Impact of Biogas Plant on Forest Community and Carbon Stock in Western Nepal

A Thesis Subimited for the Partial Fulfilment of the Requirementments for the Master' Degree in Botany

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DECLARATION

I, Shanti Pandey, hereby declare that the work presented in this dissertation is my own original work and has not been submitted for any other academic degree. All the sources of information have been specifically acknowledged by reference wherever adopted from other sources.

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RECOMMENDATION

This is to certify that **Shanti Pandey** has completed the dissertation work entitled **"Impact of Biogas Plants on Forest Community and Carbon Stock in Western Nepal"** under our supervision. The entire work is based on her original work and has not been submitted in any other academic degree. I, therefore, recommend this dissertation work to be accepted for partial fulfillment of Masters' degree in Botany from Amrit Campus, Institute of Science and Technology, Tribhuvan University.

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LETTER OF APPROVAL

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ABBREVIATIONS AND ACRONYMS

asl	-	above sea level
C	-	Carbon
°C	–	Celsius
CF	-	Community Forest
CFUGs	-	Community Forest Users Groups
cm	-	centimeter
DBH	-	Diameter at breast height
DFRS	-	Department of Forest Research and Survey
GtC	-	Gigatons of carbon
ha	–	hectare
HCF	-	Harsa community forest
HH	-	Household
IVI	-	Importance Value Index
Kg	-	Kilogram
No.	-	Number
Pls	-	plants
SCF	-	Sarsa community forest
T	-	Tons
UNFCCC	-	United Nations Framework Convention on Climate Change

ABSTRACT

In Nepal, the rural residential sector is highly dependent on firewood energy, which is the major cause of deforestation. Biogas is one of those and has become an important alternative energy source that reduces rural dependence on fuel-wood consumption and helps in forest conservation. These forests play an important role in reducing global warming and climate change by conserving atmospheric carbon dioxide (CO_2). Therefore, this study aimed to assess the impact of the biogas plant on fuel consumption in the Kaligandaki rural municipality, Gulmi district, Nepal. Two different community forests users' groups (CFUGs) were selected for the study namely, Harsa Community Forest (HCF) users' and Sarsa Community Forest (SCF) users' group. To assess the Important Value Index (IVI), species diversity, regeneration, and carbon stock, in total 40 sample plots (20 plots in each forest) of 10m radius were sampled using systematic random sampling method. Within the 10m radius plots, 2 subplots of 5m radius were laid for shrubs and 3 subplots of 2m radius for herbs. Tree biomass was estimated using an allometric equation, and regeneration was estimated by calculating the density of each species in seedling, sapling, and tree phases. To know about biogas plant, data were collected from field observation and personal interview. Of 40 households, 20 were selected for each forest user group in the Kaligandaki rural municipality. The carbon stock of HCF was found to be slightly higher (38.46 t/ha) than in SCF (34.46 t/ha) and increased with increasing use of a larger number of biogas plant users' group. Similarly, total species diversity was found to be higher in HCF, but the diversity of herbs species was higher in SCF. HCF had a very good regeneration status with 12715 seedlings/ha, 6025 saplings/ha and 1230 trees/ha compared to SCF. The open canopy of HCF might have favoured the regeneration of a larger number of seedlings and saplings. This result revealed that the ground vegetation and regeneration was high in the less dense canopy forest and the installation of biogas plants helped in forest conservation.

Keywords: Kaligandaki rural municipality, Carbon stock, Regeneration, Diversity, Important value index

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CHAPTER 1: INTRODUCTION

1.1 Background

In Nepal, forests cover 5.96 million ha (40.36%) and other forests cover 0.65 million ha (4.38%). Forests and other woodland together comprise 44.74% of the total area of the country (DFRS, 2015). Nepal's forest contributes approximately 1,054.97 million tons (176.95 t/ha) carbon stock. Tree component constitute 61.53%, forest soil 37.80% and litter and debris constitute 0.67% (DFRS, 2015). The carbon stock increased with the duration of management (Thapa Magar *et al.*, 2015) but due to population growth, every year 13 million ha of forests are destroyed or degraded (CBD, 2011). Therefore, for the conservation and protection of the forests, community forestry program has been adopted worldwide.

The community forest (CF) is a branch of forestry in which the local community plays a significant role in forest management. In the 1970s, the CF program was started in Nepal. These forests have multiple environmental and socio-economic functions that play a vital role in sustainable development. CF is considered as one of the most successful natural resource management practices (Acharya, 2004) and it significantly contributes to the reversal of deforestation and forest degradation (Nagendra *et al.*, 2008). These forests act as a source of carbon sink, storing about 20% of the total carbon stock (Pokharal and Byrne, 2009) with a sequestration rate of 1-5 Mg ha^{-1} (Pokharal *et al*., 2007). CF has found to sequester carbon 1.8 t/ha/year (Baral, 2010). A total of 2237670.5 ha of CF was handed over to 22,266 community forest users' group through the country (DOF/CFD, 2018).

Regeneration is the presence of young plants in the growth stage in the forest. Forests that have the highest regeneration have the highest carbon sequestration. The regeneration status of a forest indicates its health and vitality, while a healthy forest ensures good future regeneration. The regeneration and productive character of the forest is determined by the presence of different age groups of seedlings, saplings and trees (Chauhan *et al*., 2008). Deforestation, overexploitation of resources, grazing, fragmentation, industrialization, and many other factors are responsible for the depletion and degradation of forests and regeneration. Regeneration is said to be good if the forest has seedling >5000 and sapling >2000 per ha (HMG, 2004) (cited in Pandey *et al*., 2012). Regeneration of Sal was higher than other associated species in the Terai and Churia forest of Nepal (DFRS, 2014 a & b).

Carbon stock is the quantity of carbon contained in a 'pool', which means a reservoir or system that has the capacity to accumulate or release carbon (FAO, 2003). In the context of forest, carbon stock refers to the amount of carbon stored in the world's forest ecosystem, mainly in living biomass and soil but to a lesser extent also in dead wood and litter. Forests play an important role in reducing ambient carbon dioxide (CO_2) levels, since they sequester 20-100 times more carbon per unit area than croplands (Brown and Pearce, 1994). The rate of C sequestration is much faster in young and regenerating forests, but the C-stock is higher in old and mature forests (Luyssaert *et al*., 2008; Nair *et al*., 2009). The world's forest contains up to 80% of all C above ground and nearly 40% of all terrestrial carbon below ground (soil, litter, and roots) terrestrial carbon (Dixon *et al.*, 1994). In the world's forests, the tropical forests stored 471 Gt C (55%), the boreal forests stored 227 Gt C (32%) and the temperate forests stored 119 Gt C (13%) (Pan *et al*., 2011).

In Nepal, the rural residential sector is highly dependent on firewood energy, which is the major cause of deforestation. About 77% of the country's population demand is fulfilled by firewood (WECS, 2010). Environmental deterioration is the result of direct or indirect reduction of the forest area. Alternative sources of energy must be introduced to stop environmental and agricultural deterioration (Leermakers, 1992). Biogas is one of those and has become an important alternative energy source that reduces rural dependency on the consumption of fuel and wood from forests. Nowadays, the dependency on firewood decreased after the use of biogas and the consumption of 42.8% wood was reduced after the installation of biogas (Shrestha *et al*., 2019).

The installation of a biogas plants in Nepal was started in 1992 AD. Nepal's government has provided a subsidy to encourage the installation of a biogas plant in rural areas, which ultimately leads to the environmental protection of the entire country due to the reduction of dependence on forest for firewood (BSP, 2007). The mixture of gas produced by methanogenic bacteria acting on biodegradable materials in anaerobic conditions is called biogas. It is mainly composed of 50-70 % methane, 30-40 % CO_2, and some other gases (BSP, 2012). The biogas plant uses raw materials that are locally available, and the gas obtained from it can be cheaper and reliable. Use of biogas saves users time, improves their health and sanitation, maintains cleanliness, and reduces user's expenses on firewood. Biogas provides fuel as a source of energy that helps conserve the environment (BSP, 2005). In Nepal, the potential household that can install biogas plants is 19,37,006 (BSP, 2007). By the end of 2006, a total number of 157675 biogas plants had been installed, saving 3,05,889 tons of fuelwood per year (BSP, 2007). The mountain region, due to the cold temperature, is not feasible for biogas production. Only around 1% of biogas plants potential falls in mountainous region, whereas the hill shares 37% and the terai shares 62 % (BSP, 2007). Similarly, in the study area (Gulmi district), biogas plants installation has been started since 2052 B.S.

Knowledge on the impact of biogas on reducing the use of firewood and helping in forest conservation in the Gulmi district is still inadequate, but few research works have been done in other parts of our country such as Ishu *et al.* (2019) in Chitwan, Adhikari (2002) in Bardia. Thus, to fulfill this research gap, this study was done. The study was carried out in western Nepal to reveal the impact of the biogas plants on the forest community and carbon stock.

1.2 Justification

Numerous research studies are conducted related to carbon stock and regeneration in CF in various parts of Nepal. But there are few research works related to the impact of the biogas plants on fuel consumption and forest conservation. So, this study was carried out in two community forests in Gulmi district, where there were different numbers of households having biogas plants. The information obtained from this research will be helpful in evaluating the role of biogas plants for forest conservation and, ultimately, in planning and implementing the biogas program.

1.3 Hpothesis

i. Installation of biogas plant will help in carbon stock restorations

1.4 Research Questions

i. Is there any variation in plant diversity, carbon stock, and regeneration between two community forests having different numbers of households with biogas plant installationIs there any relationship between the carbon stock of trees and the installation of the biogas plants?

1.5 Objectives

The general objective of this research was to know the tree carbon stock and regeneration of two community forests. The specific objectives were as follows:

i. To measure the plant diversity in two community forests having different numbers of households using biogas plants.
ii. To compare the regeneration status of trees in two community forests having a different number of households using biogas plants.
iii. To compare the carbon stock in two community forests.

1.6 Limitation

i. Due to the lack of an instrument, the canopy cover was estimated using the visual method.
ii. Only the tree carbon stock of trees was calculated and those of shrubs, herbs was not measured.

