycle is completed in 21 years. Thus, the principle of sustainability is not applied here because of unavailability of large areas and unplanned scattered plantations.

The principle of sustainability is not so applied in public plantation because of the age gaps, unequal and small areas. The number of stems ha^{-1} depends upon the number of seedling planted maintaining the distance between plants and row to row. Indeed, the number of stems ha^{-1} varied from 1402 to 2814, the lowest record was found in Banauta PP and the highest record was in Shreepur PP with DBH<10cm. The another lower value was recorded only 1402 stems ha^{-1} in Jogikuti CPF while medium records were reported specifically 1637, 1832 and 1668 in Bisbitty PP, Sita CPF and Ramnagar CPF respectively (figure 29).

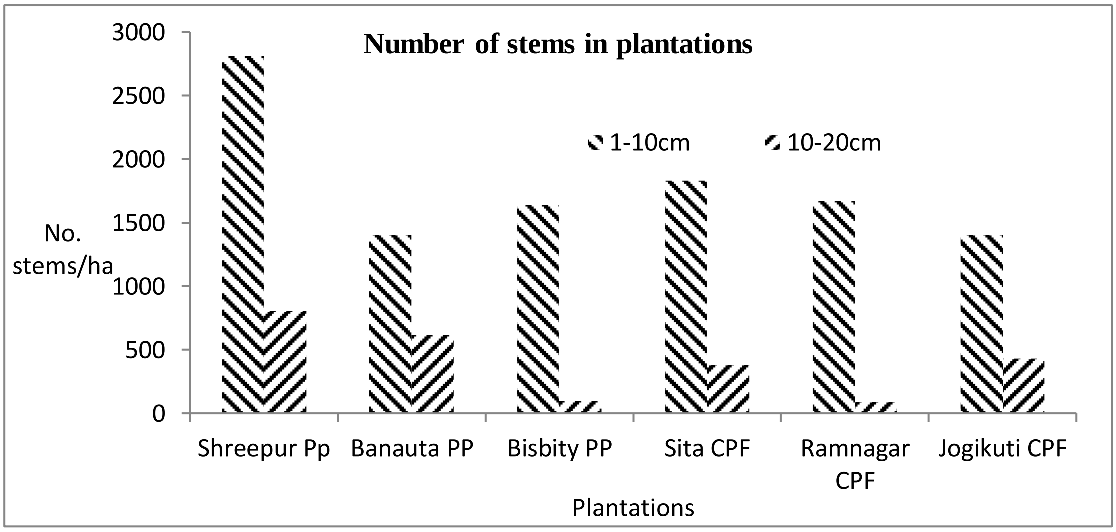

Figure 26: DBH class distribution of public plantations and community planted forests

In case of DBH= 10-20 cm, the records were 88-804 stems ha^{-1}, the lowest record was found in Ramnagar CPF and highest one was in Shreepur PP respectively. The another lower record 96 stems ha^{-1} was found in Bisbitty PP but another higher record was reported 618 stems ha^{-1} in Banauta CPF. However, the medium records were 379 and 431 stems ha^{-1} in Sita CPF and Jogikuti CPF respectively (figure 29). This will be helpful to find the variation in carbon stocks.

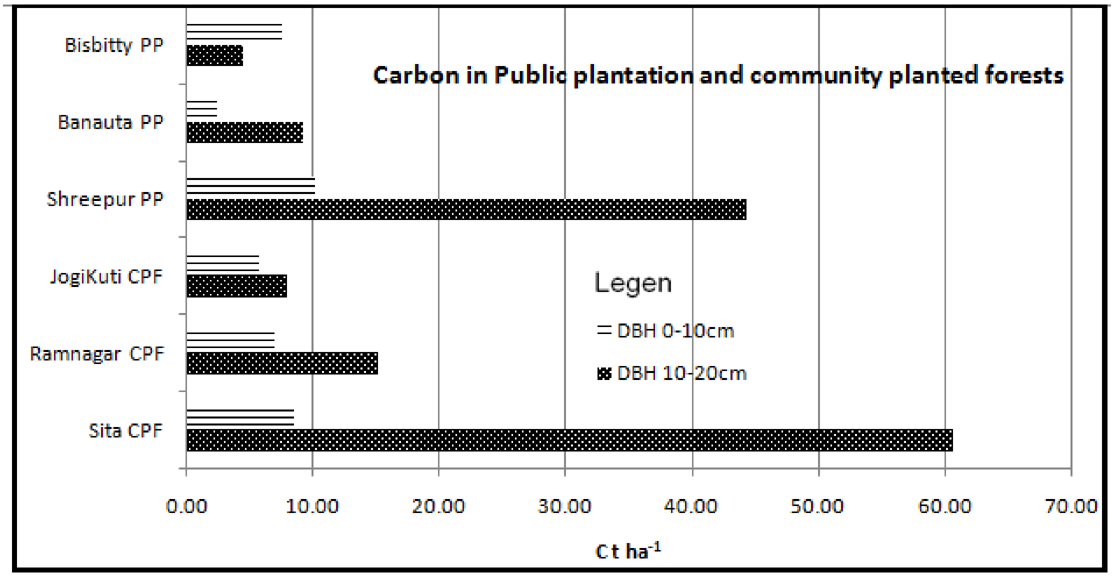

Figure 27: Carbon stock distribution in public plantations and community planted forests

The carbon stock was varied in public plantations and community planted forests according to DBH class. Generally, the higher carbon stock was recorded in higher DBH class. Specifically, the carbon stock in DBH of 10-20 cm was the highest 60.50 t ha^{-1} in Sita CPF PP but it was the lowest 4.50 t ha^{-1} in Bisbitty PP . The highest carbon stock in DBH in Sita CPF PP was because of presence of higher number of stem per ha and opposite of this is also true. Other higher records of carbon stocks in this DBH class were 44.19 and 15.08 t ha^{-1} in Shreepur PP and Ramnagar CPF respectively but lower records of this were 9.10 and 7.94 t ha^{-1} in Banauta PP and JogiKuti CP correspondingly. In case of carbon stock of DBH class 0-10cm, the highest records was 10.15 t ha^{-1} in Shreepur PP and lowest record of carbon stock was 2.38 t ha^{-1} in Banauta PP. Other records of carbon stocks of this DBH class were 8.39, 7.53, 6.92 and 5.71 t ha^{-1} in Sita CPF, Bisbitty PP, Ramnagar CPF and Jogikuti CPF respectively (figure 30). The higher the DBH class the higher is the carbon stock. Though, there was high number of stem per ha in DBH class 10-20cm, the carbon stock was very less in Banauta CPF, because most of the stems have 10-11cm DBH (figure 29). The carbon stocks in DBH class of plantation sometime influenced most of the stems falls to either upper or lower DBH of that particular class too (Sah, 2010). The progress report showed that, a volume of stem having 15cm have $0.23m^3$

and there are 800-900 stem ha^{-1} (Sah, 2010) which is equivalent to about 65-70 t C. This record is near about similar to the carbon quantity of Sita CPF. In same report it was reported that, volume of 5 cm DBH was 21 m^3 ha^{-1} which is equivalent to 7.1 tC. This value was quite close to the record of C of DBH having 0-10cm of Bisbity PP and Ramnagar CPF. These similarities were because of the same geographical condition.

4.4.2.1 Mean Annual Carbon Increment in Public Plantations and Community Planted Forests

The MACIs of plantation can be categorized broadly into two main categories specifically under high MACI and low MACI. The records showed that, there were higher MACIs 5.21, 4.13 and 3.12 t ha^{-1} in Shreepur PP, Banauta PP and Bisbitty PP respectively, while other plantations showed lower MACIs 2.65, 1.32 and 1.11 t ha^{-1} particularly in Sita CPF, Jogikuti CPF and Ramnagar CPF correspondingly (figure 31).

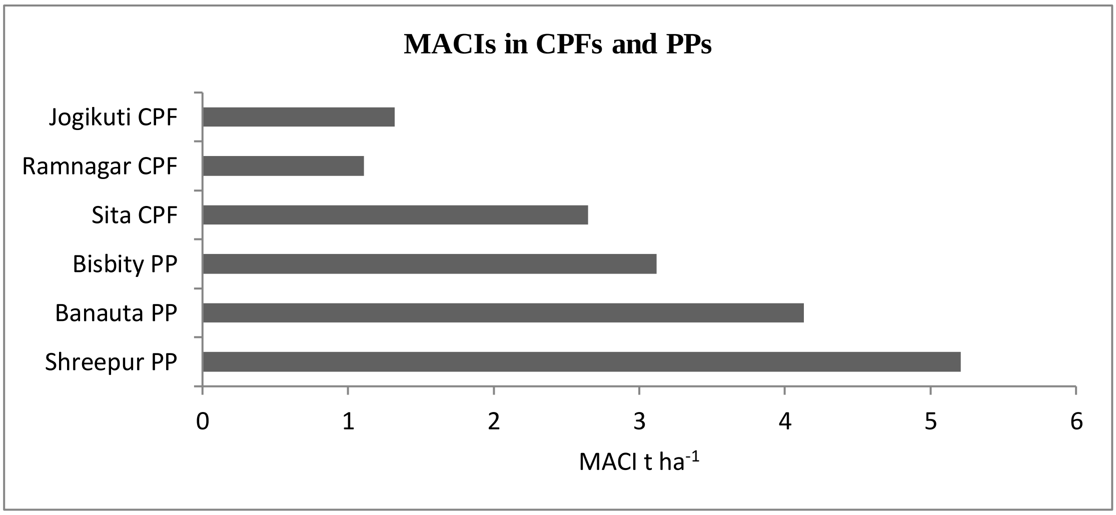

Figure 28: Mean Annual Carbon Increment of public plantations and community planted forests

The higher records of such MACIs may be due to silvicultural operations practiced in public plantations while these operations were not so appropriately and regularly practiced in CPFs. Here, study done by Amatya *et al.* (2002) showed that, the values of MAI of 4 years *Eucalyptus Camaldulensis* plantations at poor site was 5.8 m^3 ha^{-1}, (Amatya & Shresth, 2002). It means the estimated values of MACI, which is equal to MAI (m^3) x 0.47x wood density (wood density of *Eucalyptus Camaldulensis* is 0.96 g/cm^3), was nearly 2.63 t ha^{-1}, which is close to the MACI of *Eucalyptus* *camaldulensis* of Sita CPF. Infact, the growth of *Eucalyptus Camaldulensis* depends upon the site quality, spacing and silvicultural operation. There is better growth of *Eucalyptus Camaldulensis* on non-saline soil than on moderately saline soil Amatya & Shresth, 2002).

4.5 Plant Biodiversity Status and its Relationship with Forest Carbon

Biodiveristy status in collaborative forests, community forests, public plantations and community planted forests are assessed using indexes. In addition, the regression analysis was done to show the relationship between biodiversity and carbon stock in these forests.

4.5.1 Biodiversity Status of Collaborative and Community Forests

The values of biodiversity indices were not same in collaborative and community forests. Specifically, the Shannon-Weiner biodiversity index was the highest 2.33 in Banke- Maraha CFM but it was the lowest 2.21 in Gadhanta- Bardibash CFM and the record of this was 2.28 in Tuteshwarnath CFM. Similarly, the records this were 2.40, 2.37 and 1.93 in Chure- Parwati CF**,** Chyandanda CF and Baudh CF respectively. In case of species richness, they were 8.45, 8.12 and 7.94 in Banke- Maraha CFM, Tuteshwarnath CFM, Gadhanta- Bardibash CFM respectively while they were 8.13, 9.09 and 7.76 in Chure- Parwati CF, Chyandanda CF and Baudh CF respectively (table 42).

The plant species diversity was found higher in the fringe areas of forest types. There are two rivers namely Banke river in the west and Maraha river in the east. Because of riverain tropical and *Shorea robusta* mixed forest in Banke- Maraha CFM, there was the highest biodiversity. The research done by Sapkota *et al.*, (2009) in *Shorea robusta* forest in hills showed that values of Shannon Weinner index and Simpson Index were 2.42 and 0.64 respectively (Sapkota *et al*., 2009), which are close to the present findings. Here, the value of Shannon Weinner index was close to the values of Banke- Maraha CFM.

The Chyandanda CF lies in the fringe areas of tropical and subtropical forests. Chure- Parwati CF lies in the edge of subtropical forest. Remarkably, the Shannon-Weiner Biodiversity Index was recorded higher in Chure- Parwati CF. In particular, Sapkota *et al*., (2009) investigated in *Shorea robusta* mix forest in hills and observed that the value of Shannon-Weiner index is close to the present findings (Sapkota *et al*., 2009). The study done in Lalitpur showed that, the value of Shannon-Weiner index recorded 2.25 in Fulchowki community forest and 2.01 in Muldol community forest (Oli, 2012), which are close to the value of Chyandanda community forest. Noany management operations were carried out in collaborative forests except extraction of dead, dying and decayed fallen trees but selection felling, thinning operations and cleaning to remove unwanted species are common in community forests to produce quality timber. So there is higher diversity in the collaborative forests than community forests.

