Carbon Sequestration and Fuel wood Assessment of Kahinure Plantation Forest in Rural Area of District Mau, Uttar Pradesh, India

THESIS

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2018

Dedicated
to My
Revered Parents

Declaration

This is to certify that the material embodied in the present work entitled "**Carbon Sequestration and Fuel wood Assessment of Kahinure Plantation Forest in Rural Area of District Mau, Uttar Pradesh, India**" is based on candidate original research work. It has not been submitted in part or full for any other diploma or degree of any University. The indebtedness of the candidate to others has been duly acknowledged at relevant places. I hereby also undertake that the thesis is essentially free from all kinds of plagiarism.

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CERTIFICATE

This is to certify that the thesis titled "**Carbon Sequestration and Fuel wood Assessment of Kahinure Plantation Forest in Rural Area of District Mau, Uttar Pradesh, India**" submitted by **Mr. Mohd Baqir** is an original research work and has not been previously submitted in part or full for the award of any other degree or diploma to this or any other university.

The thesis submitted to Babasaheb Bhimrao Ambedkar University, Lucknow satisfies all the requirements as stipulated in the *Doctor of Philosophy (Ph.D.) regulations-1999 as amended in 2008/2010/2013* and it is fit for submission and evaluation for the award of the degree of Doctor of Philosophy of the University.

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Head of the Department

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PREFACE

Globally, the level of carbon dioxide (CO_2) concentration has been reached an unprecedented level up to 406.68 ppm in 2018 and has been predicted that it will soon exceed the present level. This concentration is going to have a serious impact on forest ecosystem and climate change. Forest ecosystem is a major carbon sink due to the process of photosynthesis. Recently, the role of forest ecosystem in storing the carbon stock in soil and its dynamics for mitigation of climate change has highlighted the need for developing the knowledge databases of different tree species for their carbon sequestration potential that can be suitable for mitigating climate change. Contribution of plantation forest in the total balance of terrestrial carbon stock is small but in future it will contribute significantly in climate change mitigation. Increasing afforestation rate may further add incentive for sequestration of carbon and protection of natural forests from the degradation. The present study was conducted in Mau district in Eastern Uttar Pradesh, India. The study area is a plantation forest developed by the forest department of Uttar Pradesh under the plantation drive of mixed plant species during the year 1983 for production of fuelwood, non-wood products and other ecosystem services. The area of the plantation forest is approximately 118 hectare. The present study was done with a view to assess carbon sequestration potential of the selected plantation forest and inter-specific and intra-specific variation in carbon concentration in different species to evaluate better tree species as atmospheric carbon sequesters. Our results indicate that the afforestation or forest plantation enhances the soil organic carbon stock (SOC) and other soil properties and species. Among the studied tree species, maximum carbon accumulation was found in *Prosopis juliflora, Putranjiva roxburghii, Pithecellobium dulce* and *Artocarpus heterophyllus* depict that these tree species can be recommended as atmospheric carbon reducers for their better potential to sequester and store carbon. On the basis of fuel wood value index (FVI) and other fuel wood properties species *P. juliflora, T. grandis, F. benghalensis, Alstonia scholaris* and *Holopetelea integrifolia* are the most preferred fuel wood species and attention should be given on such tree species for large scale energy plantation in future, especially in this region of Uttar Pradesh, India to fulfil the future demand of rural communities. Further, the conceptual framework was designed to evaluate the scenario of fuel wood in that particular area of India. Very limited numbers of case studies are available on this region of India. All the literature available on this concept belong mainly to the Himalayan region. After the extensive survey, it was found that the majority of the households use traditional mud chulha for cooking in this area, which is thermally and environmentally inefficient. To overcome this drawback we have designed cook stoves with apparent modification in the conventional chulhas for rural people in view of their health care, economic concerns and climate benefits.

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List of Abbreviations

UNFCC	United Nation Framework Convention on Climate Change
IPCC	Inter Governmental Panel on Climate Change
CO_2	Carbon Dioxide
NOAA	National Oceanic and Atmospheric Administration
FAO	Food and Agriculture Organization
FSI	Forest Survey of India
WHO	World Health Organization
NPIC	National Program of Improved Cook stove
GHG	Green House Gases
CH_4	Methane
CDIAC	Carbon Dioxide Information Analysis Centre
REDD	Reducing emissions from deforestation and forest degradation
C	Carbon
Mg	Mega gram
SOC	Soil Organic Carbon
DHA	Dehydrogenase Enzyme
FRA	Forest Resource Assessment
NAEB	National Afforestation and Eco-development Board
WWF	World Wildlife Fund
IIASA	International Institute for Applied Systems Analysis
ISFR	India State of Forest Report
UPFD	Uttar Pradesh Forest Department
UP	Uttar Pradesh
NSS	National Sampling Survey

LPG	Liquid Petroleum Gas
UNDP	United Nations Development Programme
ICS	Improve Cook Stove
MNRE	Ministry for New and Renewable Energy
PM	Particulate Matter
IAP	Indoor Air Pollution
NGOs	Non-Government Organizations
UCA	Unnat Chulha Abiyan
NBCI	National Biomass Cook stove Initiative
WBT	Water Boiling Test
VITA	Volunteers in Technical Assistance
ITDG	Intermediate Technology Development Group
BIS	Bureau of Indian Standards
DBH	Diameter at Breast Height
AAS	Atomic Absorption Spectroscopy
EDX	Energy Dispersive X-ray
SEM	Scanning Electron Microscope
ANOVA	Analysis of Variance
NPK	Nitrogen Phosphorus Potassium
SMBC	Soil Microbial Biomass Carbon

Chapter 1

Introduction

1.1. Introduction

Global warming is a major concern throughout the world. The global carbon dioxide (CO_2) levels have reached to an unprecedented level. According to the intergovernmental panel on climate change (IPCC, 2007), continuous greenhouse gas emission at or above the current rate will cause further warming and induce serious change in the global climate system in 21st century. Currently, the level of CO_2 concentration in the atmosphere has risen from 277 ppm in 1750 (Joos and Spahni, 2008) to 406.42 ppm in 2017 (NOAA, 2017), and it is predicted that it will soon exceed the present levels. The change in land cover and land use pattern due to developmental activities are the major contributors to this shift (IPCC, 2007). Climate change is likely to show a significant impact on global environment at large and the forest ecosystem in particular. Global flow of carbon from plant and soil pools is much larger than the surface ocean or atmospheric pools and the fluxes from the terrestrial carbon pools to and from the atmosphere are as large as those to the surface oceans (Scharlemann *et al*., 2014). Therefore, it is important to manage the carbon pool in soil and plants to reduce atmospheric carbon concentration. This could be achieved by better management of forests which acts as a sink for atmospheric carbon (Brahma *et al*., 2016; Vashum and kumar, 2012; Patil *et al*., 2015).

1.2. Forestry as a mitigation option

According to food and agriculture organization (FAO) forest may be defined as minimum land area of 0.5 hectare with crown density more than 10% and minimum trees height of 5 meter at maturity stage. Forest surveys of India define forest as all lands; more than one hectare in area, with a tree canopy density more than 10% (FSI, 20011). Carbon sequestration in terrestrial ecosystem is considered as an important target for research. Recently, the role of forest ecosystem in soil organic carbon (SOC) stocks and dynamics for mitigation climate change has highlighted the need for more knowledge on effects of tree species on carbon sequestration (Jandl *et al*., 2007). Management of forest, afforestation or forest plantation are accepted measures for mitigation the atmospheric CO_2 concentration in national greenhouse gases (GHG) budgets.