CHAPTER 2: LITERATURE REVIEW

2.1. Biogas in Nepal

Fuelwood is the main source of energy used daily by the massive rural population of Nepal (BSP, 2012). This total dependence on firewood as a source of energy has resulted in deterioration of the quality and quantity of forests and has posed a serious threat to maintaining ecological balance, causing various problems like deforestation, flood, global warming, soil erosion, landslides, climate change, and severe health problems (Shresth *et al.,* 2019). Use of biogas saves users time, improves their health and sanitation, maintains cleanliness, and reduces user's expenses, since biogas provides fuel as a source of energy that helps to conserve the environment (BSP, 2005). Generally, the residential sector is the largest consumer sector of total energy. The rural population is highly dependent on firewood energy, which is the major cause of deforestation. About 77% of the total energy demand of the country is fulfilled by firewood (WECS, 2010). The reduction of forest area has directly or indirectly resulted in environmental deterioration. Alternative sources of energy must be introduced to stop environmental and agricultural deterioration (Leermakers, 1992). Biogas is one of those and has become an important alternative energy source for the rural dependency on fuelwood consumption from forest. In 1992 AD, the installation of a biogas plants in Nepal was started. The government of Nepal has been promoting biogas as an alternative energy and clean development mechanism in the Terai region of Nepal for the past few decades. In recent decades, conservation-related organizations such as National Trust for Nature Conservation (NTNC) and Worldwide Fund Nepal (WWF-Nepal) have also promoted the use of biogas in the Terai Arc Landscape (TAL) area to reduce pressure on forest resources. Furthermore, the main goal of the USAID-funded ‘Hariyo Ban Project’ is to minimize threats to forest resources and help conserve biodiversity. In this regard, biogas plants have been promoted in the TAL area as a means of alternative energy to reduce pressures on forest resources. Nepal is gradually shifting towards the use of alternative energy sources to minimize the dependence of forest resources, ultimately contributing to forest conservation.

2.2. Forests and carbon stock

Forest play very important role in the global carbon cycle through exchange of carbon between the land and the atmosphere (Dixon *et al.*, 1994). The rate of carbon sequestration is much faster in young and regenerating forests, but carbon stock is higher in old and mature forests (Luyssaert *et al*., 2008). The world's forests contain up to 80% of all above-ground carbon and almost 40% of all terrestrial carbon (soil, litter, and roots) below-ground (Winjum *et al.*, 1992). In Nepal, forest occupies 40.36% of the total area of the country. Out of the total area 23.04% lie in Churia and 6.90% in Terai. The total above-ground in the forest of Nepal is 1,159.65 million tones (194.51 t/ha). The total carbon stock in Nepal's forest has been estimated as 1,054.97 million tones (176.95 t/ha). Tree components constitute 61.53%, forest soils 37.80% and litter and debris constitute 0.67% (DFRS, 2015).

The CF of Nepal acts as a major source of C-stock of CO_2, which will help minimize climate change (Pokharel and Byrne, 2009). The vegetation types, age of the stand, the surrounding environment, management activities, and other human-induced disturbances are the key factors in variation of carbon stock and carbon sequestration in forests (Pandit, 2014). In collaborative forest there is positive and very weak relationship between carbon stock and species richness (Mandal *et al*., 2016). The standing C-stock of old growth forest is higher than the newly regenerating forest (Singh and Singh 1992).

In Nepal, different researchers have found different amounts of carbon stock in different types of Sal Forest (Terai and Hill Sal Forest). In nine community-managed hill Sal Forest using allometric equation of Chave *et al*. (2005), 120 Mg ha^{-1} mean C-stock was found (Thapa Magar and Shrestha, 2015). A total of 244 and 140 Mg ha^{-1} C-stock in community managed hill Sal Forest and government managed hill Sal Forest of Karyakhola Watershed was found by using "moist forest" allometric equation (Chave *et al*., 2005; Mbaabu *et al.,* 2014) and 132-202 Mg ha^{-1} living biomass C-stock in three Sal dominated collaborative forest was reported (Mandal *et al.*, 2015). Similarly, Pathak (2015) reported a sequestration rate of 115 Mg ha^{-1} C-stock and 0.8 Mg ha-1yr-1C in semi-natural tropical Sal Forest. The mean C-stock in Sal-dominated forests managed by the community and the government around Bees Hazaare Lake was reported to be 121.7 Mg ha^{-1}, Similarly, the C-stock in the community-managed forest (165.2 Mg ha-

^{1}) was reported to be higher than the government-managed forest (78.2 Mg ha^{-1}) (Sharma, 2016). Total carbon stock in the CFs of the terai and the hills were to be 479.29 t/ha and 234.54 t/ha respectively (Pandey and Bhusal, 2016). The biomass carbon stock density was higher in *Shorea robusta* CFs of terai (384.20 t/ha) than in hill forest (123.15 t/ha). Carbon densities of different carbon pools such as tree, sapling, leaf litter, grass and herbs were significantly higher ($p < 0.05$) in the Terai than in the hill forest whereas dead wood and stumps and the soil organic carbon density were not found to be significantly different in these regions (Pandey and Bhusal, 2016). In 2013 AD, average of 62.34 t/ha of carbon stock was found and in the same place 64.86 t/ha carbon stock was found in year 2014 that is increase in 2.52 t/ha of carbon stock per year.

2.3. Regeneration status of Sal Forests in Nepal

In Nepal, regeneration is said to be good if forests have seedling >5000 and sapling >2000 /ha (HMG, 2004) (cited in Pandey *et al*., 2012). Regeneration of Sal was higher than other associated species in the Terai region and Churia forests of Nepal (DFRS, 2014). Higher Sal density than other associated species in both CF and protected forests in western Nepal (Shrestha, 2009). Similarly, higher saplings and seedlings of Sal were found than other associated species in Sal-dominated forests in western Terai (Timilsina *et al.*, 2007). In tropical forests, regeneration of plants depends mainly on seed output, viability, seed dormancy, seed dispersal, seed growth, vegetation growth, reproductive growth, and seedling establishment (Basyal *et al.*, 2011).

Light-demanding species (herbs, shrubs, and tree) favors open canopy for regeneration. The presence of sufficient canopy gaps allowed enough light to reach the forest floor and made the light and dry environment favorable for abundant growth of *Shorea robusta* seedlings and saplings. Thus, light is considered very important abiotic factors that played two roles, increasing photosynthesis and ground temperature, which in turn accelerates litter decomposition (Sapkota *et al*., 2009).

From the earliest stages of development Sal is a light-demanding species and it needs complete overhead light (Champion and Seth, 1968; Kayastha 1985). Opening of the canopy in a forest stand promotes regeneration, and the growth of understory seedlings and saplings (Troup, 1986; Gautam, 1990). Human activities and livestock trails are the significant variables for the impact of sapling and seedling density in the forest. These human disturbances might have induced the spatial heterogeneity and internal dynamics that help in regeneration. The main challenge for forest managers and scientists is to identify threshold levels at which human disturbances will result in an irreversible decline in vegetation and its regeneration (Napit and Paudel, 2015).

The lower basal area, biomass, and higher density show that the forest is younger and are in state of regeneration (Giri *et al*., 1999). *Shorea robusta* was the dominant species with a sapling density of 200.49 t/ha and seedlings density of 27153.4 t/ha in Banke National Park (Napit, 2015). Regeneration was affected by species richness, canopy cover, soil pH, and nitrogen (Bhatta *et al*., 2020). In the tropical zone, the community forest was dominated by a single species, *Shorea robusta*. However, *Shorea robusta* and *Terminalia myriocarpa* were co-dominant in the government-managed forest and the density of the trees and the basal area were higher in the government-managed forest, but the density of the shrub / sapling and the basal area were higher in the community forest, suggesting a positive effect of community management on tree regeneration. From the result, the dominance of *Shorea robusta* trees in the community-managed forests suggests that people involved in forest management may be more interested in a limited number of economically valuable species while removing less important trees (Poudel and Shah 2015).

2.4. Plant diversity

In Nepal, altogether 1,001 species of algae, 2182 species of fungi, 850 species of lichens, 1213 species of bryophytes, 550 species of pteridophytes, 41 species of gymnosperms, 1600 new species of angiosperms from different parts of the country were recorded (Rajbhandari *et al.*, 2020) and also revealed that decline and loss of biodiversity are due to loss and fragmentation of habitat, unscientific land use, unsustainable use of bioresources, uncontrolled forest fire, over grazing, illegal logging and poaching, unplanned development activities and pollution (HMG/N and Govt. of the Netherlands, 1995).

Bioresources are essential to maintain the ecological process and life support system and to sustain and improve agricultural, forestry, and presence of suitable habitats for the survival of species, but the biodiversity is under threat due to high pressure by the growth of population (Joshi and Joshi, 1998). The community forestry program is considered one of the most successful natural resource management programs in terms of restoring degraded land and habitats, conserving biodiversity, increasing the supply of forest product, generating rural income, and developing human resources (Acharya, 2003). In addition to this, community forests improving the environment, contributing to rural livelihood, and is a major means of biodiversity conservation (Acharya *et al.*, 2007).

In Nepal, it is expected that a total of 1.9 million biogas plants can be installed (Rana *et al.*, 2014). In this context, biogas energy can be the appropriate option in Nepal because it is technically simple, economically viable and environment friendly. Thus, biogas energy is the major contributor in the development of renewable energy resources.

CHAPTER 3: MATERIALS AND METHODS

3.1. Study Area

The study area was located in the Kaligandaki rural municipality, Gulmi district, Lumbini Province, Western Nepal (Figure 1). The municipality covers an area of 101.04 Km^2 and expands between 28°05'N and 83°55'E. It is situated at an altitude of 400-2135 m above the sea level (asl) and climatic zone is tropical. Gulmi district has a total of 463.2 km^2 of forests area (including shrublands), out of which 48% lies in the Kaligandaki rural municipality. The annual minimum temperature is 4°C and maximum temperature is 36°C and the average annual rainfall is 111.9 mm.