Table 42: Biodiversity indices in collaborative and community forests

Collaborative and community forests	Shannon-Weiner Biodiversity Index	Average species richness	Simpson's evenness (mean value)
Banke-Maraha CFM	2.33	8.45	0.79
Tuteshwarnath CFM	2.28	8.12	0.80
Gadhanta- Bardibash CFM	2.21	7.94	0.83
Budha CF	1.93	7.76	0.85
Chure-Parwati CF	2.40	8.13	0.67
Chyandanda CF	2.37	9.09	0.69

4.5.2 Biodiversity Status of Public Plantations and Community Planted Forests

The biodiversity status of public plantation and community planted forest was evaluated using Shannon-Weiner Biodiversity Index, species richness and Simpson's evenness value. The values of Shannon-Weiner Biodiversity Index were 1.59, 1.73 and 1.75 varied in Sita CPF, Jogikoti CPF and Ramnagar CPF respectively while these values were 1.58, 1.60 and 1.61 in Shreepur PP, Bisbitty PP and Banauta PP respectively. Similarly, the values of average species richness were 4.00, 4.43 and 4.73 in Sita CPF, Jogikoti CPF and Ramnagar CPF respectively but these values were 3.62, 3.89 and 4.27 in Shreepur PP, Bisbitty PP and Banauta PP respectively. In case of Simpson's evenness values, they were 0.46, 0.41 and 0.35 in in Sita CPF, Jogikoti CPF and Ramnagar CPF respectively whereas these values were 0.31, 0.29 and 0.24 in Shreepur PP, Bisbitty PP and Banauta PP respectively (table 43).

The reason of higher biodiversity in community planted forests is because of the edge effect of neighboring natural forest. In reality, the community planted forests are established in open patch of community forests where there were natural stand before the disturbance. The public plantations are established in open areas generally on the bank of the rivers, pond and other community land. Other important points of variations in biodiversity indexes are due to the practices of agro-forestry in public plantations, which are not applied in community planted forests. So, the unwanted species were weeded from public plantation during the silvicultural practices (Tabari *et al.*, 2011). The biotic and abiotic factors affect on the biodiversity (Strassburg *et al.*, 2009). Since the public plantations are far away from the natural forest, there is less chance of increase in biodiversity while the community planted forests are situated to neighboring areas, chance of effect of seed transferring from natural forests to plantation is very high.

Table 43: Biodiversity indices in collaborative and community forests

Plantations	Shannon-Weiner Biodiversity Index	Average species richness	Simpson's evenness (mean value)
Shreepur PP	1.58	3.62	0.31
Bisbitty PP	1.60	3.89	0.29
Banauta PP	1.61	4.27	0.24
Sita CPF	1.59	4.00	0.46
Jogikoti CPF	1.73	4.43	0.41
Ramnagar CPF	1.75	4.73	0.35

4.5.3 Relationship Between Biodiversity and Carbon Stock

The relationships between biodiversity and carbon stocks were evaluated in two steps in all community managed forests and plantation. Firstly, the relationship was assessed between carbon stocks and species richness and secondly it was appraised between carbon stocks and Simpson's evenness.

Table 41: R^2 values of relationship between biodiversity and carbon stocks

Value of R^2	Collaborative forests			Community forests			Public plantations			Community plantations		
	Banke-Maraha	Tuteshwarnath	Gadhanta- Bardibash	Budha	Chure - Parwati	Chyandanda	Shreepur	Banauta	Bisbitty	Sita	Jogikoti	Ramnagar
C-stock vs species richness	0.26	0.40	0.33	0.24	0.24	0.29	0.22	0.50	0.43	0.81	0.78	0.76
C-stock vs species Simpson's evenness	0.25	0.36	0.38	0.27	0.31	0.23	0.24	0.44	0.44	0.86	0.70	0.86

The polynominal regression equation was applied to evaluate the relationship between between carbon stock and species richness as well as carbon stock and Simpson's evenness. In reality, the R^2 values of relationship between carbon stock and species richness was the lowest (0.22) in Shreepur PP but it was the highest (0.81) in Sita CPF. Moreover, the estimated R^2 values were very low specifically 0.24, 0.24, 0.26 and 0.29 in Baudh CF, Chure- Parwati CF, Banke- Maraha CFM and Banauta PP respectively. On the other hand, there were some satisfactory R^2 values too of Tuteshwarnath CFM, Bisbity PP, Banauta PP, Ramnagar CPF and Jogikuti CPF which were nearly 0.40, 0.43, 0.50, 0.76 and 0.78 respectively (table 44).

The relationship between C stock and Simpson's evenness showed that estimated values were varied in these forests. The estimated R^2 value was the highest (0.86) in both Sita CPF and Ramnagar CPF but it was the lowest (0.23) in Chyandanda CF. Some lower values particularly 0.24, 0.25, 0.31, 0.36 and 0.38 were recorded in Shreepur PP, Banke- Maraha CFM, Chure– Parwati CF, Tuteshwarnath CFM and Gadhanta-Bardibash CFM respectively. However, the higher R^2 values were recorded in Banauta PP, Bisbity PP and Jogikuti CPF about 0.44, 0.44 and 0.70 correspondingly (table 44).

The agents of deforestation and forest degradation affect the biodiversity as well as the forest carbon stock. Obviously, these are indicators of very weak relationship between biodiversity and forest carbon stock (table 44). Generally, the users have prime interest to produce the quality timber. It means they practice the silvicultural operations like thinning, climber cutting and cleaning. However, these operations have been carried out generally after seedling stage. So, the before silviculture practice there are high number of species in the forest in comparison to post operations because operations are generally focus to remove unwanted species. So, the initially there is very weak relationship between carbon stock and biodiversity. Specifically, as the carbon stock is high the species richness is high and Simpson eveness is very low.

The species richness showed that there was positive but very weak relationship between carbon stock and species richness however it showed nearly hump-shaped relationship. Generally, the variation of carbon stock does not depend up on the species diversification. The research done by Karna (2012) also supported that there is positive but weak relationship between carbon stock and biodiversity (Wang et al,

2011) and the hump- shaped relationship exists between them (Guo, 2006). The opposite hump- shaped relationship was found between carbon stock and Simpson's evenness and it was very weak which was supported by the study done by Heather et al (2010).

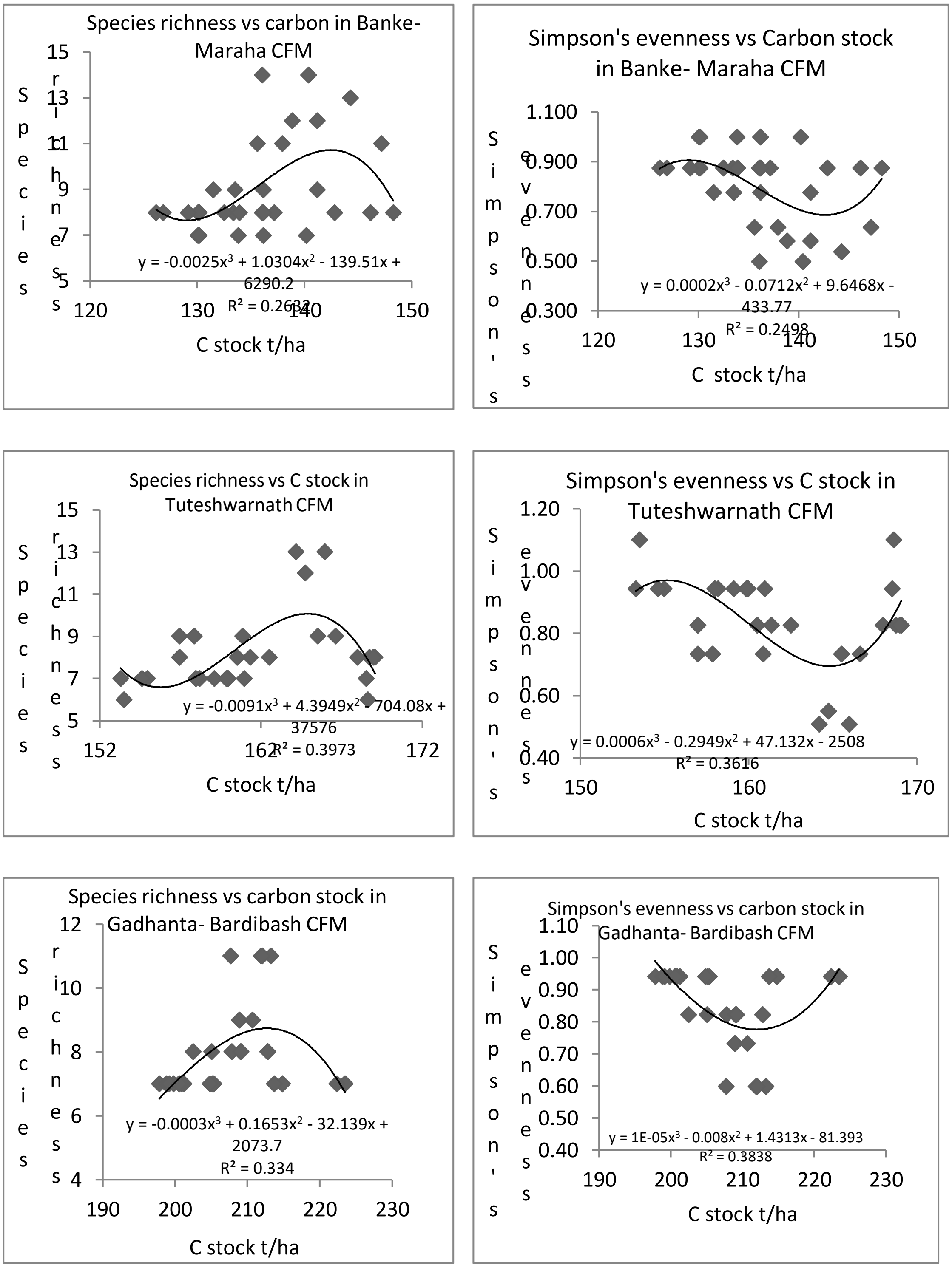

Figure 29: Relationship between carbon stock and biodiversity in CFMs

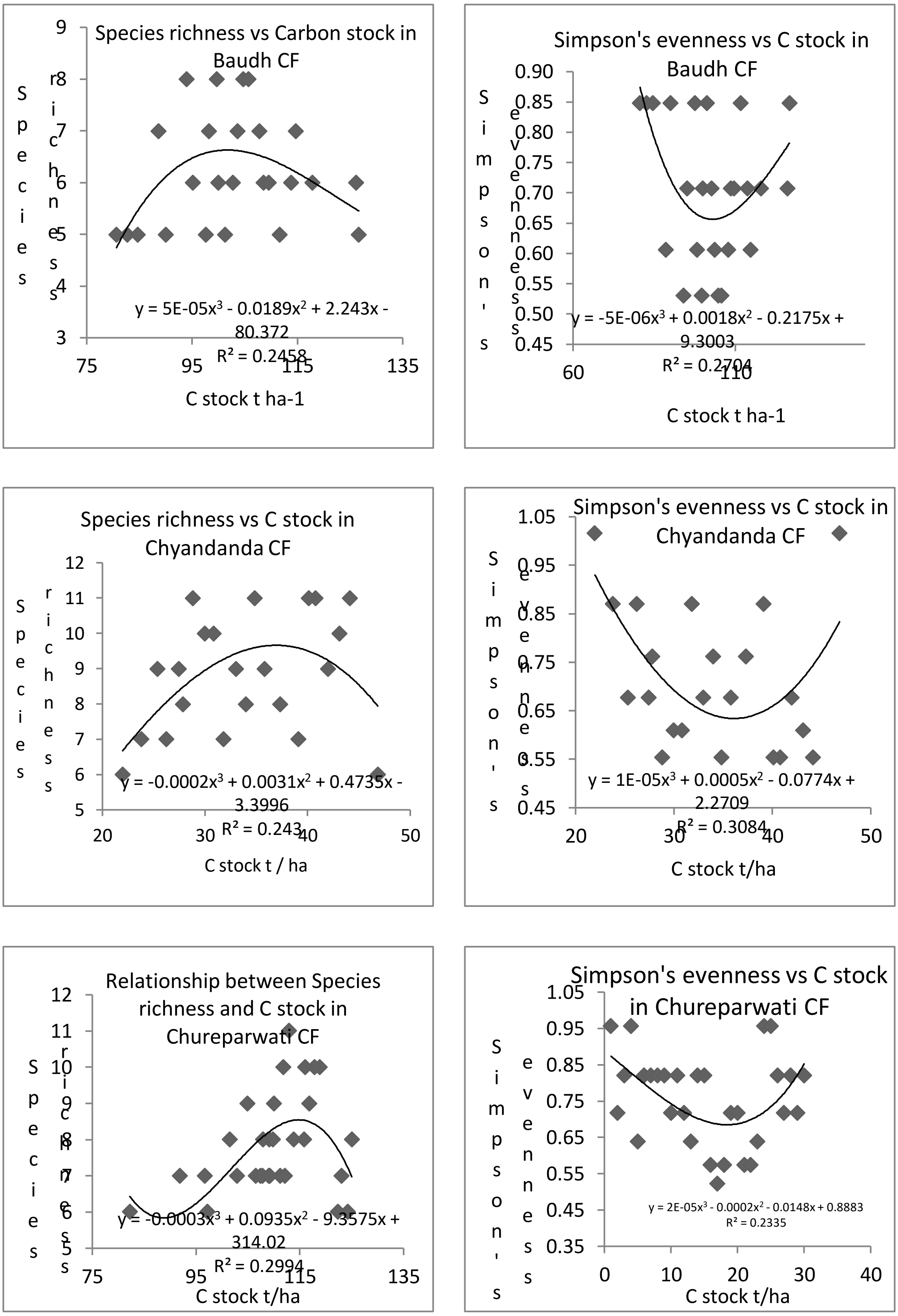

Figure 30: Relationship between biodiversity and carbon stock in community forests