The rapid changes in climate may be reduced and controlled by the capacities of forest ecosystem to assimilate the maximum carbon dioxide from the atmosphere (Hui, 2015). Therefore, absorbing or sinking of atmospheric carbon dioxide into the plant physiological system and storing in soil is one of the promising ways to remove large amount of greenhouse gases (CO_2) from the atmosphere (Sahu *et al.,* 2016). Carbon sequestration in terrestrial vegetation and soil is considered as a significant option to mitigate the global changing climate (Dinakaran and Rao, 2012). In general, carbon sequestration means capturing and long term storage of atmospheric carbon arising due to anthropogenic activities from different source as stationery source like power plant, industries and mobile source like motor vehicles etc. Afforestation and reforestation are one of the important strategies to mitigate the climate change with combined benefit of carbon storage and wood production (Kaul *et al.,* 2010).

Forestry is the most important means of sequestrating carbon and giving positive effect on the livelihood of the rural farmers because of its cost effectiveness and associated environmental and social benefits. Forest vegetation and soil share almost 60% of the world's terrestrial Carbon. Its quantity may vary according to land use system. The global carbon cycle represents the most important set of processes linking forests and other vegetation with global warming. A Forest ecosystem covers about 4.1 billion hectares of the world and is considered as the major reserve of terrestrial carbon stock. Since, forest cover is decreasing at the net rate of about 9.4m ha/year mostly due to deforestation (Keenan *et al*., 2015), which is responsible for up to 20 % of greenhouse gas emissions worldwide, with most of the forest land cleared for agricultural use. When managed effectively, forests are net carbon sinks, able to permanently absorb about one-tenth of global CO_2 emissions into biomass, soil and forest products. It is believed that the goal of reducing carbon sources and increasing the carbon sink can be achieved efficiently by protecting and conserving the carbon pools in existing forests (Brown *et al*., 1996; Gren and Aklilu, 2016).

Presently, plantation forest have small contribution in the total balance of terrestrial ecosystem carbon, about 3% or 140 million hectare of the total forest area of the world (FAO, 2006) but their contribution to store or absorb atmospheric carbon plays an important role for the future climate change mitigation . Importance of plantation forest to mitigate the climate change has been recognized by UNFCCC, to mitigate the greenhouse gas emission as well as the need to preserve, monitor and enhance terrestrial carbon stock (Updegraff *et al*., 2004; Kaul *et al.*, 2010). Afforestation increases the soil organic carbon and enhances the carbon pool in biomass (Arora and Choudhary, 2014). However, on-going activities of deforestation and disturbance due to developmental and external factors are the major the cause of loss of biotic potential which results in the deprivation of soil quality and in carbon stock (Sexena and Choudhary, 2015). Moreover, it has been estimated that about two third of the terrestrial sequestration of carbon is done by forest and forest soil (IPCC, 2007; Elizabeth *et al*., 2016).

There are different approaches to calculate biomass and carbon stocks from the tree species. One of them is a destructive way to directly estimate the biomass of leaves, branches, stems, structural roots and soil (Fonseca *et al.*, 2011). Another approach is a non-destructive method to develop an allometric equation that allows us to estimate the mass of a tree from a few simple measures, and then the application of this equation to trees in a forest (Ostadhashemi *et al.*, 2014). Forest and wooded areas are natural carbon sinks this means that trees store carbon by sequestrating atmospheric carbon in the growth of wood biomass through the process of photosynthesis and thereby increasing the soil organic carbon stock (Brown and Pearce, 1994). (Figure 1.1) shows the carbon mitigation by trees, which are regularly harvested and planted.

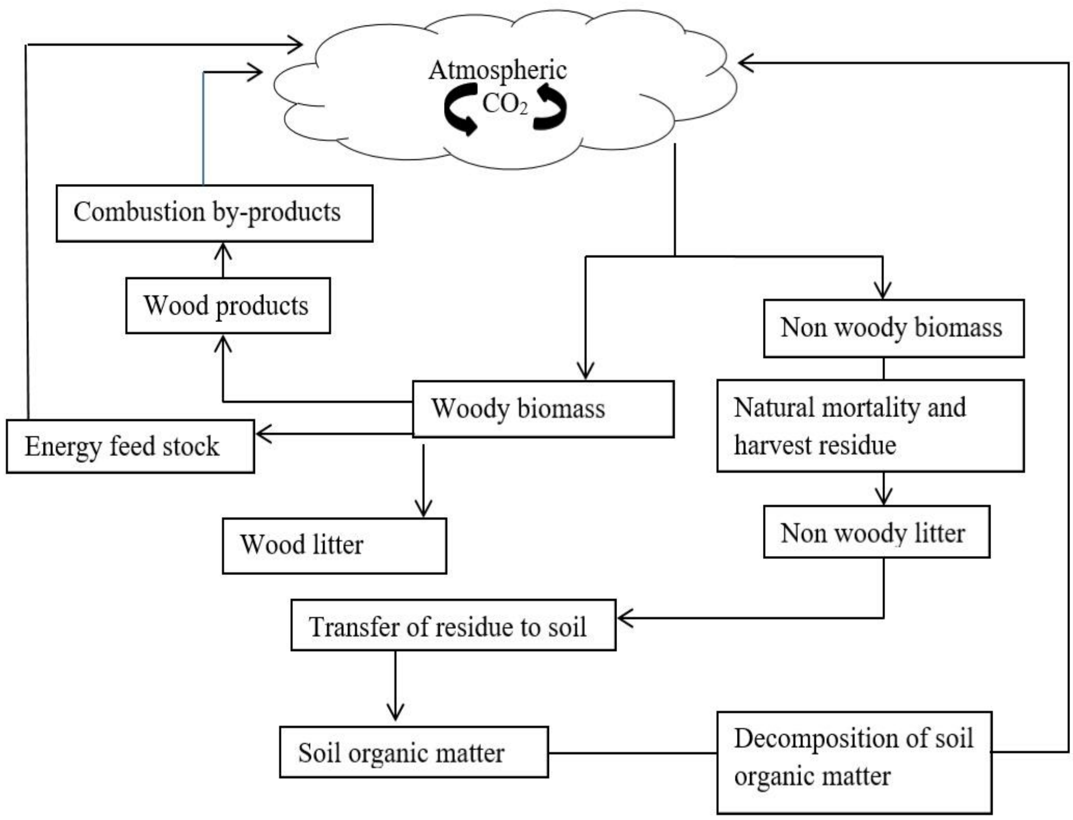

Figure 1.1. Sequestration of atmospheric carbon by trees stored in to the soil and re-emission due to the decomposition of the soil and the combustion of by-products.

Improving carbon storage capacity of forest land through afforestation is a vital aspect (Wei *et al*., 2014). However, quantitative estimates on effect of tree species on SOC stocks and other soil properties are still scarce and the scientific basis for targeted use of tree species for enhancing sequestration of SOC following afforestation is also limited to relatively few studies (Vesterdal *et al*., 2002; Korkanc, 2014). At present plantation forest have a limited share in total pool of terrestrial carbon but there contribution is supposed to be bigger in future as various countries are developing new designed or planned forest on their waste and barren lands (Payn *et al.*, 2015).