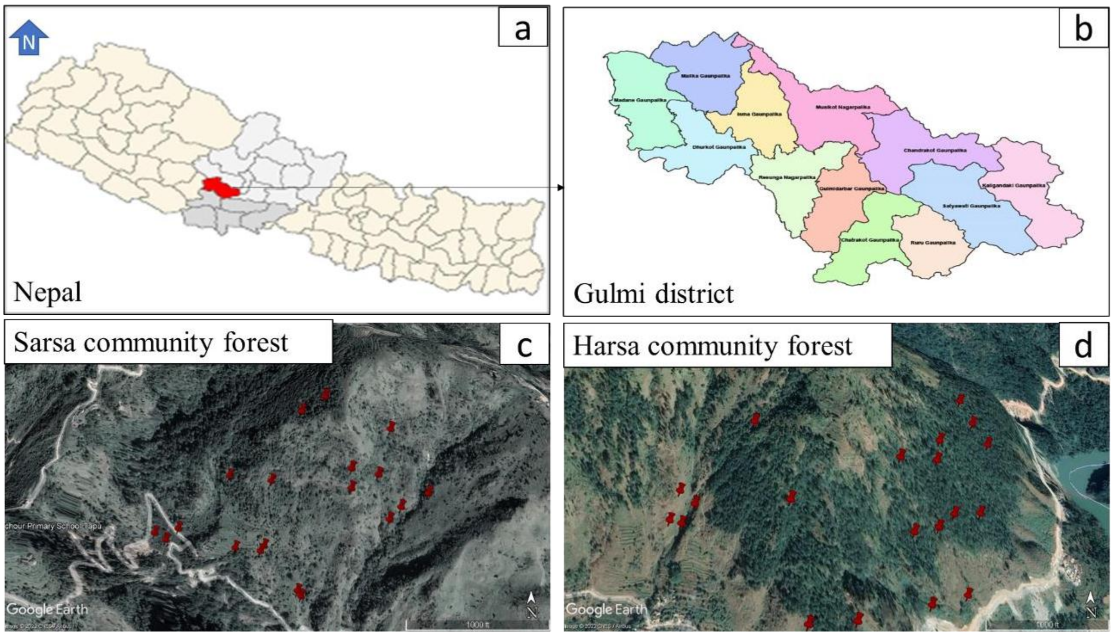


Figure 1: Map of the study area; (a) map of Nepal with districts, (b) Gulmi district with municipalities, (c) sampling plots in Sarsa community forests and (d) and sampling plots in Harsa community forests.

3.1.1 Climate and Hydrology

As shown in the figure, the average maximum temperature was 41.8℃ in May and the minimum temperature was 15.5℃ in January. The average maximum rainfall was 18.68mm in July and the minimum was 0.004mm in November (Figure: 2)

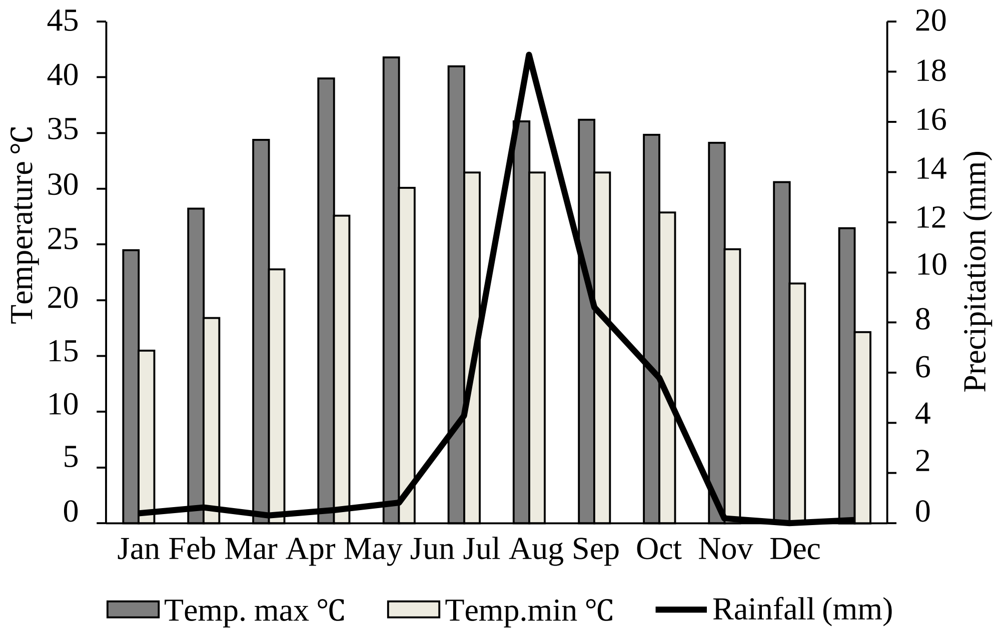


Figure 2: Variation in monthly average (maximum and minimum temperature and precipitation of last 5 years (2016-2020) at Gulmi. (Source: Climatedata.org)

The study was carried out in the Sarse community forest (SCF) and Harse community forest (HCF). SCF is located at 27 ° 98 'N and 83 ° 56 'E and HCF is located at 28 ° 99 'N and 83 ° 59 'E with an altitude ranging from 634 to 875 m altitude (Figure.1) in Kaligandaki rural municipality, Gulmi.

In the study area, *Shorea robusta* ('Sal') was the dominant species. Other common associated species were *Terminalia tomentosa* ('Saj'), *Syzygium cumini* ('Jamun'), etc. SCF was divided into 2 blocks, whereas HCF was divided into 3 blocks to prevent forest fire during the summer season. SCF was handed over to the community in 2067 B.S. SCF covers an area of 18 ha and 290 house members take membership of this forest, while HCF was handed over to the community in 2067 B.S and covers an area of 31 ha and 305 house takes membership of this forest.

3.2. Biogas Plant Estimation

The purpose of this work was to find the impact of the biogas plant on fuel consumption in the study area. For this purpose, data were collected from field observation and personal interviews (Appendix III). Out of 40, 20 households were selected for each CFUGs.

3.3 Vegetation Sampling

Systematic random sampling method was used to locate the sampling plots, the forest blocks designated by the CFUGs were considered as strata. The total number of plots to be sampled was proportionately distributed among the blocks according to their area. Forest plots were located with the help of CF member. To estimate the carbon stock of the tree, 20 circular plots of 10m radii were laid in each forest. Each tree species inside the plots was recorded. Trees on the border were also included if ≥50% of their basal area fell within the plot. Tree height >1.37 m with diameter ≥10 cm at breast height of all individual of tree species were measured. While measuring the DBH of trees of unusual shape (like tree with fork stem) method of MacDicken (1997) was adopted. DBH tape was used to measure the diameter and clinometers were used to estimate tree height. Similarly, for regeneration, sapling was considered with height <1.37 m and >15 cm and seedling of tree species were considered with height <15 cm in each plot (DFRS, 2014 a & b). The 10 m radii plot was divided into 2 sub-plots of 5 m radii for shrubs and 3 sub-plots with 2 m radii for herbs to estimate diversity adopted by Thapa Magar and Shrestha (2015). Each shrubs species inside the plots and if species ≥50% of their basal area fell within the plot were also recorded. Similarly, seedlings of tree species were considered with height <15 cm in the herb plot, while trees were recorded in the main plot. Canopy cover for each plot was estimated visually from the center of the plot. Plants were identified at the time of sampling with the help of field guides i.e., members of community forest, and by using 'Handbook of the flowering plants of Nepal' (DPR, 2017).

3.4. Quantitative Analysis

For vegetation analysis different parameters such as density, relative density, frequency, relative frequency, coverage, relative coverage, importance value index (IVI), and diversity indices (Simpson index and Shannon-Weiner index) were calculated. Formulas for different parameters were carried out following Zobel *et al.* (1987).

$$\text{Density} = \frac{\text{Total no. of species occurred}}{\text{Total no. quadrat studied}} \times \frac{1}{\text{area of quadrat}}$$

$$\text{Relative density} = \frac{\text{Density of individual species}}{\text{Total density of all species}} \times 100\%$$

$$\text{Frequency}=\frac{\text{No. of quadrat in which species occurred}}{\text{Total no. of quadrat studied}}\times 100\%$$

$$\text{Relative frequency}=\frac{\text{Frequency of individual species}}{\text{Total frequency of all species}}\times 100\%$$

$$\text{Abundance}=\frac{\text{Total no. of plant species}}{\text{No. of plots in which species occurred}}\times 100\%$$

$$\text{Relative Abundance (\%)}=\frac{\text{Abundance of individual species}}{\text{Total no. of individual of all species}}\times 100$$

3.5. Importance Value Index (IVI)

Importance value index is a measure of the dominance of species in each forest area which was calculated using following formula.

Important value index (IVI) =RD+RF+RA

Where RD=Relative density, RF=Relative frequency, and RA=Relative abundance

3.6. Plant Diversity Index

Plant diversity index can be defined as the number of plants and abundance of each plant that live in a particular location. Plant /species diversity was calculated based on Shannon diversity index and Simpson diversity index. Shannon diversity index was calculated using the general formula (Shannon and Weaver, 1949).

$$H = -\sum pi \times \ln pi$$

Where

H = Shannon's diversity index, Pi = Species proportion (based either on species count or species basal area), Ln = natural logarithm

Simpson's diversity index was calculated using the formula (1949).

$$Ds = 1\text{-}D$$

Where

$D = \frac{\Sigma n(n-1)}{N(N-1)}$; here N = total number of individual species (all species) and n = number of individuals of a particular species

3.7. Regeneration Status of Forest

To estimate the regeneration status of the forest, the density of seedlings, saplings, and trees of each species were determined separately following the method described by Zobel *et al.* (1987). Density was estimated by following equation.

$$\text{Density (stem/ha)} = \frac{\text{Total no.of individual of each species in each life form}}{\text{Total number of plots studied} \times \text{size of plot}(m^2)} \times 10000$$

Density of individual species was calculated by the following equation.

$$\text{Density (stem/ha)} = \frac{\text{Total no. of individual of each species in each life form}}{\text{total number of plots studied} \times \text{size of plot}(m^2)} \times 10000$$

Total count of plants was obtained by summation of the number of plants from all sampling plots.