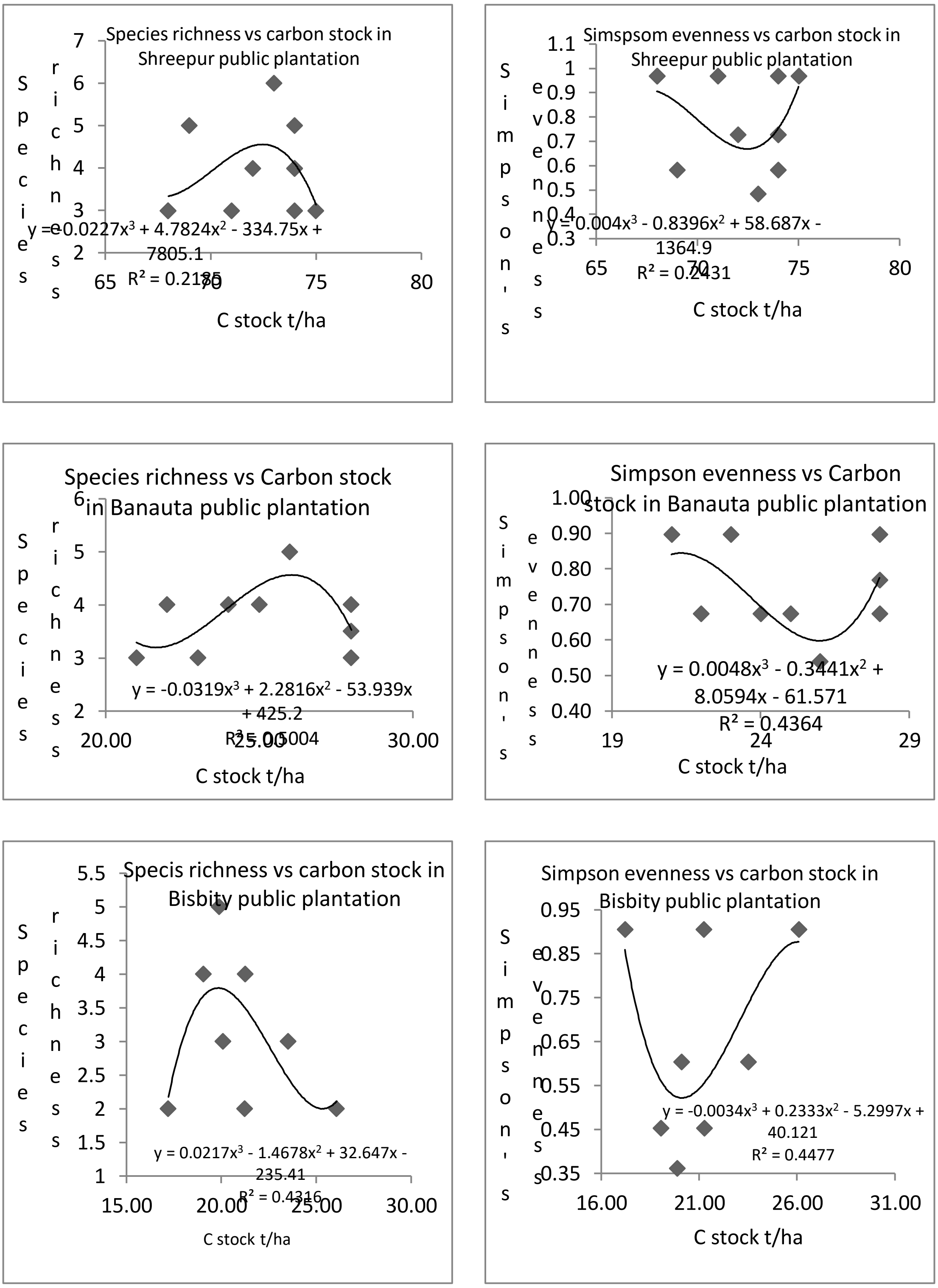

Figure 31: Relationship between biodiversity and carbon stock in public plantations

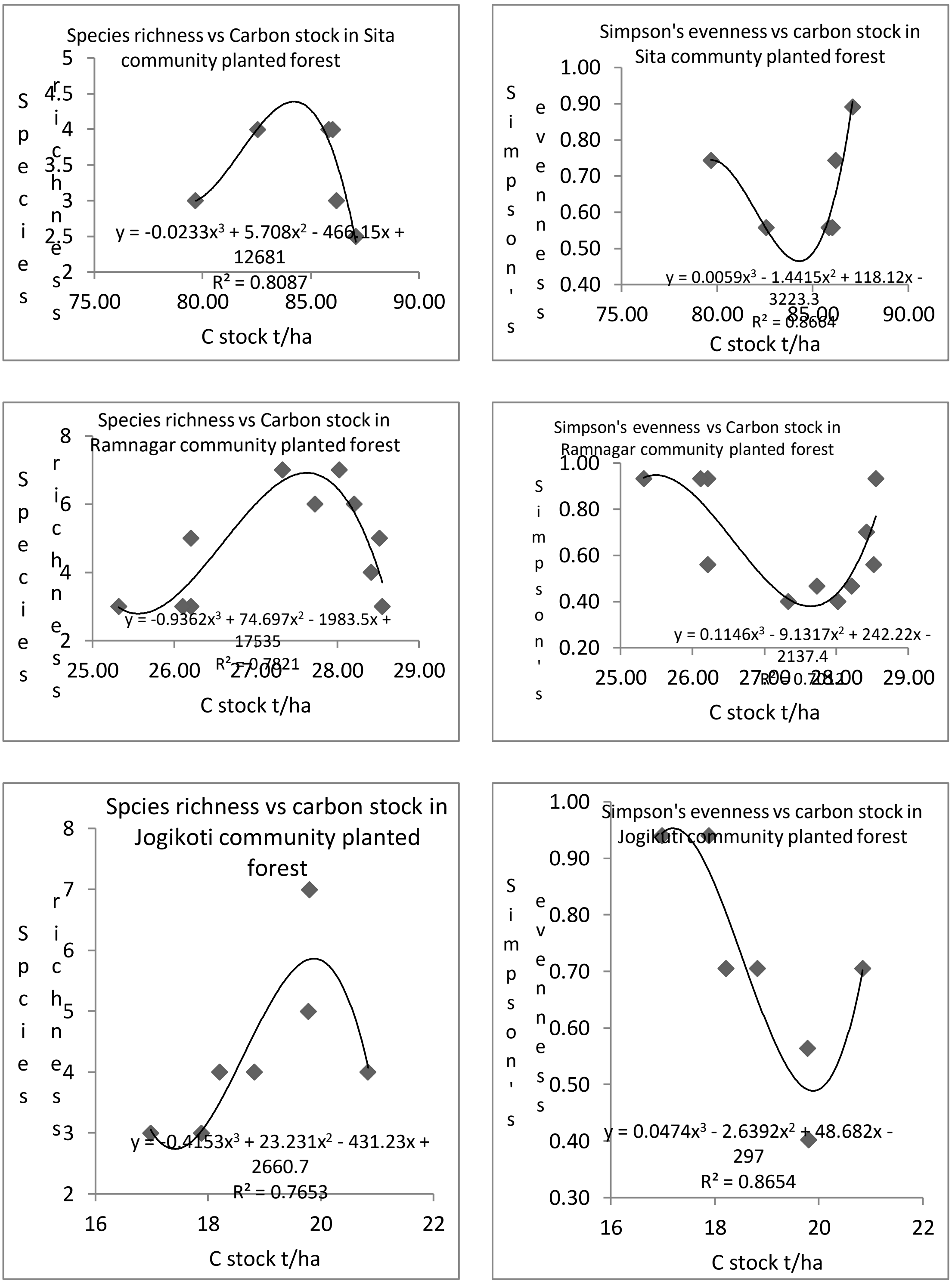

Figure 32: Relationship between biodiversity and carbon stock in CPFs

So, only enhancement of forest carbon stock may not assure the biodiversity promotion and conservation. Perhaps, it may be doubtful for the promotion of fast growing monoculture plants, which may be threat for biodiversity conservation as well. In addition, community likes to grow preferable species and remove the unwanted species. This idea is also supported by Karna (Karna, 2012).

The figures 32-35 showed the relationship between species richness and carbon stock as well as Simpson's evenness and carbon stock. The graphs showed that, there were increasing species richness biodiversity according to increasing carbon stock, after certain context they reached to the crest and showed a constant relation. Next, they decreased sharply. They formulated the hump- shaped relationship. In case of Simpson's evenness and carbon stock graph, the Simpson's evenness biodiversity decreased for a certain stage after that they showed constant relation and they decreased sharply. Lastly, they formed the opposite hump- shaped relationship. Here, Guo (2006) and Heather *et al.* (2010) have also found about same conclusion in their studies.

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4.6 Effects of Drivers of Deforestation and Forest Degradation in Community Managed Forests

The analysis showed that, the drivers of deforestation and forest degradation varied in different forest management types. Hence, the carbon stock differed too within the collaborative forests and community forests due to magnitude of effects of drivers of deforestation and forest degradation. Though the effects of drivers of deforestation and forest degradation were also observed in public plantations and community planted forests, they were not much influencing.

4.6.1 Drivers of Deforestation and Forest Degradation in Collaborative and Community Forests

Some similarities and differences were noticed in drivers of deforestation and forest degradation. The major drivers like logging, grazing and invasive species are common but their underlying causes were different in community and collaborative forests. In the past, the Churia forest was encroached for people's settlement however no more effect was observed, presently.

4.6.1.1 Drivers of Deforestation and Forest Degradation in Collaborative Forests

The drivers of deforestation and forest degradation were varied in these collaborative forests. As shown in figure 37, it was found that there were five major drivers and twelve major underlying causes listed as the influencing factors for deforestation and forest degradation in Banke- Maraha, Tuteshwarnath and Gadhanta- Bardibash collaborative forests.

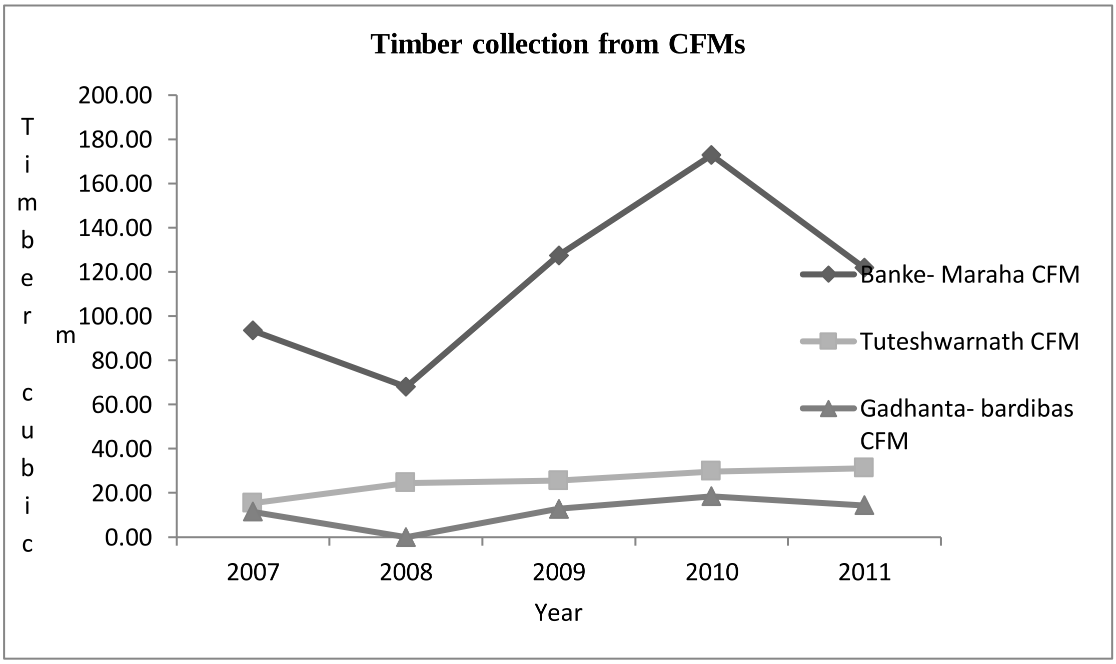

Figure 33: Collection of timber from different CFMs

There were some records of timber collection from the collaborative forests especially in the form of fallen and dried logs. Infact, the forest users collected timbers annually. The report showed, annually there were the highest quantities of timber collection from Banke- Maraha CFM among these collaborative forests, the records were 93.52, 68.01, 127.52, 172.87 and 121.86 m^3 in 2007, 2008, 2009, 2010 and 2011 respectively. On the other hand, the low records of timber collections were found from Tuteshwarnath CFM, they were 15.42, 24.51, 25.50, 29.76 and 31.17 in 2007, 2008, 2009, 2010 and 2011 respectively. In addition, the records of this were very minimum only 11.45, 0.00, 12.75, 18.48 and 1 4.48 m^3 in year 2007, 2008, 2009, 2010 and 2011 respectively form Gadhanta- Bardibash CFM (figure 36).