1.3. Fuel wood as energy source for rural households

Due to rapid industrialization, growing human population and changes in life style has increased the demand of energy during the recent decades. This demand is going to increase by 50% upto 2030 which is mostly expected in developing countries like India, China and Brazil (Kumar and Chandrashekar, 2014). This increasing demand of energy may cause depletion in reserves of fossil fuels, enhance emissions and reduce the green cover. To avoid the consumption of fossil fuel, use of biomass as energy source is considered better in reduction of CO_2 emission into the atmosphere (Fernandes and Costa, 2010). Globally, it has been estimated that approximately 3 billion people use solid biomass fuel including wood, dung cake, agriculture waste and coal throughout the world (Bond et al., 2004). Wood biomass accounts for about 14% of total energy used globally and is the largest energy source for three-quarters of the world's population living in the developing countries (Sedai *et al.*, 2016). The total average annual production of wood fuel for energy in the developing countries increases nearly 17.6% over the last decade (Simon and Singh, 2015).

Consumption of firewood is society's oldest source of household energy and is still used around the globe, even in technologically advanced countries with high energy consumption (Lindroos, 2011; Kandel *et al.*, 2016). In many countries, fuel wood consumption is now one of the most important reasons for forest degradation. It has been estimated that biomass in the form of fuel wood only accounts for approximately 9% of total global energy consumption (Lauri *et al.*, 2014). For several decades, deforestation and forest degradation have been one of the developmental agendas worldwide in an effort to find a compromise between the lifestyle of forest dwellers and forest conservation. However, due to unsustainable way of utilization of forest resources due over exploitation thereby, resulting in forest degradation. According to the Forest Survey of India, about 70 % of the Indian rural population depends on firewood to meet their household energy needs (FSI, 2011). According to the 2011 census, approximately 49% of households in India use firewood for cooking. However, in some states it is higher than 80%. Poor rural households collect fuel-wood from locally available resources from forests to meet their domestic energy needs. Firewood is the most attractive among the various forms of biomass and occupies a predominant place in the rural energy budget in India (Kataki and Konwer, 2002; Baqir *et al.,* 2017).

1.4. Clean cooking energy: Need of the hour

The collections of unsustainable fuel wood and inefficient conversion technology have serious implications for the environment (Hussain *et al.,* 2017). Burning of fuel wood produces large amounts of carbon dioxide (CO2), but fuelwood emissions are considered to be carbon neutral if fuelwood is harvested and consumed sustainably. Due to incomplete and inefficient way of combustion, the use of fuelwood may not be carbon neutral because excessive carbon is released in other forms of CO, methane, nitrous oxide, carbon monoxide, and non-methane hydrocarbons, which have more global warming potential (GWP) than CO_2 (Smith *et al.,* 2005). Exposure to indoor air pollution causes serious health risks, especially for women, who cook food and children who spend much time around the cooking chulha with their mother (Singh *et al*., 2014). Inefficient way of burning of solid biomass fuel releases large amount of air pollutant like CO, $PM_{2.5}$, PM_{10}, SO_{X}, and NO_X (Arora *et* *al*., 2014, Suresh *et al*., 2016). Among these carbon monoxide (CO) has a major share of the pollutant due to incomplete combustion in indoor and semi indoor kitchens, which is associated with several respiratory, cardiovascular, dermatological and retinal diseases (Ezzati, 2010). Fine suspended particulate matter ($PM_{2.5}$) that can travel deep into the respiratory system resulting in serious health problems. Exposure of $PM_{2.5}$ alone accounted about three million deaths annually and exposure due to the burning of solid biomass in indoor environment due to inefficient cook stove causes about 1.6 million cases of death per annum (WHO, 2014). It has been estimated that more than four million people residing mostly in rural areas die annually from exposure to indoor air pollution and a quarter of these deaths occur alone in South Asia (WHO, 2014 & 2016). Therefore, switching to cleaner fuel is one of the promising strategies for improving indoor air quality (Grieshop *et al.,* 2011). The inefficient biomass combustion for cooking also contributes to the level of global CO_2 emission significantly (Chafe *et al.,* 2014).

Burning of biomass in the traditional cook stoves is one of the widely used biomass based appliance from incenting time till date. Traditional one pot or two pot mud chulha have low thermal efficiency and huge emission of smoke as compared to the improved cook stoves (Panwar and Rathore, 2008). The government of India has initiated several programs focusing on improved cook stove, biogas plant, kerosene and energy supply, aimed to reduce the dependence on biomass fuel and reduction in emission of smoke since the early eighties. Though the success assessment is not adequately analysed. Recently different initiatives have been under taken at the grassroot level and extensive infrastructure has been created for implementing projects to overcome the problems related to the indoor air pollution and health problems.

The National Program of Improved Cook stove (NPIC 1985-2000) aims to achieve conservation of fuel wood and reduction of emissions in the indoor kitchen by the use of chimney system to make biomass combustion in improved cook stove as safe. Currently, more than 160 improved cook stove programs are operating worldwide (Gifford et al., 2010; Ruiz-Mercado et al., 2011). Some of the prominent energy efficient biomass cook stoves such as Natural and forced draft cook stove, plancha cook stove, rocket mud cook stove, patsari improved cook stove and other improved cook stoves have been developed to alleviate the problems associated with indoor pollution and thermal performance (Venkataraman *et al*., 2010; Caroline *et al*., 2013; Suresh *et al*., 2016). However, these improved chulhas have certain limitations in their thermal performance, risk to fire spark, ash collection system for proper disposal.

Reports on estimation of carbon pool in soil and plant and fuel wood consumption scenario in plantation forests are rarely available in Indian context. Therefore, in this particular study, conceptual framework is designed to evaluate the scenario of fuel wood in this particular area of India, very specific to collection and consumption also in protected forest region. Also, how the seasonal variation affects the consumption and collection pattern of fuel wood and their impact on above and below ground biomass carbon stock was also studied. Very limited numbers of case studies are available on this region of India. Further, energy consumption patterns and use of different stoves for cooking purposes in this particular area has not been described so far. Keeping the above facts under consideration, following key objectives for the present study was designed.

Objectives of the Study

1. To study above and below ground biomass for evaluation of carbon stock of the selected plantation forest.
2. To study the organic carbon stock and nutrient dynamics of soil under plantation forest and its comparison with a surrounding non forest area i.e; Waste land.
3. To study bio energy assessment of fuel wood obtained by local people from the plantation forest.
4. To develop an energy efficient metal chulha for burning of solid biomass fuel and performance evaluation for its thermal efficiency and lesser emissions.

Chapter 2

Review of Literature

The present chapter deals with the review of literature related to the present work i.e., role of plantation forest in carbon sequestration and fuel wood consumption studies at global and Indian context. Further we have also worked on review of cook stove technology used for cooking purposes in rural India very specific to advances and traditional designs and working in the particular environment.

2.1. Carbon sequestration

The term "carbon sequestration" is used to describe the processes by which carbon dioxide (CO_2) is either removed from the atmosphere or diverted from emission sources and stored in the ocean, geologic formation and terrestrial environment. The terrestrial sequestration sometimes termed "biological sequestration" is typically accomplished through forest and soil conservation practices that enhance the storage of carbon such as restoring and establishing new forest, wetland, and grassland. Terrestrial ecosystem is a major biological scrubber of atmospheric carbon dioxide that can be significantly increased by careful management. Absorbing CO_2 from atmosphere and moving in to the physiological system and biomass of the plant and finally into the soil is the only practical way of removing large volume of the major greenhouse gases (CO_2) from the atmosphere into the biological system of plant (Weissert *et al*., 2014). As part of the natural process, some of the carbon is released back into the atmosphere, but some carbon is captured within the soil and increases soil organic stock.