3.8. Estimation of Biomass and Carbon Stock of trees

3.8.1. Estimation of Above and Below Ground Biomass

The equation developed by Chave *et al.*, (2005) for moist forests stand was used to estimate above-ground tree biomass.

AGTB = $0.0509 \times \rho D^2 H$; Where, AGTB = above ground tree biomass (kg), ρ = wood density (gm/cm^3), D = tree diameter at breast height (cm), H=height of tree (m)

Similarly, below-ground biomass was calculated assuming 15% of the above-ground tree biomass (Mack Dicken, 1997). Wood density values given in Zanne *et al.*, (2009) was used for the calculation of biomass. Name of tree species and their wood density is given in Appendix IV.

3.8.2. Estimation of Carbon Stock

The total biomass of the trees was obtained by adding the biomass above ground and below ground of the tree layer. Above ground biomass was multiplied by 0.47 and below ground biomass with 0.2 separately by default carbon fraction (IPCC, 2006) to determine total C-stock in kg. Then the area of total plot was calculated and ultimately it was divided by the total area of plot to obtain value in kg/m^2. The values obtained in kg/m^2 was multiplied by 10,000 and then divided by 1000 to obtain the C stock in t/ha.

The total carbon stock in the forest was obtained by adding above-ground and below-ground C stock.

3.8.3. Carbon Stock of trees

The carbon stock of an individual species in a forest was determined by adding the carbon stock values of that particular species to all plots in that forest. The percentage contribution of carbon stock of each species in a forest was calculated by taking the proportion of the sum of carbon stock (t/ha) of all species in the forest to the sum of carbon stock of a particular species in the same forest. It was calculated by the following equation:

$$\text{Carbon stock of a tree species (\%)} = \frac{Carbon\ stock\ of\ a\ particular\ tree\ species}{Sum\ of\ carbon\ stock\ of\ all\ tree\ species} \times 100$$

CHAPTER 4: RESULTS

4.1. Firewood consumption

Firewood consumption was nearly double before the installation of biogas plants in the house in both SCF and HCF. Firewood consumption per household was approximately 130-140 kg among SCF and 110-120 kg among HCF (Table 1).

Table 1: Firewood consumption (range) before and after installation of biogas plants at SCF and HCF.

Firewood consumption in SCF		**Firewood consumption in SCF**	
Before installation of biogas plants	After installation of biogas plants	Before installation of biogas plants	After installation of biogas plants
130-140 kg/week	60-70 kg/week	120-130 kg/week	55-65 kg/week

4.2. Biogas plant

The Harsa Community Forest (HCF) users' group has more biogas plants compared to the Sarsa Community Forest (SCF) users' group (Table 2). From the sampled household study, it has been found that the people in the forests of both communities depend on the forests for firewood and fodder. Firewood consumption among households without biogas plants was about 130.69 kg/week in HCF and 112.35 kg/week in SCF. But among households with biogas plants, it was only 68.74 kg/week in HCF and 60.69 kg/week in SCF, which was nearly 50% less than the amount of firewood consumed in HH without biogas plants. This high reduction is mainly due to the use of biogas generated for cooking among households with biogas plants. Firewood consumption/capita/day is reduced almost three times among households with biogas plants. The fodder consumption per household with biogas plants in HCF and SCF was 45 kg/day and 40 kg/day respectively, but it was almost half in households without biogas plants. The more amount of consumption of fodder among households with biogas plants is mainly due to a greater number of domesticated animals, which are needed to meet the demand of dung production. To feed the biogas plants, about 30 kg of dung per house per day was used by the HCF user groups, whereas 25 kg of dung per house per day was used by the SCF user groups.

Table 2: Forest resource consumption (firewood and fodder) among 20 household members surveyed of Sarsa and Harsa community forest users' groups that have biogas plants and without biogas plants.

Parameters	HCF		SCF	
	With biogas plants	**Without biogas plants**	**With biogas plants**	**Without biogas plants**
No of households (HH)	18	2	15	5
No. of family members	135	7	92	21
No. of domesticated animals (Cattle/sheep/goat/buffalo/cow)	62	3	45	7
Family members/HH	7.5	3.5	6.13	4.2
No. of domesticated animals/HH	3.44	1.5	3	1.4
Firewood (kg/week)/HH	68.74	130.69	60.69	112.35
Firewood consumption /HH (kg/day) *	9.82	18.67	8.67	16.05
Firewood consumption kg/capita/day	1.31	5.33	1.41	3.82
Fodder consumption/HH (kg/day)	45	20	40	19
Dung use for biogas plants/HH (kg/day)	30		25	

*HHs with biogas plants use firewood to make grain soup ('Kudo') for animals only and almost not to make food for household members, since the biogas is sufficient to meet their needs.

4.3. Vegetation structure

Together, 23 plant species were recorded in HCF and 16 in SCF. The species richness in the HCF forest was found to be higher than in the SCF forest. The number of herb species was found to be higher in SCF (9) than in HCF (7), but the number of shrubs and trees was found to be higher in HCF (Figure 3). All the names of the plants encountered during the study are given in Appendix V. Dominant tree species of both forest SCF and HCF are *Shorea robusta* and *Terminalia tomentosa*, dominant shrub species of SCF are *Solanum viarum, Rubus ellipticus* and of HCF are *Solanum viarum* and *Mahona aquifolim*. Similarly, the dominant herb species of both the SCF and HCF forests are *Ageratium conyzoides* and *Imperata cylindrica*.

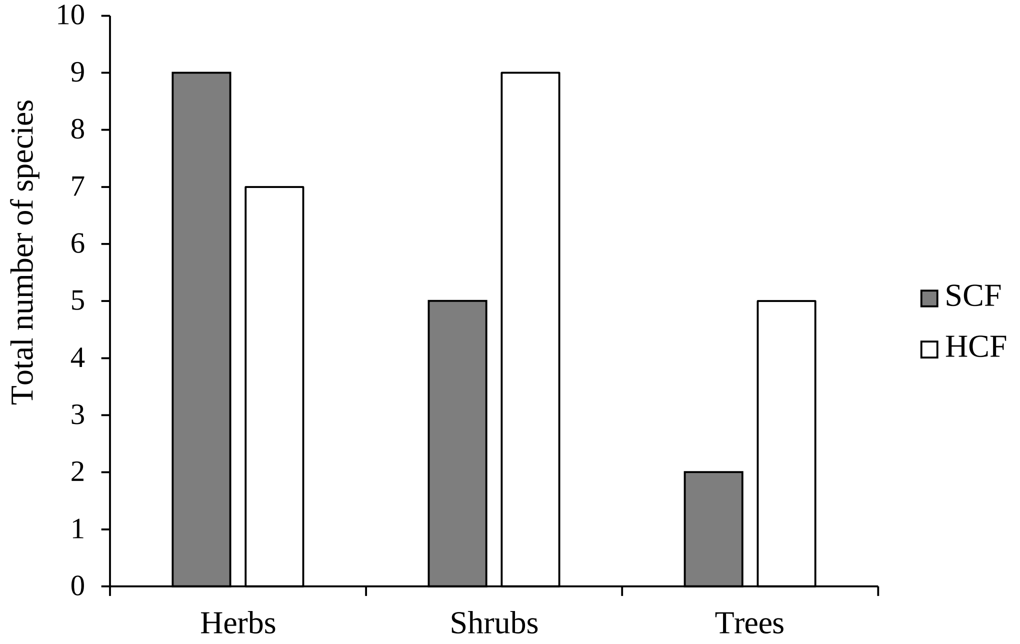


Figure 3: Species richness based on life form of plants in SCF and HCF.

4.3.1. Importance value index (IVI)

In SCF and HCF, total 9 and 7 species of herbs and seedlings were recorded, respectively. Among them, the *Ageratum conyzoides* herb had the highest IVI i.e., 35.87 in SCF and in HCF *Imperata cylindrical* had the highest IVI i.e., 68.51.

Table 3: IVI of herbs and seedlings of trees in SCF and HCF.

Plants		IVI	
		SCF	**HCF**
Herbs	*Imperata cylindrical* L.	35.87	39.71
	Cynodon dactylon L.	31.72	68.51
	Oxalis corniculata L.	9.23	5.56
	Cyperus rotundus L.	5.59	-
	Artemisia vulgaris	7.98	-
	Achyranthes bidentate Blume	2.14	11.08
	Ageratum conyzoides L.	10.16	-

Tree seedling	*Terminalia tomentosa*	132.83	39.01
	Mitragyna parvifolia	57.42	49.79
	Shorea robusta Gaertn.	-	39.33
	Senegalia catechu	-	188.35
	Syzygium cumini (L.) Skeels.	-	98.6

In both SCF and HCF, among seedlings *Shorea robusta* had the highest IVI (Table 3). Frequency, relative frequency, density, relative density, abundance, and relative abundance are given in Appendix V.

In the SCF, altogether 5 and 9 species of shrubs and saplings were recorded respectively. Among them, the *Solanum viarum* shrubs had the highest IVI, that is, 14.03 in both forests. Similarly, in both SCF and HCF, the *Shorea robusta* saplings had highest IVI value (Table 4). Frequency, relative frequency, density, relative density, abundance, and relative abundance are given in Appendix V.

Table 4: IVI of shrubs and tree saplings in SCF and HCF.

Plants		**IVI**	
		SCF	**HCF**
Shrubs	*Solanum viarum* Dunal.	14.03	31.52
	Mahona aquifolium	-	14.15
	Rubus ellipticus	7.53	5.13
	Lantana camera L.	5.19	7.4
	Asparagus racemose	2.84	-
Tree sapling	*Terminilia tomentosa*	54.02	15.56
	Shorea robusta	136.0	40.52
	Syzygium cumini	-	13.42
	Mitragyna parvifolia	-	15.56
	Terminilia tomentosa	-	14.56
	Senegalia catechu		

The determination of IVI frequency, density, abundance, and their relative values was considered (Appendix V) in all life forms-herbs, shrubs, and trees. In addition, this canopy cover of each tree species in the quadrat was also recorded and given in Appendix I.