a. Forest fire and grazing: The forest fire is very common in all collaborative forest but grazing was less common in Gadhanta- Bardibash collaborative forest. Some examples of underlying causes of the forest fire is intentional fire and carelessness while underlying causes of grazing were keeping high number of low productive livestock, limited alternatives for fodder and grasses and traditional system of grazing.

b. Invasive species: It was observed that where canopy was opened and forest fire and grazing pressure were high, the invasive species like *Lantana camara*, *Cassia tora*, *Mikania micarantha* and *Ipomoea quamoclit* flourished well. In reality, the result showed that there was high pressure of invasive species in Tuteshwarnath CFM and it was followed by Banke- Maraha collaborative forest and Gadhanta- Bardibash CFMs.

c. Logging: There were many underlying causes of illegal logging. They are: increasing population and poverty and lack of livelihood alternatives; limited access to alternatives of fuel wood and timber; inefficient forest for fuelwood and timber use, weak law enforcement and impunity due to weak governance, inefficient distribution mechanisms of timber and firewood, high cross boarder demand of forest products, insufficient technical inputs, greediness of the people (staff, users committee member and others police) to generate money and increasing unemployment. The analysis showed that, the illegal logging was very high in Banke Maraha CFM compared to Tuteshwarnath CFM and Gadhanta- Bardibash CFM (figure 37). Firewood collection and damage of small sized plants for preparation of firewood are other influencing factors of deforestation and forest degradation.

d. Encroachment: The encroachment was common in all collaborative forests however underlying causes were uncommon. For instance, the local and temporary market was expanding in Tuteshwarnath and Gadhanta- Bardibash CFMs but not in Banke- Maraha CFM; temples were built in all collaborative forests while old settlements were more serious in Banke- Maraha than Gadhanata- Bardibash CFM but not in Tuteswarnath CFM. In total, the encroached area was 10.1 ha. Out of this 2 ha was noted in Tuteshwarnath CFM, 5.5 ha in Banke- Maraha CFM and 2.5 ha were in Gadhanta- Bardibash CFM. Notably, the armed police camp was built at Gadhanta-Bardibash CFM area and temporary armed police post was at Banke- Maraha CFM and it was absent in Tuteshwarnath CFM area. In addition, the East-west highway and high tension line are common in all CFMs.

e. Effects of Mobilization of Protection and Management Unit: The Management and Protection organizations are also playing vital positive role to reduce the deforestation and forest degradation. In this context, there are five major institutions namely CFM units, Range post, Ilaka, District Forest Office and Security (arm police) camp are functioning to control the illegal logging.

These institutions have not been effective equally in protection and management of these collaborative forests. It was found that patrolling works were conducted jointly by these institutions to control the illegal logging in these collaborative forests. However, it was most effective in Gadhanta- Bardibash CFM in comparison to others, Though there were a range post and representatives in Tuteshwarnath CFM, there was less patrolling work here than other CFM areas. Likewise, the patrolling work is irregular in Banke- Maraha CFM, although there are Ilaka, Rangepost, temporary arms post and watcher of CFMs as well. Indeed, the loggers are more active during the festival and rainy season when protection units have difficulties to organize the patrolling work because of leave of the staff in festival and difficult to drive vehicles on muddy road in rain.

Other noticeable fact was the staff of Tuteshwarnath and Banke- Maraha CFM was very irregular in the field patrolling because of less monitoring and evaluation system compared to Gadhanta- Bardibash CFM. The reason of the irregularity is low payment and costly transportation fare to reach Tuteshwarnath and Banke- Maraha CFM while Gadhanta- Bardibash CFM is close to Bardibash Market where most of staffs stay. It was heard that sometimes greedy staff also involved in smuggling activities it was more frequent in Banke- Maraha and Tuteshwarnath CFM.

Moreover, CFM representatives also play a vital role to control the illegal logging. It was found that representatives of Gadhanta- Bardibash CFM were very active but it was less active in Banke- Maraha CFM and Tuteshwarnath CFM. In addition, political pressure influences in law enforcement against the illegal loggers (figure 37).

Remarkably, it can be noted that, the main drivers of deforestation and forest degradation were illegal logging, grazing, forest fire, invasive species, encroachments in these collaborative forests and their underlying causes were opening crown, intentional fire, market failure, weak governance, increasing population and poverty. Here, the finding was also supported by different type of studies, for example, it was found similar types of drivers of deforestation and forest degradation in Readiness Plan Idea Note (R-PIN) of Nepal (Baral *et al.*, 2008). Here, the R-PIN showed nine major drivers in the preliminary report (MoFSC, 2010b). Other study also indicated that illegal logging was the major drivers of deforestation and forest degradation in developing countries (Helmut & Lambin, 2001) like in Nepal.

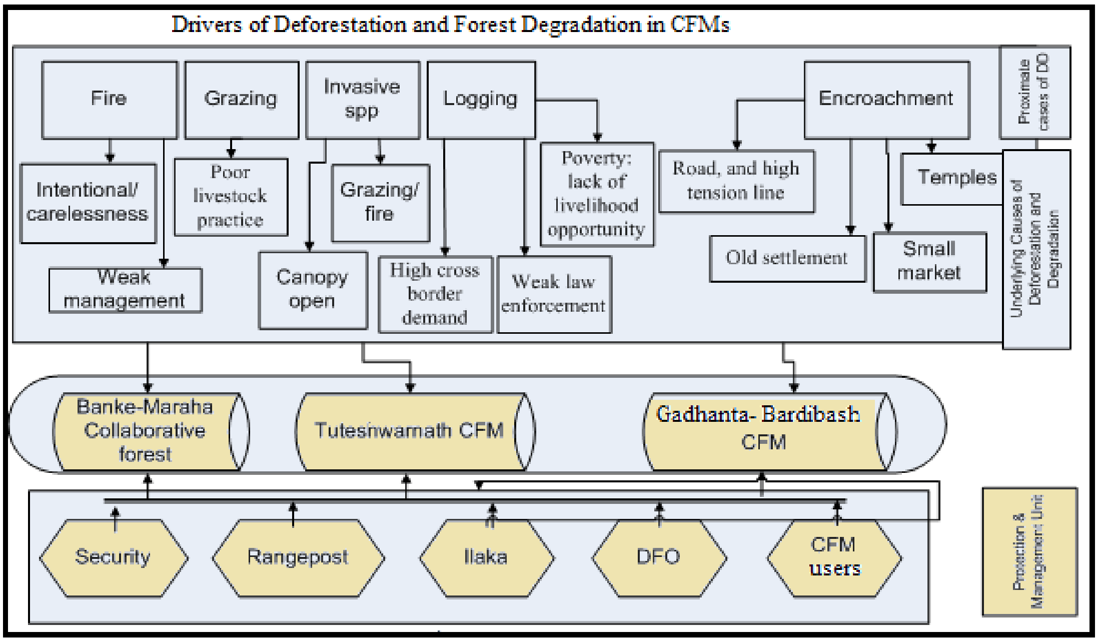

Figure 34: Drivers of deforestation and forest degradation in collaborative forests

Likewise, the finding about the drivers of deforestation and forest degradation like forest fire and grazing in collaborative forests was supported by Acharya *et al.* (2010). He advocated that the forest fire sweeps through the understory and livestock eats and tramples seedlings and saplings. These are very common drivers in tropical forests of Nepal (Acharya *et al.*, 2010).

4.6.1.2 Effects of Drivers of Deforestation and Forest Degradation on Carbon Stocks in Collaborative Forests

The Tukey's significance post hoc test showed that there was not much significant variation in carbon stocks of litter, herbs and grasses in Tuteshwarnath and Banke - Maraha CFM but it differed in Gadhanta- Bardibas CFM at 5% level of significance. In case of seedling and sapling, no variation was found in carbon stock in these CFMs while significant variation was seen in carbon stocks of pole and trees among three CFMs at 5% level of significnace. It indicated that there was less variation in damage done by grazing, fire and invasive species, which was observed in carbon stock of LHG.

Table 42: Tukey's test showing differences in carbon stocks in collaborative forests

Stage of plants	Tukey's values Subset for α = 0.05					
	Category: 1		Category: 2		Category: 3	
	Collaborative forest	Standard error	Collaborative forest	Standard error	Collaborative forest	Standard error
LHG	Tuteshwarnath Banke-Maraha	0.11 0.13	Gadhanta-Bardibas	0.20		
Seedling & sapling	Tuteshwarnath Banke-Maraha Gadhanta-Bardibash	0.29 0.40 0.43				
Pole & trees	Gadhanta-Bardibash	0.95	Tuteshwarnath	1.64	Banke-Maraha	2.30

Moreover, there was less effect of timber logging on pole and trees staged plants in Gadhanta- Bardibash CFM and it was followed by Tuteshwarnath and Banke- Maraha CFMs. Hence, there was high pressure of logging (timber and firewood extraction) on Banke- Marha CFM followed by Tuteshwarnath and Banke- Maraha CFMs (table 45).

4.6.2 Drivers of Deforestation and Forest Degradation in Community Forests

It is essential to focus on the history of community forest management in this district in order to explain about the drivers of deforestation and forest degradation. Indeed, community forest management has started since 1995/1996 in Mahottari district. In the past, there was no provision of export of timber from community forests but presently it is a general practice, legal task and regular work to sell the forest products like timber and firewood to Kathamandu and other cities.

The record showed that, community forest users have collected timbers every year, though, these forests were not well stocked. More than 1445 m^3 timber were harvested from Chure- Parwati CF while it was 745 and 231 m^3 from Baudh and Chyandanda CFs respectively since last 5 years period (figure 38).

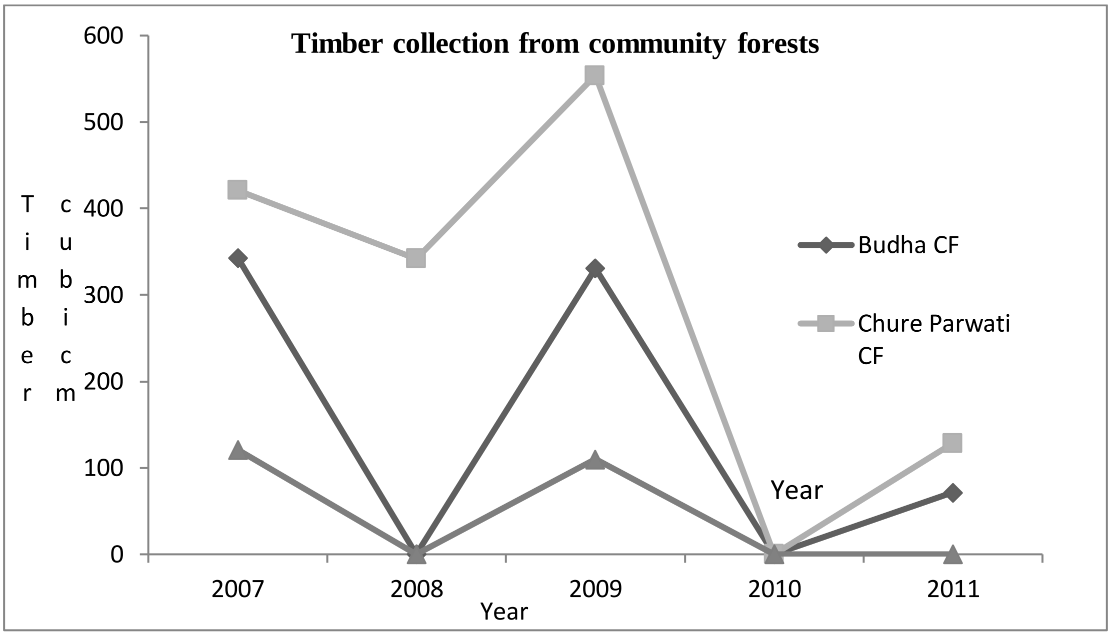

Figure 35: Timber collection from community forests

4.6.2.1 List of Drivers of Deforestation and Forest Degradation

The list of drivers of deforestation and forest degradation were logging, invasive species, fire and grazing in community forests. They are described here.

a. Logging: The forests were heavily affected nearby the villages by the local people before managing under the community forest in Tarai. Here, Baudh, Chure- Parwati and Chyandanda community forests are very close to the village so they are extremely affected by the local people for extraction of forest products especially timber for construction of houses and illegal selling. Similarly, poor communities were dependant on firewood selling for their livelihood subsistence.

Legal and illegal loggings together are responsible for depletion of community forests in Tarai. There was legal provision of transfer the houses (timber) from one place to other places in 1992/1993, which boosted the business of illegal logging in these forests. Infact, local people used to sell their built houses. So, they used to reconstruct more houses by collecting the timbers from the nearest forests. Consequently, the nearest forests, which are community forests now were heavily logged by this type of horrific timber business. This trend is still continued but in other form. Community forest users are allowed to do the legal business to sell the timber of felling green trees (timber and firewood) to Kathmandu and other cities but they have no more large sized trees so, they cut the trees (illegally) in nearest collaborative forest. Besides, some smugglers are still involved in illegal logging.