2.2. Climate change and carbon sequestration

Climate is the weather condition of a particular area averaged over a long period of time say for decades or so. The climate change manifests the change in the set weather condition or trend of an area. Two weather parameters, temperature and precipitation averaged over a long period, can be used to define the climate of an area in its simplest form. Climate change can be defined according to IPCC as any change in the climate over time weather as a result of natural activity or anthropogenic activity. According to UNFCCC, climate change that is directly attributed or indirectly altering the composition of atmosphere and variability observed in natural climate in comparable time period (Metz *et al*., 2007). Our earth is a habitat for millions of human beings. These human beings are using the natural resources of earth for their own benefit. Human have burnt increasing amount of fossil fuel and biomass and since the dawn of the industrial revolution released the CO_2 and has increased the concentration of CO_2 and other GHGs into the atmosphere significantly. Rapid industrialization which led to increase in the concentration of popular GHGs viz, CO_2, CH_4, N_2O *etc*., into the atmosphere. In addition to these gases, the greenhouse gases also include O_3, CFC, hydro fluorocarbon and water vapours *etc*. Out of these gases CO_2 contribute 60% followed by CH_4 15% and N_2O 5% and the concentration of CO_2 and CH_4 increasing 0.4 to 3% per annum while as N_2O is rising by 0.2% per annum (Huntingford and Mercado, 2016).

The global carbon dioxide (CO_2) has reached to an unprecedented level and it is predicted that it will soon exceed the present levels. A large number of environmental and forest scientist have predicted that if no action is taken to limit the emission of GHGs, the temperature will rise in the range of 2^oC to 5°C by the year 2100 (IPCC 2001). Atmospheric carbon-dioxide (CO_2), a major greenhouse gas, has been increasing steadily since pre-industrial times and it has been predicted that carbon dioxide emission to the atmosphere would increase from 7.4 Gigatons (Gt) C yr^{-1} in 1997 to approximately 26 Gt C yr^{-1} in 2100 (IPCC, 2007). The Carbon Dioxide Information Analysis Center (CDIAC), USA estimates the total fossil-fuel CO_2 emissions from India as 189 Tg C in 1990, 324 Tg C in 2000, 385 Tg C in 2005 and 508 Tg C in 2009, and the annual rate of increase as ~ 7% per year during 2005-2009 (Boden *et al.*, 2010). Therefore, it is important to remove carbon from the atmosphere and depositing it in a reservoir. Recently, the role of forest ecosystem in

SOC stocks and dynamics for mitigation climate change has highlighted the need for more knowledge on effects of tree species (Jandl *et al.,* 2007). Therefore, management of forest, including change in tree species, afforestation or forest plantation are accepted measures for mitigation of atmospheric CO_2 concentration in national GHG budgets.

2.3. Forest and carbon sequestration

The United Nations Climate Change Conference (UNFCCC) made several decisions relating to forest in 2013, named "Warsaw Framework for REDD$^+$, which further confirmed the role of forest in offsetting industrial emission of greenhouse gases. Consequently, relying on forest to uptake carbon by decreasing disturbance on forest would be an alternative approach for mitigating greenhouse gas concentration effects besides afforestation and reforestation (Yingchun *et al.,* 2014). The rapid changing in climate may overtake by sequestration of atmospheric carbon from the atmosphere. Forest contains much carbon in vegetation and soils, and play an important role in the global C cycle (Vashum *et al*., 2016). The Kyoto Protocol encouraged the promotion of sustainable forest management practices and the contribution of forest to global carbon sequestration have been recognized (IPCC, 2003). Consequently, studies on the carbon budget of forest biomass and dead organic matter have been conducted to understand temporal forest carbon stocks and balances (Lee *et al*., 2014).

According to IPPC 5th assessment report 2014, forest sector identified as one of the key area responsible for reduction in GHGs and mitigate climate change (Victor *et al*., 2014). Among the forest management practices for carbon sequestration, plantation forest has been identified as coast effective and environmental beneficial strategy for sequestration of carbon (Ostadhashemi *et al*., 2014). Sustainable forestry practices can increase the capacity of forest to capture atmospheric carbon, while improving simultaneously other ecosystem services (Giri and Rawat, 2013). Recently, the number of studies has focused on assessing the biomass and carbon storage of woody plants and forest in the world, especially after the ratification of the Kyoto Protocol (Yen, 2013). These studies suggest that carbon sequestration is one of the important objectives in current forest management in the world. According to (Li *et al*., 2011) forest have a large carbon storage function per unit area than any other ecosystem on earth, and an effective way to reduce the highest concentration of carbon dioxide in the atmosphere is by increasing the forest area (Rizvi *et al*., 2016). It has been reported that, among the forest management options for carbon sequestration, reforestation or forest plantation (i. e, the establishment of trees on previously non forested lands) has been recognized as a profitable and environmentally beneficial strategy for carbon sequestration (Ostadhashemi *et al.*, 2014).

According to FAO calculations (FAO, 2005), total forest carbon stocks in India have increased over a period of 10 year (1995-2005). The carbon stock in forest biomass has increased from 2692.474 to 2865.739 mt, registering an annual increase of 173,265 mt of carbon during the decade (Kishwan *et al*., 2009). The carbon stock projections for the period 2006–30 is projected to be increasing from 8.79 to 9.75 Gt C (Kohl *et al*., 2015)) with forest cover becoming more or less stable, and new forest carbon accretions coming from the current initiatives of afforestation and reforestation programme (Ravindranath *et al.*, 2008). With the knowledge and the information that is now emerging, the role of forests and plantations in mitigation is becoming more and more important. Further, Joint Forest Management in India could be effectively utilized for carbon sequestration so as to mitigate climate change. Number of studies reported that potentiality of the forest to capture carbon depends on the type of forest, age of the forest and size of the trees (Terakunpisut *et al*., 2007).

Table 2.1. Carbon sequestration potential of natural and plantation forest in different region of the world

Study	Region	Forest type	Classification	Carbon sequestration potential	Main species
Ostadhashemi *et al*., 2014	Iran	Plantation forest	Hyrcanian forest	49.21 Mg/ ha^{-1}	*Acer velutinum, Quercus castanifolia*
Giri and Rawat, 2013	India	Plantation	Subtropical	43.91 Mg/ ha^{-1}	*Ailanthus excels*
Xinliang and Kerang, 2010	China	Plantation	Tropical	23.05 Mg/ ha^{-1}	*Pinus masoniana and pinus koraiensis*
Chaturvedi *et al*., 2011	India	Natural	Tropical dry forest	151 Mg/ ha^{-1}	*Termininalia tomentosa, Flacourtia indica,shorea robusta and terminalia chebula*
Ullah and Amin, 2012	Bangladesh	Natural	Moist topical	283.80 Mg/ ha^{-1}	*Dipterocarpus turbinatus and Antidesma acidum*
Salunkhe *et al*., 2014	India	Natural	Tropical deciduous	25.6 Mg/ ha^{-1}	*Acacia catechu, acacia nillotica, Butea monosperma, Maduca latifolia*
Li *et al*., 2010	Korea	Plantation	Alpine forest	56.67 Mg/ ha^{-1}	*Pinus Koraiensis*
Behera *et al.*, 2017	India	Natural	Tropical deciduous	107.5 Mg/ ha^{-1}	*Terminalia elliptica, diospyros exculpta, shorea robusta, madhuca longifolia*
Kraenzel *et al.*, 2003	Panama	Plantation	-------------	351 Mg/ha^{-1}	Tectona grandis
Sahu *et al.*, 2016	India	Natural	Tropical	143.4 Mg/ ha^{-1}	*Rhizophora apiculata Avicennia officinalis*
		Plantation	Tropical	151.5 Mg/ ha^{-1}	*Avicenia marina*

However, fast-growing tree species accumulated more carbon in their biomass than other plantations of the same age. It has been reported that an increase in the size of the individual tree does not necessarily increase the level of biomass and carbon stock (Khum *et al.,* 2015).