In the HCF, altogether 5 and 2 species of trees were recorded respectively. Among them, *Shorea robusta* had the highest IVI in both forests (Table 5).

Table 5: IVI of tree in SCF and HCF.

Plants	IVI	
	SCF	HCF
Terminilia tomentosa	56.6	65.13
Shorea robusta	243.41	116.65
Syzygium cumini	-	22.64
Mitragyna parvifolia	-	21.13
Senegalia catechu	-	19.06

4.3.2. Diversity index

Both the diversity index, Shannon Wiener (H), and Simpson diversity (Ds) values for herbs, shrubs, and trees were found to be higher in HCF than in SCF.

Table 6: Shannon Wiener index (and evenness) and Simpson index of trees in the Sarsa community forest and the Harsa community forest.

Life form	Forest	Shannon's diversity index (H)	Simpson's diversity index (Ds)
Herbs	SCF	1.3	0.6
	HCF	1.5	0.71
Shrubs	SCF	1.3	0.56
	HCF	1.7	0.8
Trees	SCF	1.3	0.3
	HCF	1.5	0.5

4.4. Forest regeneration

In the present study, the total density of the seedlings, saplings, and trees of all species in SCF was 9650 stem/ha, 5590 stem/ha and 1310 stem/ha, respectively, while in HCF the seedlings, saplings and trees were found to be 12715 stem/ha, 6025 stem/ha and 1230 stem/ha, respectively (Figure 4). The density of (seedling, sapling, or tree) *Shorea robusta* was found to be higher than other species in both SCF and HCF. The density of *Shorea robusta* in SCF was 8908 stem/ha seedling, 5570 stem/ha sapling and 1195 stem/ha tree, and in HCF were 10315 stem/ha seedling, 4175 stem/ha sapling, and 925 stem/ha tree (Figure 4).

The seedling, sapling, and tree density of the dominant species were relatively very high than the seedling, sapling, and tree density of the co-dominant associated species. But the tree density of co-dominant associated species such as *Terminalia tomentosa* and *Syzygium cumini* was higher in HCF than in SCF. All species found in SCF and HCF with their regeneration status are given in Appendix VI.

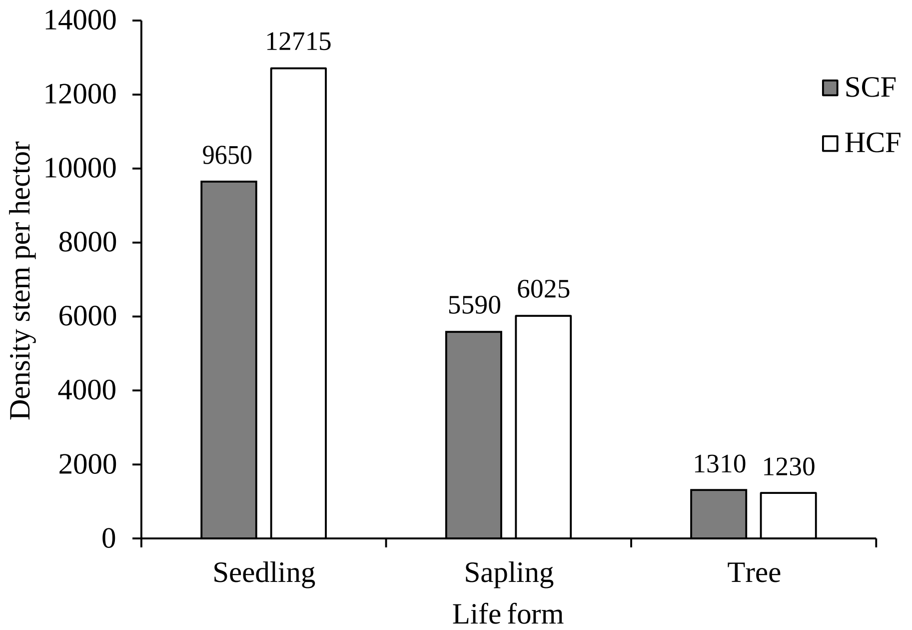


Figure 4: Life form to show the regeneration status of all species in SCF and HCF.

The seedlings, saplings, and tree density of *Shorea robusta* were found to be relatively higher in HCF than in SCF (Figure 5).

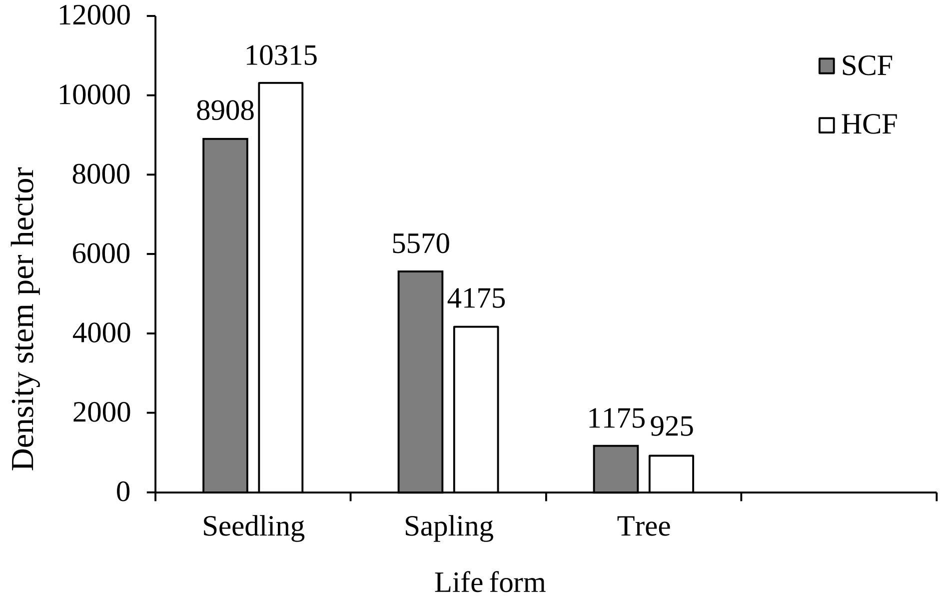
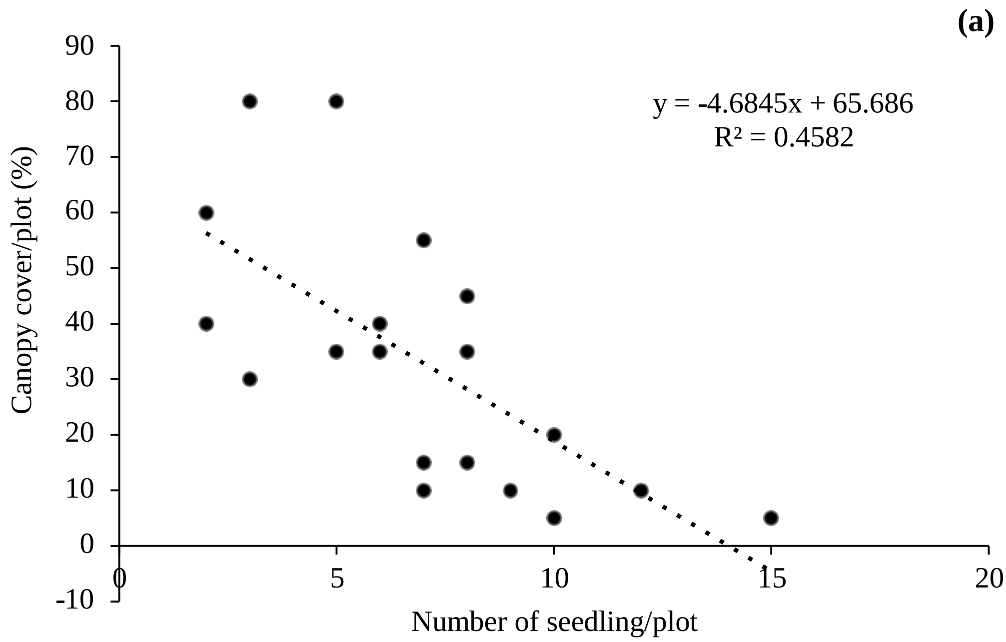


Figure 5: Life form diagram to show the regeneration status of *Shorea robusta* species in both Sarsa community forest and Harsa community forest.

In both community forests, there was no strong correlation between canopy cover and number of seedlings and saplings (Figures 6 and 7; Appendix VI).