The degree of illegal logging was high in Baudh community forest in comparison to Chure- Parwati community forest. In case of Chyandanda community forest, once it was completely degraded before handed over as community forest. Unfortunately, Chyandanda community forest was used as source of timber supply for building construction in newly suburb Bardibash in the past. Additionally, poor communities were used to collect the firewood and sell this to the market for their subsistence of livelihood.

b. Invasive species: Mainly, invasive species like *Lantana camara*, *Cassia tora*, *Mikania micarantha* and *Ipomea quamoclit* have high effects on the seedling and sapling stage of the forests. The result showed that there was high pressure of invasive species in Chure-Parwati CF and it was the lowest in Chyandanda CF.

c. Forest fire and grazing: The forest fire was not so common in these community forests however, occasional fire was observed in Chure- Parwati CF because of carelessness of local women grass collector and cigarette smoker. These driving factors were not found in Chyandanda and Baudh community forests. However, the forest users are not so serious about the grazing problem in community forests, the underlying causes of grazing is not differed from cause of collaborative forests.

d. Role of management unit: Only community forest users are full responsible for protection of the forests while there is very limited influence of forest staff units in protection of community forests but they support in technical activities to manage the forests.

Forest land encroachment for building road, temples, offices, high tension line and telephone line were common underlying causes of deforestation and forest degradation which were also supported by study done by Angelsen *et al.*, (2009) and population growth in developing countries during the 1970s and 1980s led to substantial encroachment in forests (Angelsen *et al.*, 2009; Hiemstra *et al.*, 2009).

4.6.2.2 Effect of Drivers of Deforestation and Forest Degradation in Community Forests

As shown in table 46, the regeneration like seedling and sapling were damaged due to forest fire, grazing and invasive species. Similarly, the herbs, grasses and litter were also damaged by seasonal fire and continuous grazing. However serious damages were seen in pole and trees which are converted into timber for local use and for smuggling. Since the pole and tree are valuable substantial carbon pool, any damage in this stage of plants has significant variation in carbon stock in forests.

The most important forest carbon pools is the stem of the plant so any activities like legal and illegal loggings, which were focused on removal of green and dead standing, felled and fallen trees will have highest effect on total carbon stocks. Infact, the illegal logging will have high effect on forest carbon. If the fire burned the logs or dead standing stem, the effect is serious on the forest carbon stocks. Forest fire, grazing and invasive species were generally responsible for damaging the carbon stock of regeneration like seedling and sapling and herbs, grasses and litter.

Table 43: Effect of drivers of deforestation and forest degradation on different stages of plants

Stage of the plants	Types of drivers and their damage	Remarks
Regeneration (seedling & sapling)	Generally, forest fire and grazing damage the regeneration stage of the plants	Invasive species also damage the regeneration
Trees and Pole	Logging and Harvesting of timbers for local use or smuggling	Damage to pole and trees, heavily effect on carbon stock
LHG	Forest fire and grazing affects on herbs, grasses and litters	

4.6.3 Drivers of Deforestation and Forest Degradation in Public plantation and Community Planted Forests

The drivers of deforestation and forest degradation were differed in public plantation and community planted forest. Illegal logging was not observed in public plantations except felling of 4 stems from Shreepur public plantation but it was common in community planted forests. However, expansion of invasive species and grazing were common in both types of forests. Besides, the forest fire was occasionally observed in community planted forests, which was not seen in public plantation. The encroachment problem was not observed in these sites**.** Similarly, there was no any effect of forest management unit except occasional technical supports.

4.6.4 Options to Address the Drivers of Deforestation and Forest Degradation

Though there are several drivers of deforestation and forest degradation, the logging is the primarily responsible for the heavy loss of forest in above ground carbon pools. Infact, it is very difficult to get rid from this. The proposed options may be reliable to address the drivers of deforestation and forest degradation. For example, sustainable management of forests (SMF), promotion of high quality timber species in private and common lands and diversify alternative livelihood options on a demand-driven basis, for forest dependent poor community are the prime options to address the logging (table 47). About similar options were recorded in emission reduction plan idea note (ER-PIN) (Koirala et al., 2014).

Table 44: Options to address the drivers of deforestation and forest degradation

Drivers of deforestation and forest degradation	Strategic options
Forest fire	Fire protection team and network development including security personnel, and mobilization. Incentives for fire fighter team
Grazing	Rotational grazing, promotion of grass and fodder species in private and common public land & keeping of improved variety of cattle
Invasive species	Utilize the invasive species for bio-briquette
Logging	Sustainable Management of Forests (SMF)
	The assurance of future sustainable growing stock through limiting the harvesting green trees
	Easy and regular distribution of forest products like timber and fuel wood for distant users from community forests
	Reducing demand with expansion of biogas plants and cooking stoves
	Land use planning to reduce forest conversion
	Promotion of high quality timber species in private and common lands
	Engaging private sector to bring new forest production to degraded lands
	Diversify alternative livelihood options on a demand-driven basis, for forest dependent poor community
Encroachment	Implementation of forest encroachment policy
Effects of mobilization of protection and management unit	Effective mobilisation of staff as well as monitoring and evaluation

4.7 CO_2 and CH_4 Emission from Domestic Fuel and Livestock

CO_2 and CH_4 Emissions are the major components of GHGs, which are prime process drivers of climate change. Actually, the CO_2 and CH_4 emissions are produced from fuelwood consumption as well as dung and urine of livestock respectively. It is common process, that the firewood collection and consumption as well as irregular and uncontrolled grazing causes the damage in the forests and the consequences are production of CO_2 and CH_4 Emissions.

4.7.1 Fuel Wood Consumption in Maisthan and Sahodawa Villages

Burning of firewood and other wood and non-wood materials are the important sources of CO_2 emissions. The most of the people use firewood and dung cake and sticks for energy.

The result showed that the daily fuel consumption and annual CO_2 emission varied according to family category, season and location. Daily average firewood consumption was the highest 11.50 kg by rich family of Sahodawa village and it was the lowest 5.89 kg by poor family of Maisthan village in summer. In summer, the fuel consumptions were 9.60 and 6.90 kg day^{-1} by medium and poor families respectively in Sahodawa village while the daily use of firewood in summer were 6.58 and 6.14 kg day^{-1} by rich and medium families respectively in Maisthan village (table 43).

Similarly, in winter, it was recorded the highest firewood 13.37 kg day^{-1} consumed by the rich family of Sahodawa village while it was the lowest 6.81 kg day^{-1} by the poor family of Maisthan village. Inaddition, the firewood consumptions were 7.39 and 6.89 kg day^{-1} by rich and medium family respectively in Maisthan village while they were 11.02 and 8.02 kg day^{-1} by medium and poor families respectively in Sahodawa village (table 43).

Consequently, the CO_2 emission was found to the highest (7.32 t yr^{-1} hh^{-1}) by rich family of Sahodawa village and lowest (3.93 t) by poor family of Maisthan. Thus, total quantities of CO_2 emission were 4792.25 t and 9235.68 t from Maisthan and Sahodawa villages respectively. Out of this, the CO_2 emission yr^{-1} hh^{-1} were less 4.48 t and 4.22 t by rich and medium families respectively from Maisthan village than 6.62 t and 4.79 t by medium and poor families respectively from Sahodawa village.

The quantity of CO_2 emission depends upon the use of fuel types and their heating and lighting capacity and duration, season, number of members in a household, quantity of fuels burned, types of stove, time duration for cooking and moisture content in fuels. Generally, there were more 5-10 members in Tarai communities and they like to cook thrice a day while there were less 5-7 members in Bhawar (foot hill) communities and they cook twice a day consequently more fuel is consumed in by Tarai communities than the hill communities. On the other hand, occasions of feasts and festivals and preparation of alcohol also require more fuel wood, the result is more CO_2 emissions. Moreover, the alcohol preparation was more common in hilly village than that in Tarai (table 48).

The study done by Panthi showed that, the daily firewood consumption was nearly 5.59 kg (Panthi *et al.*, 2009), which is matching the value of fuelwood used by the poor family of Maisthan village in summer. Here, Metz (1991) stated that, it was about 12.87 kg day^{-1}, which is close to the value of fuel used by rich householders of Sahodawa village in winter. Obviously, the estimated values of CO_2 emission of daily firewood consumption will be similar to the values of present research. Though, noany specific study has done so far on the estimation of CO_2 emission from different family categories.Hoeven (2012) reported that it was about 3.7 million t CO_2 emitted from fire wood consumption from Nepal in 2010.

Table 45: CO_2 emission from fuelwood consumption

Village		**Maisthan village**			**Sahodawa village**		
Family Types		Rich	Medium	Poor	Rich	Medium	Poor
Types of fuel used		generally fire wood in all family types			Fire wood/ dung in both family types		Fire wood, dung, litter, straw
Consumption of fuel (kg/day)	Summer	6.58	6.14	5.89	11.50	9.60	6.90
	Winter	7.39	6.89	6.81	13.37	11.02	8.02
CO_2 emission (t yr^{-1} hh^{-1})		4.48	4.22	3.93	7.32	6.62	4.79
Total CO_2 emission (t yr^{-1})		1811.94	1788.01	1192.31	3074.82	3574.26	2586.60

4.7.2 Comparison of Annual CO_2 Emission Among Rich, Medium and Poor Family

The CO_2 emission per households was differed in both villages, it was evaluated applying one way ANOVA and Tukey's Honestly Significant Difference (HSD) test and paired samples t-test.

One way ANOVA showed that, there were significant differences ($p<0.005$) in CO_2 emission per household among rich, medium and poor families of both Maisthan and Sahodawa villages at 5% level of significance (table 49).

Table 46: One way ANOVA of CO_2 emission according to family types

Village	CO_2 emission	Sum of Squares	df	Mean Square	$F_{calculated}$	P- value
Maisthan	Between Groups	2.60	2	1.30	9.34	0.00
	Within Groups	7.39	53	0.14		
	Total	9.99	55			
Sohadawa	Between Groups	112.33	2	56.16	170.80	0.00
	Within Groups	23.35	71	0.33		
	Total	135.67	73			

The comparisons were also carried out to test whether there was a significant difference in CO_2 emission hh^{-1} among family categories. In this context, the Tukey's Honestly Significant Difference (HSD) test showed that, there was a significant difference ($p<0.005$) in CO_2 emission hh^{-1} between rich and poor families of Maisthan at 5% level of significance but in case of Sahodawa village, average values of CO_2 emission hh^{-1} differed among rich, medium and poor families (table 50).

Table 470: Tukey's Honestly Significant Difference (HSD)

Location	Family Category (I)	Family Category (J)	Mean Difference (I-J)	Std. Error	P - value
Maisthan	Rich	Medium	0.27	0.12	0.07
		Poor	0.55(*)	0.13	0
	Medium	Poor	0.28	0.13	0.07
Sahodawa	Rich	Medium	1.11(*)	0.17	0
		Poor	3.01(*)	0.17	0
	Medium	Poor	1.90(*)	0.16	0

*denotes significant difference at 5% level of significant

Besides, the independent samples t-test was used to test whether there was significant difference in CO_2 emissions between Sahodawa and Maisthan villages at 5% level of significance. Here it was found that, there was a significant variation in average CO_2 emissions between Sahodawa and Maisthan villages at 5% because the value of Z - stat (-5.24)> z Critical (1.96) and P value was 0.00 (Table 51).

Table 51: Two-tail z test showing differences in CO_2 emission in two villages

CO_2 emission from	z-calculated	P (Z<=z) two-tail	z Critical two-tail
Maisthan	-5.24	0.00	1.96
Sahodawa			

4.7.3 CH_4 Emission from Maisthan and Sahodawa Villages

The result showed that the CH_4 emissions were varied according to family category and types of cattle. Specially, the enteric fermentation and manure management are two main activities responsible for CH_4 emission in both villages. Infact, the CH_4 emission depends upon the different types of cattle and their number.

Explicitly, the record of CH_4 emission by cow/ox due to the enteric fermentation and manure management were differed. These values were 52.73, 23.64 and 0.00 t yr^{-1} due to enteric fermentation while 1.12, 0.50 and 0 t yr^{-1} due to manure management by rich, medium and poor respectively in Maisthan village. Differently, in case of Sahodawa village, the annual CH_4 emission were 41.36, 32.62 and 6.06 t yr^{-1} due to enteric fermentation while 0.88, 0.69 and 0.13 t yr^{-1} by rich, medium and poor households respectively.

The annual CH_4 emission from dung and urine of buffalo were varied in these villages. Specifically, it was found the CH_4 emission from dung and urine of buffalo keeping were 23.76, 52.75 and 0 t yr^{-1} respectively due to enteric fermentation while they were 0.86, 1.92 and 0 t yr^{-1} due to manure management by rich, medium and poor families respectively in Maisthan village. Differently, these values were 22, 23.82 and 20.35 t yr^{-1} due to enteric fermentation while they were 0.8, 0.87 and 0.74 t yr^{-1} due to manure management by rich, medium and poor families respectively in Sahodawa village (table 47).

The annual CH_4 emissions from goat keeping were less in both villages. Particularly, they were 0.22, 0.61 and 2.0 t yr^{-1} due to enteric fermentation while they were 0.01, 0.03 and 0.09 t yr^{-1} due to manure management by rich, medium and poor respectively in Maisthan village but they were more 2, 2.17 and 2.85 t yr^{-1} due to enteric fermentation while they were 0.09, 0.1 and 0.13 t yr^{-1} due to manure management by rich, medium and poor families respectively in Sahodawa village (table 47).

There were very less CH_4 emission by keeping pig and chicken. Specially, the CH_4 emission due to enteric fermentation and manure management were recorded 0.60 and 0.09 t yr^{-1} respectively by poor family in Maisthan village but they were not applied in Shodawa village because there were no any pig and chick farming here. The record of manure management due to chicken keeping were 0.66 and 1.08 t yr^{-1} CH_4 emission by medium and poor families respectively in Maisthan village (table 52).