2.4. Soil and carbon sequestration

Soil carbon is the last major pool of the carbon cycle. The carbon that is fixed by plant is transferred to the soil. Soil carbon sequestration in soil refers to capture and secure by storage of atmospheric CO_2 with pedosphere in a manner that also increases its mean residence time and minimizes sinks of re-emission (Lal, 2007). The SOC is a strong indicator of soil quality and important constituent of soil physicochemical and biological health. Measurement of SOC will help to assess the sustainability, productivity and fertility of soil (Lal, 2007). Important role played by soil in global carbon cycle by storing about 300 times the amount of carbon released due to anthropogenic activities (Schulze and Freibauer, 2005). However this storage is dynamic and depends on change in land use, management of land system and environmental changes (Miranda *et al.*, 2013). Distribution of variable SOC stock has been identified due to several factors including type of soil, soil texture, rainfall, moisture, temperature, geological substrate, altitude, slope and practice of management (Zhang *et al.*, 2011).

SOC pool is determined by the input of carbon by litter fall and rhizodeposition on one hand and emission of carbon during the decomposition process on the other hand (Lal e*t al.*, 2017). Forest ecosystem store more than 80% of total terrestrial above ground carbon and contribute more than 70% of soil organic carbon in forest soil among all the soil organic carbon (Jandl *et al*, 2007). Decomposition of organic matter and soil microbial activity and other factor effects the SOC stock in to forest soil as precipitation (Mehta *et al.*, 2014), slope (Prichard *et al*., 2000), temperature (Telles *et al.*, 2003), Vegetation (Callesen *et al.*, 2015) and Conversion of forest land into agriculture land (Tabi *et al.*, 2013). Other factor include management that can directly influence the C flow into the soil, and aim should be to secure a high productivity and, in particular, to avoid soil disturbances for enhancing the SOC pool by formation of stable organo-mineral complexes (Pardona *et al*., 2017). This entire factor affects the ability of forest to store SOC stock. Comparison of SOC stock in primary and secondary forest showed that ability of forest ecosystem to sequester more carbon into the soil if the forest is under minimum disturbance (Vashum *et al*., 2016).

Selection of tree species for better soil carbon sequestration was emphasized by a recent meta- analysis (Jandl *et al.*, 2007). The influence of tree species on the properties of forest soil has been studied by ecologists for a long time (Vesterdal *et al.*, 2008). Vertical patterns of soil organic carbon (SOC) and other soil properties are crucial to understanding the biogeochemical cycles in ecosystems, but they remain poorly understood (Yang *et al.*, 2010). Studies reported that enhancing forest plantation would improve other soil properties as well as sequestration of carbon and help in global climate change mitigation (Cardinael *et al.*, 2015). Carbon stock can be changed after plantation establishment because tree species have different nutrient requirement and carbon storage mechanisms (Cardinael *et al*., 2015). In addition, the role and the importance of forests for carbon and nutrient storage may likely to be quite variable with forest types because nutrient converting rates among species are different (Baqir *et al.*, 2017). Contradictory to this, decreasing levels of SOC with increasing soil depth have also been reported which may be attributed to slow cycling of nutrients and carbon pool and may also be due to compaction of soil (Dar and Somaiah, 2015). Optimized forest management with respect to carbon sequestration in the soil should aim to ensure high productivity of the forest on the input side, and avoid disturbances of the soil floor as much as possible on the output side. In addition to compensating anthropogenic emissions, SOC sequestration has numerous collateral benefits. In the recent years many studies have assessed soil organic carbon (SOC) pools in different forest type. However, specific knowledge of plantation forest and there role in soil carbon sequestration as a carbon mitigation is still scare especially at Indian context. (Table 2.2) shows forest soil carbon stock in different region of India.

2.5. Physico-chemical properties of forest soil

The vegetation influences the physicochemical characteristic of soil to a great extent. Forest in general have a greater influence on soil conditions than most other plant ecosystem types, due to a well-developed ‘‘O’’ horizon, moderating temperature, and humidity at the soil surface, input of litter with high lignin content, high total net primary production, and high water and nutrient demand (Binkley and Giardina, 1998). Moreover, different tree species can differ significantly in their influence on soil properties as well as soil fertility (Augusto *et al*., 2002). Plant tissue (aboveground and belowground litter) are the main source of soil organic matter, which influences the physicochemical characteristics of soil such as, texture, water holding capacity, pH and nutrient availability (Ding *et al*., 2011). Further, soil microbial biodiversity help in maintenance of soil organic carbon (SOC) and nutrient recycling in soil (Song *et al.,* 2016).

Table 2.2. Forest soil organic carbon stock in different region of India

Site	Type of forest	Soil depth	SOC%	Sources
Natural forest northern region of India.	Natural forest	----	1.92	(Majumdar *et al*., 2004)
Natural forest of Terai zone West Bangal.	Natural forest	0-10	1.77	(Koul *et al*., 2011)
		10-20	1.53	
		20-30	1.38	
		30-40	1.16	
Oke forest Uttarakhand central Himalayas.	Plantation forest	-----	1.82	(Bora and Singh, 2012)
Garwal Himalaya Uttarkhand.	Natural forest	0-10	4.44	(Goirola *et al*., 2012)
		11-30	2.55	
		31-60	2.16	
Temperate Coniferous forest Kashmir Himalayas.	Natural forest	0-30	2.25 to 1.245	(Wani *et al.*, 2014)
Semi-arid tropical forest of south India.	Natural forest	0-60	0.82	(Venkanna *et al*., 2014)
Populous deltoids plantation Tarai region central Himalaya.	plantation forest	0-30	2.07-1.58	(Arora *et al.*, 2014)
		31-60	1.33-1.39	
		61-90	1.31-1.25	
Tropical Sal forest (*Shorea Robusta*) Odisha India.	Natural forest	0-20	1.41-0.41	(Ahirwal *et al*., 2016)
		20-40	1.18-0.27	
		40-60	1.14-0.14	
Pantnagar Uttrakhand.	plantation forest	-----	0.45	(Kanime *et al.*, 2013)
Subtropical forest of North East India.	plantation forest	Up to 20 cm depth	3.80-4.20	(Pandey *et al.*, 2016)
Kolli hills, Tamil Nadu.	Natural forest	0-30	1.4	(Ramachandran *et al*., 2007)
		30-60	0.86	
		60-90	0.66	

Soil microbial biomass, which can be either a source or sink of available nutrients, plays a critical role in nutrient transformation in terrestrial ecosystems (Shao *et al.,* 2015). Soil enzyme activities linked to the decomposition of organic matter; transfer of energy and recycling of the soil nutrients (Sharma *et al*. 2015). The soil enzyme activity directly reflects the soil fertility as these activities are directly linked with the soil microorganism (Das *et al.,* 2014). Tree species has an impact on soil fertility and microbial community composition, which in turn can affect the soil microbial biomass and microbial efficiency in carbon (Shao *et al.*, 2015). Soil Microbial biomass carbon varies with the seasonal patterns of soil temperature, moisture content, and substrate availability (Basiliko *et al*., 2005) and also with seasons and soil depth (Tsai *et al*., 2007).