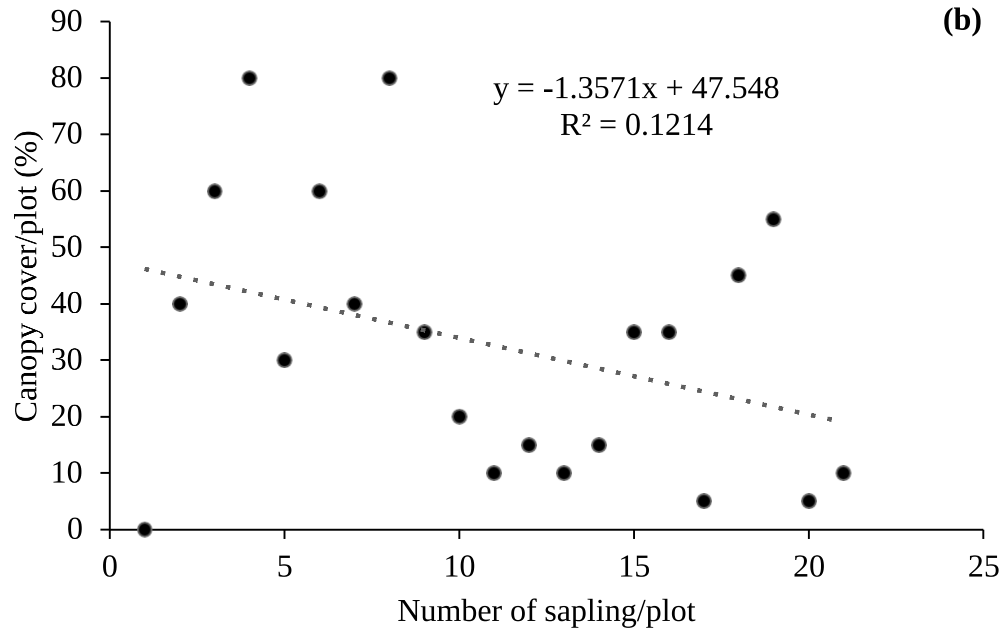
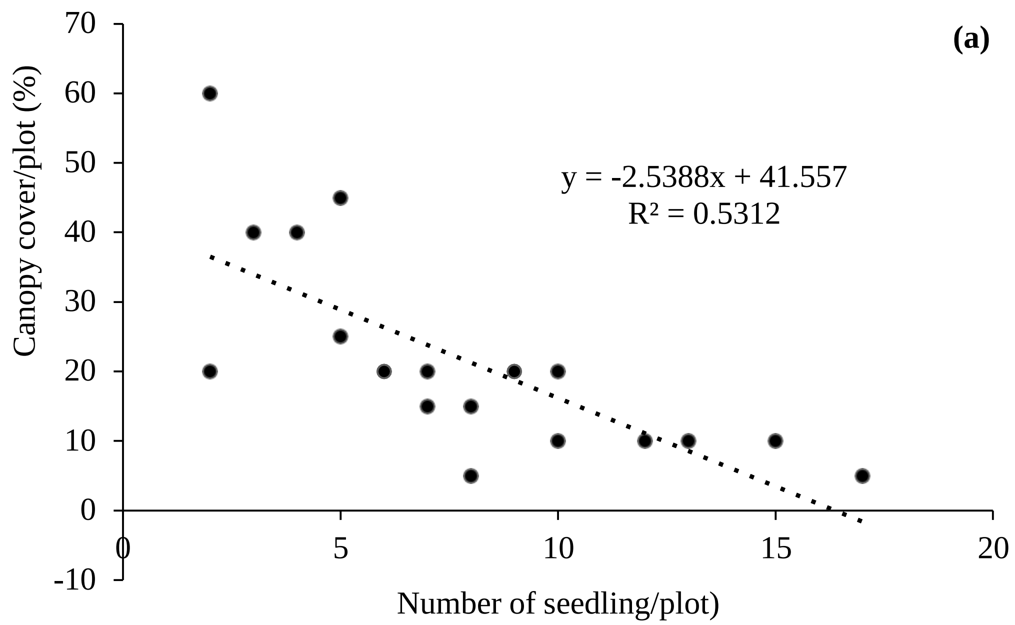


Figure 6: Regression analysis showing the relationship between canopy cover and number of a) seedling and b) sapling of Sarsa community forest (SCF).



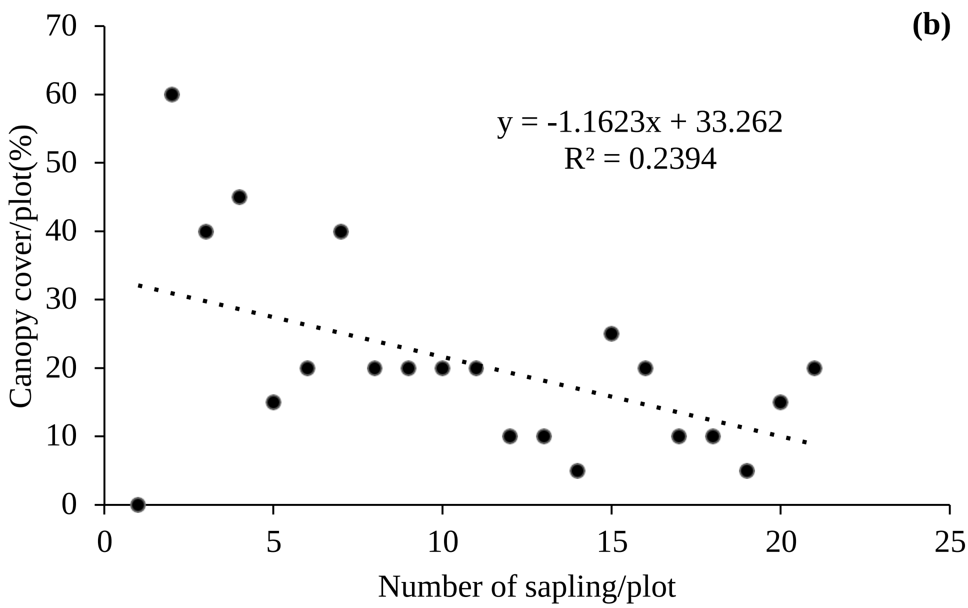


Figure 7: Regression analysis showing the relationship between canopy cover and number of a) seedling and b) sapling of Harsa community forest (HCF).

4.4.1. Density diameter relationship

The tree density (per ha) was highest in the density class 60-70 (250 stem/ha) followed by 90-100 (245 stem/ha) in SCF (Figure 8) where as in HCF the tree density (per ha) was highest in the density class 90-100 (260 stem/ha) followed by 80-90 (235 stem/ha) in HCF (Figure 9). This showed that most of the stands were in the mature stage of growth.

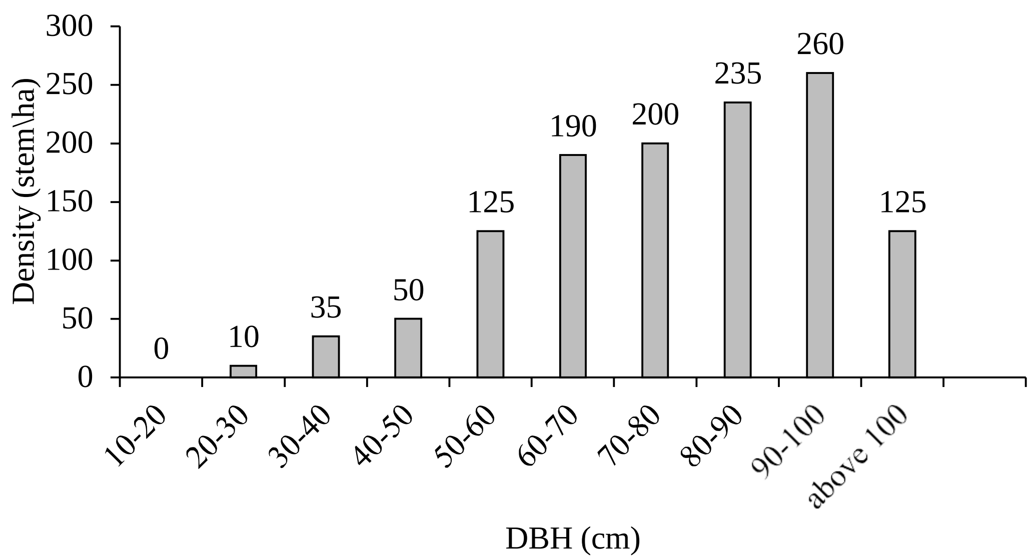


Figure 8: Density diameter relationship of trees ≥ 10 cm in SCF.

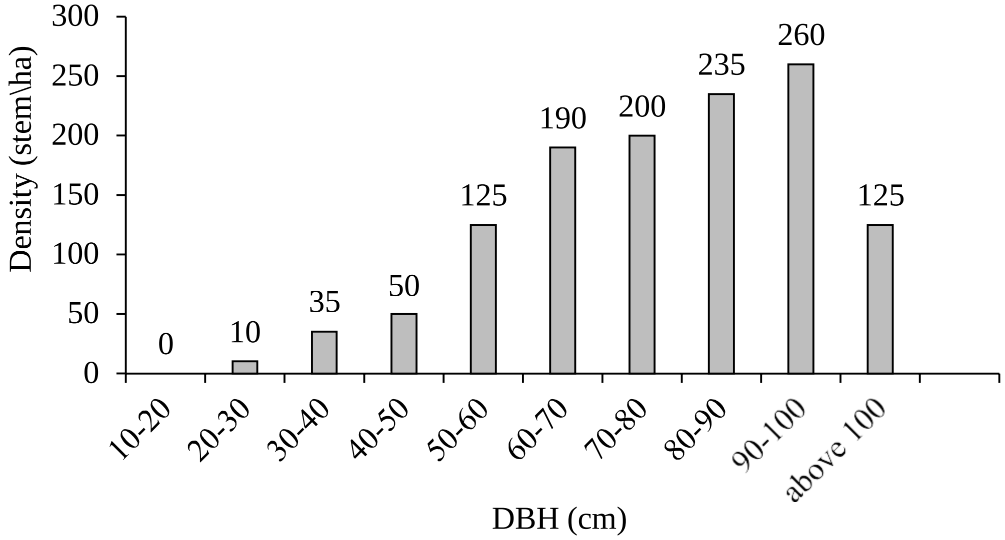


Figure 9: Density diameter relationship of trees ≥ 10 cm in Harsa community forest (HCF).

4.5. Biomass and carbon stock of Tree

4.5.1. Tree biomass

In trees, the biomass above ground was higher than the biomass below ground. Among the species of plant trees, *Shorea robusta* had the highest biomass in both forests (Table 7)

Table 7: Above ground and below ground biomass of tree species in Sarsa community forest (SCF) and Harsa community forest (HCF).

Tree species	**Aboveground biomass (t/ha) of SCF**	**Below ground biomass (t/ha) of SCF**	**Above ground biomass (t/ha) of HCF**	**Below ground biomass (t/ha) of HCF**
Shorea robusta	43.32	7.6	37.92	6.7
Terminalia tomentosa	10.4	7.6	13.86	2.44
Syzygium cumini			6.8	1.2
Senegalia catechu			1.7	0.3
Mitragyna parvifolia			5.1	0.9
Total	53.72	15.2	65.38	11.54

4.5.2. Tree carbon stock

In trees, the above-ground biomass contains more carbon than the below-ground biomass.