Total estimated CH_4 emission was 320.33 t yr^{-1} from both villages by keeping the different types of cattle. Out of this, quantities of CH_4 emissions were 162.67 t yr^{-1} and 157.66 t yr^{-1} from Maisthan and Sahodawa villages respectively by keeping livestock, which together can emit 7367.59 t CO_2 equivalent to the atmosphere. The annual CH_4 emission recorded highest 80.11 t by medium family and lowest 3.86 t by poor family in Maisthan village. This is because of large number of buffalo and cow keeping in Maisthan village while there were no buffalo and cow keeping by poor families in this village. In fact, the total CH_4 emission due to cow keeping was 159.73 t. from both villages CH_4 emission, due to buffalo keeping was 147.87 t, due to goat, pig and chick was 12.73 t from both villages (table 52).

Total estimated CH_4 emission was 320.33 t yr^{-1} from both villages by keeping the different types of cattle. Out of this, quantities of CH_4 emissions were 162.67 t yr^{-1} and 157.66 t yr^{-1} from Maisthan and Sahodawa villages respectively by keeping livestock, which together can emit 7367.59 t CO_2 equivalent to the atmosphere. The annual CH_4 emission recorded highest 80.11 t by medium family and lowest 3.86 t by poor family in Maisthan village. This is because of large number of buffalo and cow keeping in Maisthan village while there were no buffalo and cow keeping by poor families in this village. In fact, the total CH_4 emission due to cow keeping was 159.73 t. from both villages CH_4 emission, due to buffalo keeping was 147.87 t, due to goat, pig and chick was 12.73 t from both villages (table 52).

Table 52: CH_4 emission from Maisthan and Sahodawa villages

Types of Cattle	**Village**	**Maisthan village**			**Sahodawa village**		
	HH types	**Rich**	**Medium**	**Poor**	**Rich**	**Medium**	**Poor**
	CH_4 emission types	**CH_4 emission t yr^{-1}**			**CH_4 emission t yr^{-1}**		
Cow/ox	Enteric Fermentation	52.73	23.64	0	41.36	32.62	6.06
	Manure Management	1.12	0.50	0	0.88	0.69	0.13
Buffalo	Enteric Fermentation	23.76	52.75	0	22	23.82	20.35
	Manure Management	0.86	1.92	0	0.8	0.87	0.74
Goat	Enteric Fermentation	0.22	0.61	2.00	2	2.17	2.85
	Manure Management	0.01	0.03	0.09	0.09	0.1	0.13
Pig	Enteric Fermentation	0	0	0.60	0	0	0
	Manure Management	0	0	0.09	0	0	0
Chick	Enteric Fermentation	0	0	0	0	0	0
	Manure Management	0	0.66	1.08	0	0	0

Quantity of CH_4 emission varied according to the types and number of livestock. Generally, rich families like to keep more cows, oxen and buffaloes so the values of enteric fermentation and manure management were higher and ultimately the total CH_4 emission was higher in that case. Most of the households keep cows and buffaloes in Maisthan village whether they were rich or medium families so it was higher CH_4 emission here than that in Sahodawa village. Additionally, pigs and chickens farming were common in Maisthan especial keeping by poor families, whereas they were not allowed in Sahodawa village. This may be another reason of more CH_4 emission in Maisthan than in Sahodawa village.

The profile of Mahottari district showed that rich families keep 1-2 buffaloes or 1 cow and 2 oxen while medium families keep 1 buffalo or 1 cow and 1-2 oxen but poor households keep only 2-4 goats in Tarai as well as 2-4 goats, 2-4 pigs and 3-5 chickens in Bhawar area (CBS, 2011). The quantities of CH_4 emission from the livestock may be similar, however the research related to the estimation of CH_4 emission has not been done yet. Moreover, the CH_4 emission also depends upon the weight of the cattle. Meanwhile, the record of the department of livestock services showed that the number of cows is only 954680 but the number of buffaloes, goats and pigs has increased to 4836984, 8844172 and 1064858 respectively (DoLS, 2012) from 2010 to 2011. So, the estimated total CH_4 emission will be 356189.8, 20028.37 and 376218.2 t respectively by these animals only.

4.7.4 Comparison of CH_4 Emission in Maisthan and Sahodawa Villages

One way ANOVA showed that there was significant variance in CH_4 emission t yr^{-1} hh^{-1} by cattle keeping among rich, medium and poor households at 5% level of significance from both Maisthan and Sahodawa villages since the $P<0.00$ at both cases (table 53).

Table 53: One-way ANOVA of HH based CH_4 emission from Maisthan and Sahodawa villages

Villages		Sum of Squares	df	Mean Square	F	Sig.
Maisthan village	Between Groups	0.12	2	0.06	27.87	0.00
	Within Groups	0.11	53	0.002		
	Total	0.23	55			
Sohadawa village	Between Groups	0.12	2	0.06	34.80	0.00
	Within Groups	0.13	73	0.002		
	Total	0.24	75			

At the same time, HSD Tukey's test showed that there was significant differences ($P<0.05$) in CH_4 emission (t yr^{-1} hh^{-1}) produced by the cattle of each family types from Maisthan village at 5% level of significance. In case of Sahodawa village, it was found that the CH_4 emission by cattle of poor families differed ($P<0.05$) from that of rich and medium households (table 54).

Table 54: Tukey's HSD test of household based CH_4 emission

Location	(I) Variable	(J) Variable	Mean Difference (I-J) t yr^{-1} hh^{-1}	Std. Error	P- value
Maisthan village	Rich	Medium	0.05(*)	0.01	0.00
		Poor	0.12(*)	0.02	0.00
	Medium	Poor	0.07(*)	0.02	0.00
Sahodawa village	Rich	Medium	0.01	0.01	0.66
		Poor	0.09(*)	0.01	0.00
	Medium	Poor	0.08(*)	0.01	0.00

* denotes the mean difference at the 5% level of significant

Moreover, the two- tail Z-test showed that there was no significant difference in CH_4 emissions by cattle keeping from Sahodawa and Maisthan village at 5% level of significance because value of Z -stat (0.09)< z Critical (1.96) and P value was 0.93 (table 55).

Table 48: Independent samples two tail t-test of CH_4 emission according to family types

Ch_4 emission from	Z-calculated	P (Z<z) two-tail test	z Critical two-tail
Maisthan Sahodawa	0.09	0.93	1.96

4.7.5 Sources of CO_2 and CH_4 Emission

There were some similarity and differences in sources of CO_2 and Ch_4 emisions. Generally, the source of CO_2 emision was fuel wood burning in both villages, but the burning of dung cake and dung stick, straw and leaves were only found in Sahodawa village. Similarly, cow, buffalo and goat keeping are common in both villages but pig and chicken keeping were not found in Sahodawa village (table 56).

Sources of CO_2 emission differed according to locations because families living in Sahodawa village have no, or very limited access to the national forest but households of Maisthan village have noany problem in collecting and using firewood. That is why households of Sahodawa village use dung cake and stick, straw, leaf for cooking and heating. Likewise, livestock of Maisthan village were openly grazed in the forest but that was not applicable for livestocks of Sahodawa village.

Table 49: Sources of domestic emission

GHGs	Sources of Domestic Emissions		Emission % by domestic sources in Maisthan village	Emission % by domestic sources in Sahodawa village	Remark
CO_2	Common sources	Fuel wood	99%	90%	1% HH used biogas in both villages
	Differences	Dung cake & stick	Nobody use these materials	7%	
		Straw, litter		2%	
CH_4	Common sources (dung & urine of live stock)	Cow & ox	47.94%	55.27%	
		Buffalo	48.74%	40.97%	
		Goat	1.82%	3.77%	
	Differences	Pig	0.42%	Nobody keeps pig & chick	
		Chick	1.07%		

The proportion of sources of fuel consumption was not same in both villages. Particularly, it was found that, about 99% households used firewood for cooking and heating in Maisthan but in case of Sahodawa village, 90% households used firewood 7% and 2% families used dung cake, stick and other materials simultaneously. About 1% household uses the biogas in both villages. The study done by Bhattrai (2005) showed that about 89.2 % people used firewood for domestic energy in Nepal, this value is matching with the record of households used firewood of Sahodawa village. About 3470224 households have been using firewood and nearly 563126 households have been using cow dung, which is common in Tarai (CBS, 2011).

Likewise the sources of CH_4 emission from dung and urine of cattle was also differed in both villages. They were 47.94% by cow and ox; 48.74% by buffalo; 1.82% by goat; least 0.42% by pig and very less 1.07% by chicken from Maisthan village. The record of sources of CH_4 emission showed that, there were 55.27% by cow and ox; 40.97% by buffalo and only 3.77% by goat. Nobody keeps the pig and chicken in this village. However, there is no any study done on the CH_4 emission by cattle in Nepal.

4.7.6 Management and Policy of CO_2 and CH_4 Emission

The use of dung and urine of livelstock for biogas are the best alternative options to reduce domestic emissions (BSP, 2009). The establishment of biogas has double roles to reduce the GHGs emissions. The first role is the management of dung of cows, buffaloes and pigs to produce biogas as fuel for cooking and heating while the second role is to ease the pressure from the forest by reducing firewood consumption.

The establishment of biogas can play a significant role to manage the cow dung, which is useful to reduce the use of firewood. In reality, the use of biogas can save about 9514.27 t CO_2 which would be emitted from use of firewood by the households of Sahodawa and Maisthan villages together. However, poor communities in Sahodawa village cannot afford to establish a biogas plant because of their low economic capacity (table 52) and high installation cost nearly US$ 300 to 350 per biogas plant of 4 m^3 size (BSP, 2009).

The large number of cattle keeping is showing the potentiality for establishment of biogas plants in these villages. The result showed that, there were more 3020 large cattle and 86 pigs in Maisthan village, which are suitable for establishment of 1215 biogas plants. These are candidate to save 4864.27 t CO_2 which is worth of US $ 24321.35 of certified emission reduction (CER). On the other hand, there may be less number 1162 biogas plants in Sahodawa village because of less number of 2906 large cattle and these plants can save 4650 t CO_2 equivalent burning of firewood which value would be US $ 23247 CER (table 57). Here it is essential to remark that, the rich and medium families have a lot of large cattle so there is high potentiality of installation of biogases in both villages.

Saving the CO_2 by use of biogas plant, indicated to be a candidate for certified emission reduction (CER) under clean development mechanism (CDM) or reducing deforestation and forest degradation (REDD+). Thus economic evaluation of this is essential which showed that establishing biogas plants in these two villages can offer about US$ 47568.35 CER but presently, only 11 households are using the biogas plants, which are less than 1% of total households in these villages. In reality, the record showed that, about 2.43 % of the total households are using biogas in Nepal (CBS, 2011).

Table 50: Valuation of CO_2 saving from biogas

Location	Household category	Total (cow, ox, buffalo)	Total Pigs	No. of Biogas	t CO_2 equivalent	Value US $	Remarks
Maisthan	Rich	1553		621	2485.76	12428.78	Installation cost is not included
	Medium	1462		584	2339.20	11696.00	
	Poor	5	86	10	39.31	196.57	
Sahodawa	Rich	1280		512	2048	10240	
	Medium	1127		451	1804	9018	
	poor	499		199	798	3989	

Nepal has put high emphasis on alternative energy promotion programmes specifically on the establishment of biogas plants. In reality, the dung of the domestic animals can be managed using the biogas which will be helpful to reduce the use of firewood consumption. Hence, the objective of this programme is fully aligned with the climate change policy of 2012, which aims to reduce the GHGs emission using alternative energies. Similarly, the ministry of energy has prioritized use of alternative energy in order to reduce the load shading (MoEST, 2014) as a preferable option. In addition, the department of livestock development under the ministry of agriculture has started to promote the improved variety of livestock keeping, and to integrate it with rural energy transformation (MoAD, 2012). This is why; the Biogas Support Programme (BSP) has been functioning to promote biogas in rural areas and about 260899 domestic biogas plants were installed in over 2800 villages in between 1992 to 2012 in this country.

A standard method and reliable data can guide to develop the policy and plan. This gap has clearly noticed in the preparation of communication report for estimation of GHGs from various domestic sources. In this context, this type of scientific analysis of CO_2 and CH_4 may be helpful to prepare the national communication report for estimation of GHGs from various domestic sources. Additionaly, the estimation will be suitable base to find the proper management options.

CHAPTER 5

5. CONCLUSION AND RECOMMENDATION

The conclusions deal with the brief notes on concrete findings and based on that the further recommendations are presented.

5.1 Conclusion

The research was concluded in six points. They are carbon sequestration potential, exploration of opportunities and challenges of forest carbon trade under the REDD+ programme, evaluation of the sustainability of carbon stock, appraisal of biodiversity status and its relationship with the carbon stock. In addition, effect of drivers of deforestation and forest degradation on carbon stock as well as CO_2 and CH_4 emission from fuel consumption and cattle.

Generally, the higher carbon stock higher was the IVI. However, some species were affected their rank because of effect of carbon stocks. The ranking of plant species based on IVI was not completely represented the carbon stock. So, other criterion was proposed based on Mix (IVI+Carbon).