Soil respiration signifies efflux of co_2 from the soil surface and considered as a measure of total microbial activity of soil. Soil respiration reflects the capacity of soil to sustain plant growth, soil fauna, and microorganisms. It indicates the level of microbial activity and SOM content and its decomposition. Respiration by soils is dependent on temperature and moisture (Lloyd and Taylor, 1994), the composition of the community of soil organisms (Bardgett *et al.,* 2008). Forest soil respiration is a major carbon flux that is characterised by significant variability in space and time. Soil respiration is the second largest flux in the terrestrial carbon balance, with about 80–98 Pg C being emitted to the atmosphere every year (Bond-Lamberty and Thomson, 2010). Because forest occupy about 30% of the world's land area, respiration from forest soils make a major contribution to the global carbon cycle. Soil temperature, soil moisture, forest productivity, and soil carbon content are all important factors influencing soil respiration. Heterotrophic respiration, which is derived from soil organisms and fuelled by plant detritus and soil C, increases under warmer conditions if carbon substrate or moisture is not restrictive (Suseela *et al*., 2011) and the quality of organic compounds used to fuel heterotrophic metabolism (Conant *et al*., 2011). In addition, there is strong evidence that soil respiration is linked to plant photosynthesis (Kuzyakov and Gavrichkova, 2010). Because of this linkage, a large fraction of carbon in the soil efflux has resided in the biosphere for only hours, days or weeks (Hogberg *et al.*, 2001). Understanding the complicated role of the biosphere in the global carbon cycle is thus essential for the prediction of future climate (Friedlingstein *et al*., 2014). Thus a clear positive effect of resource conservation technology is observed on soil respiration and thus on the soil microbial activities.

Soil enzyme activity has been considered as a major index for soil microbial activity and soil organic carbon status (Singh *et al.*, 2008). These include dehydrogenase, urease, acidic and alkaline phosphatase, Ferredoxin diacetate hydrolysis (FDHA) and Glucosidase etc., (Luo *et al.,* 2009). Soil dehydrogenase activity is an important indicator of soil microbial activity (Singh *et al.,* 2008). Among various soil enzymes, dehydrogenase activity (DHA) has been recognised as important biochemical indicators in soil (Ryoichi and Senaratne, 2009). (Lenhard, 1956) introduced the concept of determining the metabolic activity of microorganisms in soil and other habitats by measuring DHA. Soil DHA reflects the total range of oxidative activity of soil micro flora and, consequently it may be a good indicator of microbiological activity in the soil (Skujins, 1976).

The activity of soil phosphatases can be influenced by numerous factors viz. soil temperature, salinity, concentration of phosphate-phosphorous, pH (Tripathi *et al*., 2007) and soil properties and farming systems play a key role among them (Oprica *et al.*, 2011). Phosphorus generally may occur as phosphates in both inorganic and organic compounds in the soil and sediment. Microorganisms, in general, phosphate solubilizing bacteria are involved in assimilation of inorganic phosphate and they may mineralize organic phosphorus. Those enzymes that hydrolyse phosphorous esters are commonly called phosphatases. Acidic and alkaline phosphatases have been studied extensively (Dodor and Tabatabai, 2003). These enzymes are classified acidic and alkaline phosphates because they show optimum activities in acidic and alkaline ranges respectively. Importance of this enzyme in plant nutrition and in organic phosphorus mineralization in soils. These two enzyme especially acidic phosphatase are among the most studied enzyme.

2.6. Plantation forest

Since the year 1980 the food and agriculture organization (FAO) of the United States through its forest resource assessment and has been classified forest in to natural and plantation forest. In addition to this during the year 2005 forest resource assessment (FRA) added two more classification as semi natural forest and modified natural forests. Which results forest are classified into five major categories based on human intervention, these are primary forest or natural forest, semi natural forest, modified natural forest, plantation forest and tree outside forest (FAO, 2010). According to FAO plantation forest are the types of forest which are established by planting, seedling or coppicing.

At global level about 4% of the world forest is under plantation forest developed for number of ecosystem services both direct and indirect benefits and reducing the negative impact on natural forest (Powson *et al.*, 2013). Globally, it has been reported that area of natural forest are going to declining (about 13 million ha per year) and the plantation forest has been increasing about 5 million ha per year between the year 2000 to 2010 and now planted forest cover 264 million hectares accounting for 7% of all forests (FAO, 2012). Plantation forest which are established for the number of purposes principally to mitigate the climate change, ecosystem services, wood production, biodiversity conservation and minimizing the negative impact on natural forest (Pawson *et al*., 2013). On the basis productive and protective plantation forest can be divided into two sub-group. In turn, they are defined as productive plantation are forest plantations predominantly intended for the provision of wood, fibre and non-wood products and protective plantation are forest plantations predominantly for the provision of services such as protection of soil and water, rehabilitation of degraded lands, combating desertification, etc.

2.7. Role of Plantation forest in Carbon sequestration

Increasing afforestation or forest plantation may further incentive for sequestration of carbon and protection of natural forest from degradation. According to FAO and United Nations Framework Convention on Climate Change (UNFCCC) has recognized the importance of plantation forestry as a greenhouse gas mitigation option, as well as the need to monitor, preserve and enhance terrestrial carbon stocks (Updegraff *et al.,* 2004). Transformation of degraded and lower biomass land area into carbon reach tree based system as plantation forest and agroforestry system can have higher potential to sequestration of carbon from atmosphere and stored in to the biosphere (Chavan and Rasal, 2012). However, Plantation forests have small contribution in the total balance of terrestrial ecosystem carbon, about 3% or 140 million hectare of the total forest area of the world (FAO, 2006).but their contribution to store or absorb atmospheric carbon plays an important role for future climate change mitigation (Fonseca *et al*., 2011). In addition, production from plantation forest may relieve pressure on timber extraction from natural forest, and thus contribute to forest conservation for 89% (Fang *et al*., 2007).