Table 8: Carbon stock above ground and below ground of tree species in Sarsa Community Forest (SCF) and Harsa Community Forest (HCF).

Tree species	Aboveground carbon stock (t/ha) of SCF	Below ground carbon stock (t/ha) of SCF	Above ground carbon stock (t/ha) of HCF	Below ground carbon stock (t/ha) of HCF
Shorea robusta	21.66	3.8	18.96	3.35
Terminalia tomentosa	5.2	3.8	6.93	1.22
Syzygium cumini	-	-	3.4	0.6
Senegalia catechus	-	-	0.85	0.15
Mitragyna parvifolia	-	-	2.55	0.45
Total	26.86	7.6	32.69	5.77

Among the species of plant trees, *Shorea robusta* had the highest carbon in both the above and below ground in both forests, that is, 21.66 t/ha above ground and 3.8 t/ha below ground in SCF and 18.96 t/ha above ground and 3.35 t/ha below ground in HCF (Table 8).

The total carbon stock in SCF and HCF trees was calculated to be 34.46 t/ha and 38.46 t / ha, respectively (Figure 10). The average contribution of *Shorea robusta* was highest in both community forests.

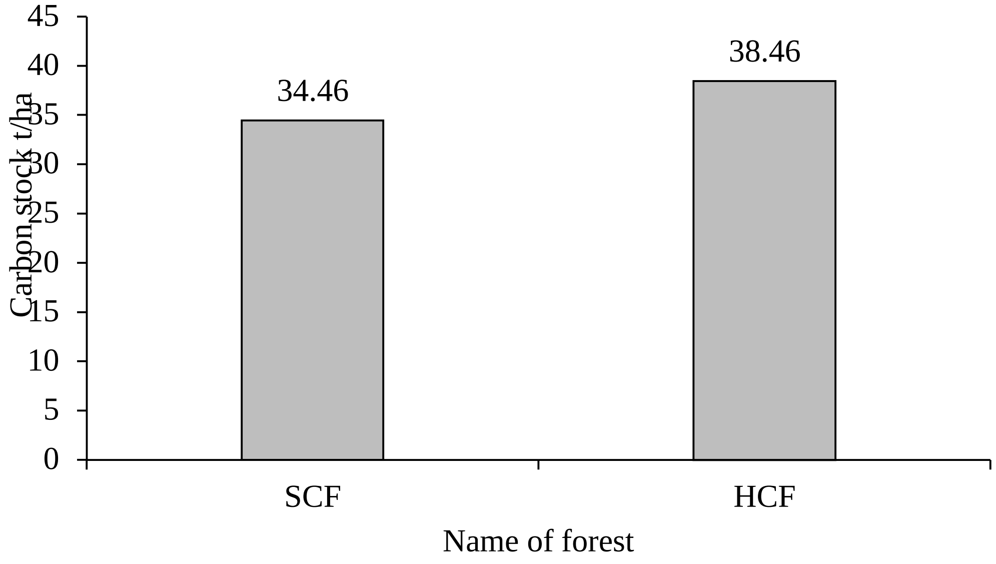


Figure 10: Total carbon stock in Sarsa community forest (SCF) and Harsa community forest (HCF).

Among all plant species, *Shorea robusta* had the highest contribution in carbon stock in both community forests. In both forests *Shorea robusta* was followed by *Terminalia tomentosa*, which are given in Table 9.

Table 9: Carbon stock by species in the Sarsa community forest (SCF) and Harsa community forest (HCF).

Name of plant species	SCF carbon stock (t/ha)	HCF carbon stock (t/ha)
Shorea robusta	25.48	22.3
Terminalia tomentosa	9.0	8.15
Syzygium cumini	-	4.0
Senegalia catechu	-	1.0
Mitragyna parvifolia	-	3.0
Total	34.46	38.46

CHAPTER 5: DISCUSSION

5.1. Community attributes

The total diversity of plant species was found to be higher in the HCF than in the SCF. However, the diversity of herbs was higher in SCF than in HCF. Berlow *et al.* (2003) also observed a higher species diversity of herbs in areas with less shrub cover due to response of herbs to removal of shrubs or low availability of shrubs. In this study, possibly MCF with a high moisture content must have supported more species of shrubs and trees.

The diversity of tree species in the HCF was found to be higher than in the SCF. It could be due to the use of biogas plants, which help reduce deforestation. The HCF user group uses more biogas plants compared to the SCF user group.

Among all tree species, *Shorea robusta* IVI was found higher in both community forest (i.e., 243.41 in SCF and 116.65 in HCF). The high IVI of a species indicates its dominance and ecological success, its good regeneration, and greater ecological amplitude (Sameem and Kangaroo, 2011). *Shorea robusta* regeneration in both forests was high. Hence, it indicates that *Shorea robusta* was the most important and dominant species in both forests.

HCF had higher tree diversity and higher carbon stock than SCF. Similarly, Mandal (2016) also reported the positive and very weak relationship between carbon stock and species richness of collaborative forests.

5.2. Regeneration

The seedling and sapling density was higher in HCF than in SCF. It could be due to a lower tree density and open canopy in HCF than in SCF. The opening of the canopy in a forest stand promotes regeneration and growth of seedlings and saplings in the understory (Troup, 1986; Gautam, 1990). The open canopy favours the regeneration of light-demanding species (Sapkota *et al.*, 2009). The presence of sufficient canopy gaps allowed enough light to reach the forest floor and made the light and dry environment favourable for the abundant growth of *Shorea robusta* seedlings and saplings. Thus, light is very important abiotic factors that played two roles in increasing photosynthesis and ground temperature, which in turn accelerates litter decomposition (Sapkota *et al.*, 2009). Hence, the regeneration condition of *Shorea robusta* light-demanding plant (Champion and Seth, 1968; Kayastha, 1985) in HCF was higher than in SCF.

Shorea robusta constitutes a higher density in all three life forms than other associated species in both community forests. Poudel (2000) also reported the high dominance of *Shorea robusta* in the community forest and the equal dominance of *Shorea robusta* and *Terminalia tomentosa* in the national forest of the Udayapur district. Similarly, Poudel and Shah (2015) reported the dominance of *Shorea robusta* in the community forest, while *Shorea robusta* and *Terminalia alata* were co-dominant in the government forest in the lowlands of eastern Nepal. The result of the present study is also similar to that of Poudel (2000) and Poudel and Shah (2015). Similarly, seedlings from associated species such as *Terminalia tomentosa, Syzygium cumini,* were also found to have high HCF content, which could be due to the open canopy of HCF that could have been favoured for abundant growth of seedlings from these species. Although seedlings and saplings of associated species were not found to be good in both forests, which could be due to lack of proper forest management, illegal logging, herd grazing, and bush fire, this evidence were also observed during the field study.

The regeneration status of the forest is said to be good if the forest have seedling >5000 and sapling >2000 per hectare (HMG, 2004) (cited in Pandey *et al.*, 2012). The regeneration status of the forests in the present study was 9650 seedlings and 5590 saplings per hectare in SCF and 12715 seedlings and 6025 saplings per hectare in HCF, which were higher than the above-mentioned values. Therefore, the regeneration status in both SCF and HCF was in good condition. Regeneration are the determinant factors for the sustainability of forests.

5.3. Carbon Stock

In the present study, the canopy cover of the species was found to be higher in SCF than in HCF. Similarly, the density of the species was also found to be higher in SCF than in HCF, and the relationship of this characteristic with the total C stock was found to be statistically insignificant, similar to Thapa Magar and Shrestha (2015).

In SCF, a high density of individuals with trees with fewer diameters at breast height was observed. But in the HCF more tree individuals with maximum diameter at breast height were observed, indicating that it was older than the SCF. The rate of carbon sequestration is much faster in young and regenerating forests, but the C-stock is higher in old and mature forests (Luyssaert *et al*., 2008; Nair *et al*., 2009). This is why the standing C-stock of old growth forest (MCF) is higher. Singh and Singh (1992) also observed a similar result in Himalayan forests, India.

Shorea robusta was the highest contributor of C-stock in both community forests, this could be due to the highest basal area of *Shorea robusta* in both forests than other species. These values are less than the value obtained for the *Shorea robusta* dominated two CFS of Gorkha where *Shorea robusta* contributed 95% and 86% in the C-stock (Neupane and Sharma, 2014).

Pandit (2014) reported that vegetation types, stand age, surrounding environment, management activities, and other human-induced disturbances are the key factors in carbon stock variation and carbon sequestration in forests. In SCF, the forest management group provided a lot of firewood to the community members, but the HCF community members use less firewood because they have a biogas plant in more numbers than the SCF members. Therefore, this disturbance factor may also be one of the reasons for having fewer carbon stocks in SCF.

Variation in carbon stock might depend on some environmental factors such as temperature, rainfall, forest management, etc. Barbour *et al.* (1999). The present study was conducted based on the impact of the biogas plant on fuel consumption. Regeneration was higher in HCF. Therefore, the hypothesis that regeneration will be higher in less dense canopy forests had been accepted. Similarly, HCF had a higher carbon stock than SCF. Therefore, the hypothesis that the installation of the biogas plant will help with the restoration of carbon in forests has been accepted.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

6.1. CONCLUSION

From this study, it can be concluded that the installation of a biogas plant helps to conserve forests, restore carbon, and reduce fuel consumption. More bigas plants were observed at Harsa community forest and more carbon stock was observed at this community forest. At Sarsa community forests comparatively less biogas plants were present but the biodiversity and regeneration were high. Both community forests were dominated by *Shorea robusta* and its contribution was highest for C-stock in both community forests. In addition to this, the installation of a biogas plant helped the forest conservation and reduces fuel consumption which has resulted slight increase in Carbon stock.

6.2. RECOMMENDATION

i. For the conservation of forests and to help in carbon storage, the installation of a biogas plant should be encouraged.

ii. The increase in carbon stock need to be evaluated regularly and forest user groups should take part in carbon trade through the REDD + scheme for the benefit of the community livelihoods.