There were high carbon stocks in collaborative forests in comparison to community forests. In addition, the carbon stocks also varied in different plantation areas for instance, the estimated total carbon stock was found to be highest in Sita community planted forest while it was lowest in Bisbitty public plantation. Equally, the estimated soil carbon varied according to the sites of forests and planted areas. It was found about similar values of soil carbon in collaborative and community forests. However, in case of plantation, the soil carbon was rich in Shreepur PP and Sita CPF because these sites have good soil in comparison to other plantations. The carbon sequestration potential is based on annual or periodic carbon increment. The estimated current annual carbon increment (CACI) was found to be highest in Chyandanda community forest but it was leakage negative in Banke- Maraha CFM. Except Banke-Maraha collaborative forest, other all community managed forests specifically collaborative and community forests as well as public plantation and community planted forests indicated positive increment. In addtiona, the annual carbon sequestration was generally higher in community forests than collaborative while it was higher in public plantations than community planted forests. Therefore, it can be concluded that there is variation in carbon sequestration potential according to adopted management practices.

The community managed forests have immense opportunity of carbon sequestration to be candidate under REDD+ programme. Though, there are many challenges particularly developing the MRV, REL, SES, issues of leakage, linking with the payment mechanism for sub-national projects are some of them. The opportunity and challenges go together under REDD+ programme.

The diameter distribution of community managed forest did not show the normality based on De Liocourt's law. Similarly, checking the values of carbon stock of these forests with Biolley's "Check Method" varied according to DBH class in these forests. Thus, there is less chance of sustainable yield regulation from these forests without applying the scientific forest management. Since the yield regulation based on Biolley's "Check Method" is considered as the most effective tool for controlling the growing stocks especially volume in forest, it can be applied for carbon management with some modification to regulate yield for users and also to prepare for REDD+ programme.

The biodiversity index values were differed in community and collaborative forests. Similarly, these values were also differed in public plantations and community planted forests. Meanwhile, no any significant relationship was found between carbon stock and biodiversity in community managed forest but hump shape relationship between carbon stock and species richness while opposite hump- shaped relationship was found between Simpson's evenness and carbon stock.

Logging, grazing, encroachment, fire and invasive species were five major drivers of deforestation and forest degradation in collaborative forests but underlying causes were different. Especially, smuggling of timbers was very common in Banke- Maraha and Tuteshwarnath CFMs. Moreover, domestic use of timber and firewood was also most common in Banke- Maraha CFM. So, the estimated carbon stock t ha^{-1} was low in Banke- Maraha and Tuteshwarnath CFMs than in Gadhanta- Bardibash CFM. Grazing and invasive species were common drivers of deforestation and forest degradation in community forests, public plantations and community planted forests but level of damage was diversified.

The CO_2 emission due to firewood consumption was found to be higher from Sahodawa village compared to Maisthan village but the quantity of CH_4 emission was higher from Maisthan village than the next village. The higher CH_4 emission, the higher is the potential for biogas plant installation.

5.2 Recommendation

Some areas are very important for further research because of certain limitation, thus they are recommended here.

1. The trend of carbon sequestration is essential to assess in Tarai. This will be helpful to design the future research and demonstration project for forest performance based carbon trade. The intensive studies should be carried out in other areas too in order to prepare the database of forest carbon stock based on forest management types.
2. The ranking of species based on Mix which include carbon and IVI should be tested for other types of forests too so that its performance can be evaluated.
3. The proposed emission reduction plan under REDDprogramme should be expanded for whole Tarai district so that scope of REDD+ project will be broadened and issues of leakage will be addressed, pertinently. The scope of the research should be extended to analysis of the risk of forest carbon market.
4. The small scale forests like public and community planted forests should be bundled with collaborative and community forests to show the credit under the REDD+ programme. Similarly, the bundling of services like carbon sequestration with biodiversity, ecotourism and ecosystem services will be better approach of motivation towards forest management for carbon sequestration and bundling of institution like FECOFUN, ACOFUN and APLFUN to show the unity and strength to formulate user friendly policy.
5. It will be better to check the diameter class distribution based on Meyer's (1943) simplification of De Liocourt's law in order to know how much and from which diameter class should be removed to control the carbon stocks with Biolley's "Check Method" and what will be their effect on carbon sequestration.
6. REDD+ programme has major focus on carbon stock enhancement but biodiversity is considered as co-benefit. Thus, the REDD+ programme should

emphasize on biodiversity conservation and livelihood promotion as well to carry out the demonstration project under the REDD+ programme.

7. It is essential to carry out the detail research work to show effects of drivers of deforestation and forest degradation on carbon sequestration.

8. The national communication report needs the intensive estimation of GHGs, which is not based on the research in depth. Thus the research should be more focused on estimation of CO_2 emission and CH_4 emission from fuel wood burning and cattle keeping. Moreover, other study should be focused on analyzing the best potential options to reduce the use of fire wood, dung cake and dung stick. It is recommended to assess the livestock population and their CH_4 emission factors based on the average weight of animals so that enteric fromentation and manure management can be calculated more precisely.

CHAPTER 6

6. SUMMARY

The research thesis is arranged into six chapters. The first chapter deals with the introduction, which covers the introduction of the study, rational of the study and research objectives. The second one includes the literature review in order to cover the theoretical framework of the research, theory of common resource pools and their management, collective action, history of forest management, forest carbon dynamic, context of sustainability, relation between biodiversity and carbon, drivers of deforestation and forest degradation and climate change process drivers. Likewise, third chapter focuses on materials and method, which consist of method of data collection and analysis. Meanwhile, the fourth chapter encompasses the results and discussion based on the research objectives. The fifth chapter comprises the conclusion and recommendation while the sixth chapter encompasses summary of the research and list of published articles based on the research.

Besides, the references cited in the the research thesis, annexes and published articles are also included as part of thesis at the end while the cover part consists of abstract, table of contents and acknowledgement. This research work is a contribution in forest carbon trade potential, which will be additional opportunities for Nepal.

The research was begun with the concept of role of forest for carbon sequestratiom to capture the atmospheric CO_2, which is beneficial to reduce the global warming. Such research has not carried out particularly in Tarai. Thus this study objectively carried out to show the carbon sequestration potential in community managed forests; to explore the opportunity and challenges of forest carbon trade under the REDD+ programme; to evaluate the sustainability in carbon stocks of community managed forests; to appraise the biodiversity status and its relationship with the forest carbon stock; to assess the effects of drivers of deforestation and forest degradation on carbon stocks in community managed forests and to quantify the CO_2 and CH_4 emission from domestic fuel and livestock keeping of household living living near to forest and distant from the forests.

6.1 Carbon Stock Status and Dynamic

The task of carbon stock is globally concerned with ecosystem services and environmental services. The REDD+ programme has been functioning as an institution for performance based carbon trade. So, the sufficient record of carbon stock change is needed. Thus, three collaborative forest, three community forests, three public plantations and three community planted forsts were selected, randomly. Randomized block design (RBD) was set for data collection from collaborative and community forests while complete random design was set for data collection from public plantations and community planted forests. The collaborative forest and community forests were stratified based on the stage of the plants, they are regeneration, pole and tree and the data were collected applying the stratified random sampling. On the other hand, simple random sampling was applied to collect the data from public plantations and community planted forests. The number of sample plots was determined based on the optimum allocation method (coefficient of variables) for community and collaborative forests while it was fixed by maintaining 1% sample intensity. Then the permanent sample plots were established in the field and the height and DBH were measured. Samples of herbs, shrubs, litter, grasses and soil were collected from the sample plots. For, tree stratum 20m x 25m sample plot was established and nested plots for poles (10m x 10m), sapling (5m x 5m), seedling (5m x 2m) and litter, herbs and grasses (1m x 1m) were established simultaneously. The soil sample plot was established in the centre of the nested plot as well. There was no any tree in public plantation and community planted forest so plot size of tree is not applicable otherwise same process was applied for these sites too.

The estimated records of carbon stock were the highest 274.67 t ha^{-1} in Gadhanta-Bardibash CFM, the least 197.11 t ha^{-1} in Banke- Maraha CFM and the 222.58 t ha^{-1} in Tuteshwarnath CFM. Similarly, the records of carbon stock were found to be highest 172.05 t ha^{-1} in Chure- Parwati CF, the lowest 92.08 t ha^{-1} in Chyandanda community forest and 163.95 t ha^{-1} in Baudh community forest.

The high records of carbon stock were found 140.32 t ha^{-1} in Shreepur PP and 148.89 t ha^{-1} in Sita CPF. The medium records of carbon stock were 57.80 t ha^{-1} in Ramnagar CPF and 52.29 t ha^{-1} in Banauta PP. Meanwhile, the least records of carbon stock were 30.34 and 30.88 t ha^{-1} in Bisbitty PP and Jogikuti CPF respectively.

6.2 Issues of Sustainable Forest Carbon Management

The other major concern of this research was to evaluate the sustainability in carbon stock of community managed forests. The same biophysical data were used and they were evaluated applying Biolley's Check Method & De Liocourt's Law. The records of carbon stocks of Banke- Maraha CFM, Tuteshwarnath CFM, Gadhanta- Bardibas CFM were overstocked and records of carbon stock of community forests were understocked. This was not applied for public plantation and community planred forests. No any forests showed the sustainability.

6.3 Opportunity and Challenges of Forest Carbon Trade

The biophysical data were collected for three years from establishing the permanent sample plots.

The result showed that, over all carbon sequestration was 3915.82 t. However, the emission was recorded in Banke- Maraha CFM, where there was annual carbon loss as leakage -2.90 t ha^{-1} of CO_2 emission and total leakage was -5075.17 t, if the whole study area is assumed as one REDD+ research project. The other lower but positive carbon sequestration was 2.40 t ha^{-1} of Tuteshwarnath CFM and total carbon sequestration was 2934.47 t. Another low value of carbon sequestration was recorded about 2.48 t ha^{-1} by Gadhanta- Bardibash CFM so the total removal carbon sequestration was 3056.19 t. On the other hand, the carbon sequestration rates were higher of community forests, they were 6.98, 5.56 and 9.45 t ha^{-1} by Baudh, Chure-Parwati and Chyandanda CFs respectively so the total carbon sequestration were 385.44, 2338.96 and 275.93 of Baudh, Chure- Parwati and Chyandanda CFs respectively.

The carbon sequestration depends up on the CACI, the records of the CACIs were varied in plantation so the removal of CO_2 also varied. The annual records of carbon sequestration were remarkably higher 19.82, 17.80, 13.64 and 11.00 t ha^{-1} of Shreepur PP, Banauta PP, Bisbitty PP and Sita CPF respectively so the total carbon sequestration were 176.38, 131.73, 85.93 and 47.52 t by Shreepur PP, Banauta PP, Bisbitty PP and Sita CPF respectively. However, the records of carbon sequestration were lower 4.60 and 6.34 t ha^{-1} of Ramnagar CPF and Jogikuti CPF respectively and hence the total removal of carbon sequestration was 17.07 and 46.22 t in Ramnagar CPF and Jogikuti CPF respectively.

The total monetary value of carbon sequestration in the natural forests and plantation was US$ 5967.62. Out of this, estimated monetary value of carbon sequestration in the community and collaborative deducting the leakage from Banke- Maraha collaborative forest was US$ 3580.85 whereas the estimated value of carbon sequestration in public plantation and community planted forest was US$ 2386.77.

The records of carbon sequestration varied in community managed forests and hence their values were also varied. The estimated values of carbon sequestration were found to be higher US$ 83.99 and 74.85 in Shreepur and Banauta PPs respectively. Medium values of carbon sequestration US$ 33.37, 43.84 and 33.37 were found in Chyandanda CF, Sita CPF and Chyandanda CF respectively. The lower values were US$ 27.64, 26.87 and 26.48 found in Baudh CF, Jogikuti CPF and Chure- Parwati CF respectively. The very lower values of carbon sequestration were recorded US$ 17.34, 11.00 and 10.54 in Ramnagar CPF, Tuteshwarnath CFM and Gadhanta- Bardibash CFM respectively while the lowest and negative leakage value was recorded US$ -12.64 in of Banke- Maraha CFM. These evidences showed the high opportunity of carbons sequestration in community managed forests. However, there are many challenges like developing the MRV, designing the RL, setting the SES and controlling the leakage.

6.4 Relationship Between Biodiversity and Forest Carbon

Same biophysical data were used to find out the relationship between plant biodiversity and forest carbon. They were evaluated following two major steps. Firstly, the relationship was assessed between carbon stocks and species richness and secondly it was appraised between carbon stocks and Simpson's evenness.

The R^2 values of relationship between carbon stock and species richness were the lowest 0.1 in Banke- Maraha CFM and highest 0.34 in Chyandanda CF. The estimated R^2 values were very low 0.17, 0.17, 0.19, 0.20 in Banauta PP, Ramnagar PP, Gadhanta- Bardibash CFM and Jogikoti CPF respectively. Similarly, the R^2 values were also low in the relationship between carbon stock and Simpson's evenness, they were lowest 0.10 and highest 0.32 in Banke- Maraha CFM and Bisbitty PP respectively. The hump- shaped relationship exists between species richness and carbon stock while the opposite hump- shaped relationship was found between carbon stock and Simpson's evenness.