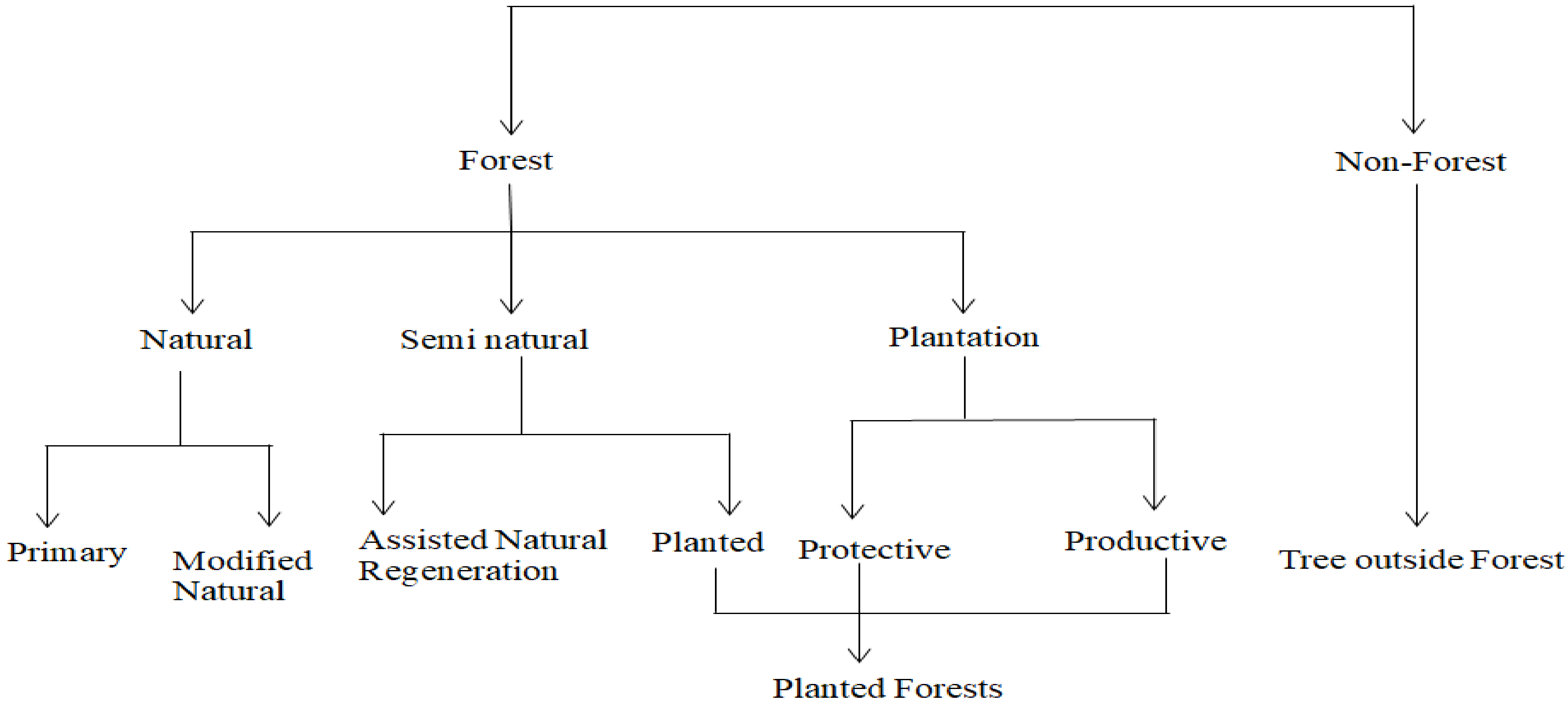

Figure 2.1. Continuum of forest characteristics and definition of different forest types according to FAO: Source; (Carle and Holmgren, 2008)

Involvement of communities in increasing tree plantation, improve forest health and other developmental strategies help in mitigation of climate change and significant ecological benefit. Report obtained from numerous studies that forest plantation has been done almost exclusively as monoculture (Nichols *et al.,* 2006). However, many reviews provide evidence that production of biomass and other ecosystem services can be enhanced with diversity of tree species (Nadrowski *et al*., 2010). Different tree species have significant potential to sequestration of atmospheric carbon. It varies with climate, soil, topography and management practices (Patil *et al*., 2015). Therefore, forest plantation that are diverse in genetic, species, structure, and function should be better in changing environmental condition then monoculture plantation (Bahus *et al*., 2010).

According to the records of the National Afforestation and Eco-development Board (NAEB) of the Ministry of Environment and Forest of the Government of India, the cumulative area under forest plantations up to 2005–2006 was 42.17 million ha (Pandey, 2008). Using recent remote-sensing based estimates of tree cover and growing stock outside forest in India, the estimated 2.68 billion trees outside forest contribute to an additional national average tree carbon density of 4 Mg Cha^{-1} in non-forest area, in comparison to an average density of 43 Mg Cha^{-1} in forests (Kaul *et al*., 2010). However, there is a large variation in the carbon sequestration potential of different plantation species and there are varying estimates of the carbon sequestration rates of common plantation species (FAO, 2003). At present plantation forest have a limited share in total pool of terrestrial carbon but there contribution is supposed to be bigger in future as various countries are developing new designed or planned forest on their waste and barren lands (Payn *et al*., 2015). Reports on estimation of carbon pool in soil and plant in plantation forest are also rarely available in both global and Indian context.

If we look globally, plantation forest area increased from 1990 to 2015 from 167.5 million ha to 277.9 million ha with the increase varying by region and climate domain (Payan *et al.*, 2015). Annualised rates of increase in area were highest in the 1990–2000 periods (2.0%) and the 2000–2005 periods (2.7%) but dropped in 2005–2010 (1.9%) and further in 2010–2015 to 1.2%. This drop may be of concern given that a study by WWF and IIASA have suggested that a rate of increase of 2.4% is needed to meet future demands and supply all of the world's timber and fibre and thus offset deforestation impacts on wood supply (WWF and IIASA, 2012). In addition, when incorporated into integrated landscape management, forest plantation can play an important role in achieving biodiversity conservation objectives by offsetting the need to extract resources from natural forest (Verheyen *et al.*, 2016). Overall East Asia and Europe had the largest areas of planted forest, followed by North America and Southern and Southeast Asia (FAO, 2015).

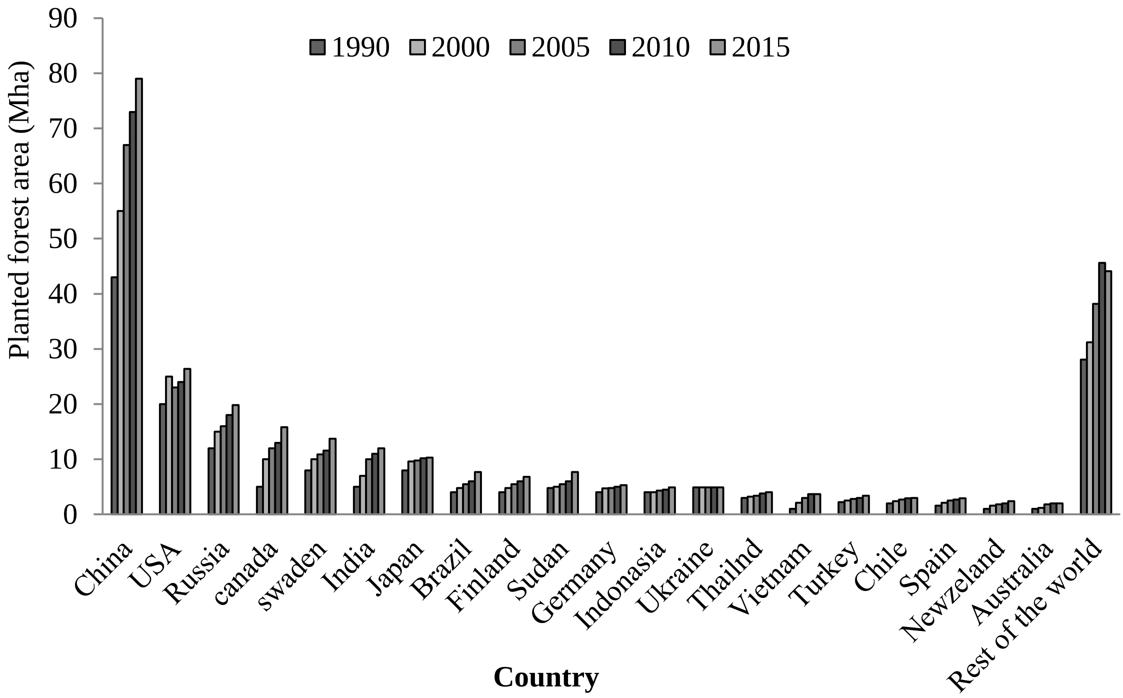

Figure 2.2. Trends of planted forest area between the years (1990-2015) for the 20 top countries by area of planted forest. Source: (Payan *et al.*, 2015).

(Figure 2.2) shows planted forest at global level of some important countries, area of the planted forest increased from the year 1990 to 2015 from 167.5 to 277.9 million ha and the trend of planted forest at country level, 20 top most countries contribute 85 % of planted forest area (payn *et al*., 2015). Out of this china contribute 79 million ha of land area under planted forest followed by USA (26.4), Russia (19.8), Canada (15.8), Sweden (13.7) and India (12.0). India comes on 5th position on top 20 countries.