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APPENDICES

APPENDIX I: Data sheet used in field sampling.

Date:	District:
Locality:	Altitude:
Slope:	Latitude:
Longitude:	Plot no:
Quadrat no:	Quadrat size:
Canopy cover (%):	Disturbance:

S. SN	**Plant species**	**Local name**	**DBH (cm)**	**Height (m)**	**Remarks**
1					
2					
3					
.					
.					
.					

APPENDIX II: Geographical position of plots with different variables measured in these plots.

Where, plot number 1-20; for SCF and 21 -40 HCF (Alt- altimeter and CC-canopy cover).

Plot Number	Alt(m)	Latitude	Longitude	CC (%)
1	843	27°98’43”	83°56’13’’	30
2	834	27°98’46”	83°56’17”	35
3	841	27°98’46”	83°56’22’’	60
4	839	27°98’43”	83°56’31’’	30
5	845	27°98’46”	83°56’39”	50
6	863	27°98’45”	83°56’40’’	40
7	851	27°98’47”	83°56’35’’	55
8	863	27°98’45”	83°56’27”	35
9	862	27°98’46”	83°56’28’’	20
10	853	27°98’41”	83°56’24’’	10
11	860	27°98’36”	83°56’58”	10
12	833	27°98’40”	83°56’57’’	10
13	859	27°98’44”	83°56’56’’	15
14	864	27°98’31”	83°56’60”	35
15	871	27°98’30”	83°56’7’’	35
16	870	27°98’36”	83°56’9’’	40
17	872	27°98’40”	83°56’58”	45
18	862	27°98’47”	83°56’56’’	55
19	865	27°98’51”	83°56’34’’	5
20	880	27°98’54”	83°56’45”	10
21	670	27°99’39”	83°57’43’’	40
22	669	27°99’39”	83°57’38”	35
23	669	27°99’40”	83°57’45’’	30
24	656	27°99’51”	83°57’46’’	15
25	636	27°99’57”	83°57’50”	20
26	630	27°99’57”	83°57’48’’	40

27	625	27°99’588”	83°57’53’’	20
28	622	27°99’40”	83°57’58”	20
29	680	27°99’27”	83°57’59’’	20
30	682	27°99’28”	83°57’14’’	10
31	705	27°99’21”	83°57’5”	10
32	710	27°99’33”	83°57’22’’	10
33	711	27°99’30”	83°57’31”	5
34	715	27°99s’31”	83°57’35’’	25
35	717	27°99’28”	83°57’39’’	20
36	719	27°99’29”	83°57’43”	10
37	730	27°99’29”	83°57’47’’	10
38	732	27°99’24”	83°57’43’’	5
39	760	27°99’15”	83°58’42”	15
40	762	27°99’35”	83°58’49”	20

APPENDIX III:

Name of respondent:

Family size:

Livestock number and types

Having biogas plant: yes/No

Quantity of fire wood consumption before the installation of Biogas plant:

Quantity of fire wood consumption after installation of biogas plant:

Quantity of fodder consumption before the installation of Biogas plant:

Quantity of fodder consumption after installation of biogas plant:

Quantity of cow dung used for biogas plant/day :

APPENDIX IV: Wood density of tree species used to estimate carbon stock using equation Chave *et al*., (2000).

Species name	Wood density (g/cm^3)
Shorea robusta	0.73
Terminalia tomentosa	0.73
Syzygium cumini	0.673
Mitragyna parvifolia	0.58
Senegalia catechus	0.88

Source*:* Zanne *et al., 2009*

APPENDIX V: Frequency, density, abundance and their relative values of herbs, shrubs and tree in Sarsa community forest and Harsa community forest.

Herbs

In Sarsa community forest

Plant name	**Total number of individual in 60 plot (Q)**	**F**	**RF %**	**D**	**RD %**	**A**	**RA %**	**IVI**
Ageratum conyzoides	227	80	14.54	5.68	12.06	14.19	9.29	35.87
Imperata cylindrical	187	75	13.63	4.68	9.94	12.47	8.17	31.72
Artemisia vulgaris	2	5	0.9	0.05	0.11	2	1.31	2.14
Achyranthus bidentate	29	30	5.45	0.72	1.53	4.83	3.16	10.16
Cynodon dactylon	24	15	2.72	0.6	1.27	8	5.24	9.23
Cyprus rodentus	10	5	0.9	0.25	0.53	10	6.55	7.98
Oxalis corniculate	9	20	3.63	0.23	0.49	2.25	1.47	5.59
Shorea robusta	124	97	39.37	0.31	0.23	317.9	93.23	132.83
Terminalia tomentosa	9	100	50.63	0.0225	0.02	22.5	6.77	57.42

Herbs in Harsa community forest

Plant name	**Total number of individual in 60 plot (Q)**	**F**	**RF %**	**D**	**RD %**	**A**	**RA %**	**IVI**
Ageratum conyzoides	144	55	13.58	3.6	13.16	13.1	12.97	39.71
Imperata cylindrical	318	85	20.99	7.95	29	18.71	18.52	68.51
Artemisia vulgaris	17	25	6.17	0.42	1.54	3.4	3.37	11.08
Cynodon dactylon	4	5	1.23	0.1	0.37	4	3.96	5.56
Syzygium cumini	17	80	20.17	0.0	0	35.42	18.84	39.01
Shorea robusta	95	75	18.91	0.02	57.14	211.1	112.3	188.35
Terminalia tomentosa	19	80	20.17	0.003	8.57	39.58	21.05	49.79
Mitragyna parvifolia	12	81	0.59	0.00	5.71	24.49	13.03	39.33
Senegalia catechu	45	80	20.17	0.01	28.57	93.75	49.86	98.6

Shrubs

In Sarsa community forest

Plant name	Total number of individual in 40 Q	F	RF %	D	RD %	A	RA %	IVI
Solanum viarum	20	5	0.58	0.1	1.54	10	12	14.03
Rubus ellipticus	14	7.5	0.87	0.0	1.02	4.7	5.64	7.53
Lantana camera	11	10	1.16	0.0	0.73	2.75	3.30	5.19
Asparagus racemose	2	2.5	0.29	0.01	0.15	2	2.4	2.84
Shorea robusta	114	97	39.37	0.029	0.025	292.3	96.61	136.0
Terminalia tomentosa	4	100	50.63	0.001	0.0008	10	3.39	54.02

Shrubs in Harsa community forest

Plant name	Total number of individual in 40 Q	F	RF %	D	RD %	A	RA %	IVI
Solanum viarum	80	25	7.58	0.4	11.83	8	12.11	31.52
Mahona aquifolium	24	20	6.06	0.12	3.55	3	4.54	14.15
Rubus ellipticus	4	5	1.51	0.02	0.59	2	3.03	5.13
Lantana camera	4	2.5	0.76	0.02	0.59	4	6.05	7.4
Mitragyna parvifolia	12	2	0.29	0.0	0.87	12	14.40	15.56
Shorea robusta	88	28	10.58	0.7	14.83	11	15.11	40.52
Terminalia tomentosa	12	2	0.25	0	0.87	12	14.40	15.56
Senegalia catechu	24	20	6.06	0.12	3.55	3	4.54	14.56
Syzygium cumini	13	5	1.51	0.07	2.07	6.5	9.84	13.42

Trees

In Sarsa community forest

Plant name	**Total number of individual in 20 Q**	**F**	**RF %**	**D**	**RD %**	**A**	**RA %**	**IVI**
Shorea robusta	239	100	74.07	0.12	90.9	1195	78.44	243.41
Terminalia tomentosa	23	35	25.93	0.012	9.1	328.57	21.57	56.6

Trees in Harsa community forest

Plant name	**Total no. of sp. in 20Q**	**F**	**RF %**	**D**	**RD %**	**A**	**RA %**	**IVI**
Shorea robusta	185	100	40.82	0.0925	75.20	925	0.63	116.65
Terminalia tomentosa	40	75	30.61	0.02	16.26	266.6	18.26	65.13
Mitragyna parvifolia	7	35	14.29	0.006	4.88	28.57	1.96	21.13
Senegalia catechu	2	10	4.08	0.001	4.88	28.57	1.96	19.06
Syzygium cumini	7	25	10.20	0.0035	2.85	140	9.59	22.64

APPENDIX VI: Regeneration status of all tree species in Sarsa community forest and Harsa community forest.

In Sarsa community forest

S.N	Name of plant	Forest regeneration stem/ha		
		Seedling	**Sapling**	**Tree**
1	*Shorea robusta*	8908	5570	1175
2	*Terminalia tomentosa*	742	20	135

In Harsa community forest

S. N	Name of plant	Forest regeneration stem/ha		
		Seedling	**Sapling**	**Tree**
1	*Shorea robusta*	10315	4175	925
2	*Terminalia tomentosa*	975	500	100
3	*Syzygium cumini*	780	610	35
4	*Mitragyna parvifolia*	600	500	60
5	*Senegalia catechus*	45	240	10

APPENDIX VII: Canopy cover and numper of seedling and sapling in each plot in both SCF and HsCF.

In Sarsa community forest

Plot	Canopy cover (%)	No. of seedling	No. of sapling
1	30	2	5
2	35	-	2
3	60	3	6
4	30	3	7
5	50	2	6
6	40	6	5
7	55	5	5
8	35	8	8
9	20	10	9
10	10	12	12
11	10	8	6
12	10	9	7
13	15	7	5
14	35	5	6
15	35	6	9
16	40	10	8
17	45	8	8
18	5	7	7
19	5	15	15
20	2	7	12

In Harsa community forest

Plot	Canopy cover (%)	No. of seedling	No. of sapling
1	40	2	-
2	35	3	1
3	30	5	-
4	15	8	2
5	20	9	3
6	40	4	-
7	20	9	7
8	20	7	6
9	20	6	3
10	10	10	2
11	10	12	4
12	10	10	1
13	5	8	6
14	25	5	2
15	20	2	2
16	10	13	8
17	10	15	7
18	5	17	5
19	15	7	6
20	20	6	4

APPENDIX VIII: Photo plates