6.5 Drivers of Deforestation and Forest Degradation

Drivers of deforestation and forest degradation are one of the major factors affecting on the carbon stock. The carbon stock can be enhanced but it is essential to clearly identify and control the drivers of deforestation and forest degradation and their underlying causes. Generally the environmentalists have interest not to degrade the environment and not to exploit the common resources so this was theoretically framed under the Garrett Herdin's theory as a Tragedy of commons. The studies on assessment of drivers of deforestation and forest degradation and their underlying causes are very limited in Nepal especially in central part of Tarai. Therefore, the socio-economic data were collected to find the data regarding drivers of deforestation and forest degradation and their underlying causes as well as effects of forest management and protection units on forest carbon stock. Also, the key informants interview and workshops were organized to gather the data.

The result showed that, major drivers like logging, grazing and invasive species are common but their underlying causes were different in community and collaborative forests. In the past, the Churia forest was encroached for people's settlement. Other noticeable fact is the magnitude of effect of drivers of deforestation and forest degradation is not similar in all community and collaborative forests. The activeness of protection and management unit also plays a vital role in deforestation and forest degradation.

Illegal logging was not observed in public plantations except felling of four stems from Shreepur public plantation but it is common in community planted forests. However, expansion of invasive species and grazing are common in both types of forests. Forest fire is occasionally observed in community planted forests, which is not seen in public plantations. The drivers of deforestation and forest degradation have been chiefly contributing in emission.

6.6 CO_2 and CH_4 Emission From Domestic Fuel and Cattle

Most of the people have been using the firewood for cooking and heating in Nepal. Their major occupation is farming and cattle keeping. The use of fuel like firewood, dung, litter and crop residues is responsible for CO_2 emission while the dung and urine of cattle are accountable for CH_4 emission. Such types of research works have not done before, thus this work is focused on assessment of CO_2 and CH_4 emission from use of domestic fuel and cattle keeping.

Maisthan village, which is instant to the forest and Sahodawa village, which is distant from the forest of Mahottari district was selected for this task. The record of total household was collected from centre bureau of statistics (CBS, 2011) and village profile. Next, these households were categorized into three groups explicitly rich, medium and poor applying the participatory well being ranking process. Total 404, 424 and 303 households were in rich, medium and poor respectively in Maisthan village while they were 420, 540 and 540 respectively in Sahodawa village. Lastly, 138 households were selected randomly from these villages for sampling, maintaining 5% sample intensity. They were 60 samples including 22 rich, 22 medium and 16 poor households were of Maisthan village while 78 samples (24 rich, 27 medium and 27 poor households) of Sahodawa village. Meanwhile, a short meeting was organized to find the best management options of CH_4 emission targeting to reduce the source of CO_2 sand CH_4.

The records of fuel consumption were taken in April (summer) and January (winter) from selected families. Then, fuels used by each family were weighted in the morning and evening for 7 days in summer and 7 days in winter to determine the daily consumption. Similarly, the records of cattle keeping like number of oxen, cows, goats, buffalos, pigs and chicken were taken from selected households using participatory rural appraisal (PRA) technique. The simple statistics and method suggested by IPCC (2006) was applied to analyze the collected dta.

The result showed that total records of CO_2 emission by rich, medium and poor were 1811.94, 1788.01 and 1192.31 t yr^{-1} respectively in Maisthan village while they were 3074.82, 3574.26 and 2586.60 t yr^{-1} respectively in Sahodawa village. The CO_2 emission yr^{-1} hh^{-1} were less 4.48 t, 4.22 t and 3.93 t by rich, medium and poor families respectively in Maisthan village than 7.32 t, 6.62 t and 4.79 t t by rich, medium and poor families respectively in Sahodawa village. The daily use of firewood in summer were 6.58, 6.14 and 5.89 kg day^{-1} by rich, medium and poor families respectively in Maisthan village while these were 11.50, 9.60 and 6.90 kg day^{-1} by rich, medium and poor families respectively in Sahodawa village. In winter, the firewood consumption were 7.39, 6.89 and 6.81 kg day^{-1} by rich, medium and poor families respectively in Maisthan village while they were 13.37, 11.02 and 8.02 kg day^{-1} by rich, medium and poor families respectively in Sahodawa village.

The result showed that the CH_4 emissions were varied according to family category and types of cattle. The record of CH_4 emission yr^{-1} due to enteric fermentation by cow/ox were 52.73 and 23.64 t by rich and medium families respectively while they were 1.12 t and 0.50 respectively CH_4 emission yr^{-1} due to manure management in Maisthan village. In case of Sahodawa village, the annual CH_4 emission were 41.36, 32.62 and 6.06 t due to enteric fermentation by rich, medium and poor respectively while they were 0.88, 0.69 and 0.13 t due to manure management by rich, medium and poor respectively.

The annual CH_4 emission from keeping buffalo were 23.76 and 52.75 t by rich and medium families respectively due to enteric fermentation while they were 0.86 and 1.92 t by rich and medium families respectively due to manure management in Maisthan village. These values were differed in Sahodawa village, they were 22, 23.82 and 20.35 t due to enteric fermentation by rich, medium and poor respectively while they were 0.8, 0.87 and 0.74 t due to manure management by rich, medium and poor respectively. The annual CH_4 emission from goat keeping were very less annual CH_4 emission by keeping pig and chicken. The CH_4 emission due to enteric fermentation and manure management were recorded 0.60 and 0.09 t respectively by poor family in Maisthan village but they were not applied in Shodawa village because there were no any pig and chick farming here. The record of manure management due to chicken keeping were 0.66 and 1.08 t CH_4 emission by medium and poor families in Maisthan village.

6.7 List of Published Articles Based on The Research

Followings are the list of published articles and full articles are available in annex 4.

1. Mandal, R.A., Dutta, I.C., Jha, P.K., Karmacharya, S.B. & Chaudhary, A.K. (2014). Valuation of CO_2 sequestration in public plantations and community planted forests in Tarai, Nepal. *e-planet*, **11**(2), 1-7 . URL: http://e-planet.co.in/
2. Mandal, R.A., Dutta, I.C., Jha, P.K., Karmacharya, S.B. & Haque S. (2013). Evaluating Public Plantation and Community Planted Forests under CDM and REDD+ Programme for Carbon Stock in Nepal. *International Journal of Conservation Science,* **4**(3), 347-356. full article available on www.ijcs.uaic.ro
3. Mandal, R.A., Dutta, I.C., Jha, P.K., Karmacharya, S.B. & Yadav B.K.V. (2013). Relationship between carbon stock and plant biodiversity in collaborative forests in Tarai, Nepal. Hindawi Publishing Corporation, International Scholarly Research Network (ISRN) Botany, Volume 2013, Article ID 625767, 7 pages. URL: http://dx.doi.org/10.1155/2013/625767

4. Mandal, R.A., Dutta, I.C., Jha, P.K., Karmacharya, S.B., Yadav, K., Yadav, B., Thapa, U. & Haque S.M. (2012). Effects of Drivers of Deforestation and Forest Degradation on Forest Carbon Stocks in Collaborative Forests, Nepal. *International Journal of Conservation Science*, **3**(4), 325-338. URL: www.ijcs.uaic.ro

5. Mandal, R.A., Dutta, I.C., Jha, P.K. & Karmacharya, S.B. (2013). Evaluating sustainability in community and collaborative forests for carbon stocks. *International Academy of Ecology and Environmental Sciences*, **3**(2), 76-86 URL : http://www.iaees.org/publications/journals/piaees/onlineversion.asp

6. Mandal, R.A., Dutta, I.C., Jha, P.K. & Karmacharya, S.B. (2013). CO_2 and CH_4 Emission from Domestic Fuel and Livestock Keeping in Tarai and Bhawar in Nepal: A Household-level Analysis. *Environment and Natural Resources Journal*, **11**(1), 1-11. URL: http://www.ennrjournal.com/2013_v11_n1.htm

7. Mandal, R.A., Dutta, I.C., Jha, P.K. & Haque, S.M. (2013). Potential Carbon Offset in Public Plantation, Tarai, Nepal: Offering Opportunity for REDD+ and Soil Fertility. *International Journal of Ecology & Development* (India), URL:isder_ceser@yahoo.co m

8. Mandal, R.A., Yadav, B.K., Yadav, K.K., Dutta, I.C. & Haque, M.S. (2013). Biodiversity comparison of natural *Shorea robusta* mixed forest with *Eucalyptus camaldulensis* plantation in Nepal. *Scholars Academic Journal of Biosciences* (*SAJB*), **1**(5), 144-149 ©Scholars Academic and Scientific Publisher, (An International Publisher for Academic and Scientific Resources) URL:www.saspublisher.com

Two more papers have accepted and they are in press:–

9. Mandal, R.A., Dutta, I.C., Jha, P.K. & Karmacharya, S.B. (2014). Carbon Sequestration Potential in Community and Collaborative Forests in Terai, Nepal. *Tropical Ecology* (Accepted 11/21/2014).

10. Mandal, R.A., Dutta, I.C., Jha, P.K. & Karmacharya, S.B. (2014). Effects of Forest Carbon on Ecological Value of Species in Collaborative Forests, Tarai, Nepal. *Conservation & Science* (Accepted 10/17/2014).

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Annexes

Annex 1: Wood density of plants species

S. No.	Local name	Botanical name	Specific wood density (g/cc)
1	Sal	*Shorea robusta*	0.88
2	Asna	*Terminalia tomentosa*	0.75
3	Botdhairo	*Lagerstroemia parviflora*	0.62
4	Khirro	*Sapium insigne*	0.4
5	Sindure	*Mallotus philipinensis*	0.64
6	Satisal	*Dalbergia latifolia*	0.75
7	Raj briksha	*Cassia fistula*	0.71
8	Aule	*Croton roxburghii*	0.48
9	Jamun	*Eugenia jambolana*	0.68
10	Siris	*Albizzia procera*	0.52
11	Banjhi	*Anogeisus latifolia*	0.78
12	Odal	*Sterculia villosa*	0.31
13	Kushum	*Schleichera trijuga*	0.96
14	Khayar	*Acacia catechu*	0.88
15	Amala	*Phyllanthus embelica*	0.76
16	Tantari	*Dillenia pantaguana*	0.53
17	Sissoo	*Dalbergia sissoo*	0.76
18	Karma	*Adina cordifolia*	0.59
19	Semal	*Bombax ceiba*	0.25
20	Chatiwan	*Alstonia scholaris*	0.4
21	Sandan	*Desmodium oojeinense*	0.64
22	Barro	*Terminalia belerica*	0.76
23	Gamhari	*Gmelina arborea*	0.41
24	Harro	*Terminalia chebula*	0.96
25	Bhalayo	*Semecarpus onacardium*	0.34
26	Bael	*Aegle marmelous*	0.771
27	Kadam	*Anthocephalus chinensis*	0.36
28	Gayo	*Bridelia retusa*	0.71
29	Mashala	*Eucalyptus camaldulensis*	0.73
30	Parjat	*Nyctanthes arbor-tristis*	0.88

Annex 2. Brief Questionnaire used for listing the drivers of deforestation and forest degradation

Q # 1. What are drivers of deforestation, please list out?

Also list out the underlying causes of deforestation?

Drivers of deforestation				
Underlying causes				

Prioritization of drivers of deforestation: using pair wise ranking.

List of drivers				

Q# 2. What are drivers of forest degradation, please list out?

Prioritization of drivers of forest degradation using pairwise ranking:

List of drivers				
Underlying causes				

Annex 3. Brief Report of workshop organized on analysis of drivers of deforestationa and forest degradation

The meeting was held on 08/09/2012 on the chairmanship of Raghunath Prashad Yadav, Chairman of Banke-Maraha Collaborative Forest, Mahottari. The meeting was discussed on the following issues.

Participants

1. Ragunath Prashad Yadav
2. Vijay Prashad Yadav
3. Ram Lalit Sah
4. Ram Lalit Yadav
5. Tej Prashad Shrestha
6. Ranjana Shrestha
7. Krishna Bahadur Gurung
8. Keshav Das
9. Kabita Yadav
10. Tilak Kumar Jha
11. Rabindra Uprety
12. Purna Sankar Jha
13. Kumar Lama
14. Raj Kishor Sah
15. Ghanshyam Jha
16. Ram Ashis Yadav
17. Raj Kumar Thakur
18. Ram Asheshwar Mandal

Listed drivers

Mainly, there are five drivers of deforestation and forest degradation in this forest while there are twelve underlying causes. The degree of damages and nature of damages were different.

1. Logging: Highly affects the tree and large sized pole especially of *Shorea robusta*.
2. Grazing: It affects regeneration (seedling & sapling), grasses, herbs and shrubs.
3. Invasive species: It damages the regenerations. This also stops the seed reaching to the ground.
4. Fire: It affects small plants like seed Regeneration (seedling & sapling), grasses, herbs and shrubs. It also damages the litters, deadwood and logs.
5. Encroachment: Whole forest was converted into agriculture and other purposes.

On the other hand activeness and mobilization of official staff were affecting the damages in the forests. Effective mobilization of the staff can reduce the damages in the forest while the negligence may increase the damages.

Annex 4: Photographs showing instruments, filed data collection and analysis

a. Photographs of instruments used for field data collection

GPS used in study

Clinometer used in study

Diameter tape and Linear tape

Soil corer

Sickle, hammer, Kuto and peg

Calibrating weighing machine

b. Photographs showing field data collection

Going to field for data collection

Alignment of sample plot in the field

Soil sample collection

Soil sample collection

Collecting herbs, grass and litter

Measuring trees