2.7.1. Indian scenario

Government of India has been implementing large-scale afforestation or forest plantation since 1980 under social forestry, joint forest management program, silvi-pasture, farm forestry and agro-forestry programmes, covering an area over 30 mha. This may have reduced pressure on the natural forests. According to the India State of Forest Report (ISFR, 2013) published by the Forest Survey of India (FSI), the total recorded forest area (RFA) in India is 77.18 Mha. Out of this, 48.89 Mha (63.35%) is natural forest of seed origin, 9.75 Million ha (12.64%) is natural forest of coppice origin, 4.83 Mha (6.26%) is man-made forest or plantation forest and 13.7 Mha (17.75%) is forest in water bodies, snow covered area or rocky out crop. The major distribution of plantation forest types in India are tropical and sub-tropical plantation of *Shorea robusta, Tectona grandis, Acacia catechu* and *Anogeissus pendula etc.,* and they constitute 5.78, 4.68, 1.06, and 0.75% of the RFA. In the higher elevation temperate climate zone, *Pinus roxburghii, Quercus species, Abies pindrow, and Picea smithiana* are found in majority by abundance over 1.86, 0.83, 0.33, and 0.11% of the RFA, respectively. These species are also found mixed in different proportions over other area. Mangroves constitute about 0.61% of RFA; and the major species of plantation forests include *Tectona grandis*, *Acacia auriculiformis*, *Acacia hybrid, Eucalyptus grandis, Eucalyptus citriodora, Casuariana equisetifolia*, *Greviliea robusta* and *Pinus roxburghii.*

Ministry of Environment and Forest, Government of India constituted a National Afforestation and Eco-development Board (NAEB) in the year 1992. This board has developed specific schemes for promoting afforestation and management strategies which assist the states in developing particular ‘‘eco-development’’ strategies by means of a participatory planning process. India has been implementing one of the largest afforestation programs in the world and annually between 1 and 1.5 million ha has been afforested since 1980 (Ravindernath *et al*., 2012). It is not clear how much of the total area reported as forest under SFR is constituted by plantations forest. However, large investment is going into afforestation program in India and clarity is not sufficient to how much area of planted forest has survived and matured into forest. Thus, it is important to generate separately spatial distribution of area under forest plantations at decentralized or local levels (Ravindranath *et al.*, 2014).

The Ministry of Environment and Forest recently launched an ambitious project entitled ‘National Mission for a Green India’ under the National Action Plan on Climate Change. The focus is on improving the quality of forest and ecosystem services, creating a new cadre of young foresters and adopting a landscape-based approach to forest design. The aim of the Green India Mission is to respond to climate change by a combination of adaptation and mitigation measures. These measures would help in enhancing carbon sinks in sustainably managed forest and other ecosystems adaptation of vulnerable species ecosystems to the changing climate and adaptation of forest-dependent communities. These programs will greatly benefit from information gathered in some older long-term field plots and new observational studies. Large parts of India offer good growing conditions, good rainfall and water resources, a tropical climate and ample sunshine, so that trees may grow fast. Forest plantations constitute a very important part of the forest resources as large proportion of wood produced in India comes from tree plantations established both within and outside the forest reserves. (Table 2.3) shows afforestation or forest plantation on public and forest land under plantation.

Table 2.3. Afforestation: Area Covered Under Plantation (Public and Forest Lands)

S.No.	States/UTs	Target 2015-16	Achievement 2015-16	Achievement Percentage
1	Andhra Pradesh	1,48,730	1,33,618	90
2	Arunachal Pradesh	210	8	4
3	Assam	40	0	0
4	Bihar	22,790	41,419	182
5	Chhattisgarh	50,410	1,33,531	265
6	Delhi	850	1,498	176
7	Goa	150	21	14
8	Gujarat	1,39,280	1,50,822	108
9	Haryana	57,200	30,643	54
10	Himachal Pradesh	18,000	11,449	64
11	Jammu And Kashmir	8,700	10,863	125
12	Jharkhand	3,450	NR	0
13	Karnataka	66,090	69,093	105
14	Kerala	3,890	1,117	29
15	Madhya Pradesh	1,10,700	7994	7
16	Maharashtra	1,22,880	55,793	45
17	Manipur	14,600	2855	20
18	Meghalaya	4,850	3,186	66
19	Mizoram	4,070	NR	0
20	Nagaland	1,050	NR	0
21	Odisha	1,07,290	1,70,808	159
22	Puducherry	40	86	215
23	Punjab	6,970	2,934	42
24	Rajasthan	57,100	70,893	124
25	Sikkim	4,810	1,325	28
26	Tamil Nadu	70,240	45,129	64
27	Telangana	59,970	2,36,598	395
28	Tripura	16,280	2339	14
29	Uttarakhand	16,000	17,846	112
30	**Uttar Pradesh**	**47,731**	**1,65,867**	**348**
31	West Bengal	750	12,169	1,623
32	Andaman And Nicobar Islands	1,120	1,300	116
33	Chandigarh	180	167	93
34	Dadra And Nagar Haveli	200	225	112
35	Daman And Diu	10	0	0
36	Lakshadweep	20	0	0
	Grand Total	**11,66,651**	**1,381,596**	**118**

Source: TPP-2006 Progress Report for 2015-16

2.7.2. Forest plantation at State Level (Uttar Pradesh)

Uttar Pradesh is primarily an agrarian state. However, about 6 % of the state land area under forest covers. The main forest types in the state are Tropical Semi Evergreen (0.21%), Tropical Moist Deciduous (19.68%), Tropical Dry Deciduous (50.66%), Tropical Thorn (4.61%) and Littoral and Swamp forest (2.35%).The recorded forest area in the state during the 1951 was 30,245 km^2. Additional areas were notified gradually and by 1998-99 the forest cover went up to 51,428 km^2. In 1999 Uttaranchal was separated from the state and the forest area was left with only 16,888 km^2 of recorded forest. The 2011 State of Forest Report reported the recorded forest area as 16,583 km^2, a decline of 305 km^2 of recorded forest area. Based on the interpretation of satellite data collected from October 2008 to January 2009, the forest cover in Uttar Pradesh has been estimated as 14,338 km^2, with 1,626 km^2 very dense, 4,559 km^2 moderately dense and 8,153 km^2 open forest (FSI, 2011).

However, An analysis of the trend of forest cover as presented by the respective State of Forest Reports for 2003, 2005, 2009 and 2011 indicates that the forest cover has been constantly improving in Uttar Pradesh (14,118 km^2 in 2003 to 14,338km^2 in 2011) and although much below the policy guidelines or the actual National figures growing from 5.86% of the States Geographical area to 5.95%. The area under very dense forest has also increased (1,297 km^2 in 2005 to 1,626 km^2 in 2009 and 2011) while the area under moderately dense forest has registered a decline (FSI, 2013). The tree cover has come down from 7,715 km^2 in 2003 to 7,382 km^2 in 2011. Further, tree planting on farms is one of the options to increase tree cover towards 33 %. Tree planting practices in the state vary considerably according to agro-climatic zone, socioeconomic conditions and profitability. *Eucalypts* sp and poplars as well as fruit trees are favoured species groups in the west of the state, whereas *Dalbergia sissoo* and *Tectona grandis* are preferred in the east largely due to site suitability and their uses by the farmers. The task of greening the state Uttar Pradesh as well as meeting the growing demand of fuel wood is therefore challenging and creates increased pressure to protect and maintain the existing forest cover. Growing trees on waste land and farm land is thus a solution to meeting the fuel wood resource demand in the future for rural poor households (Dhiman, 2012).

The Uttar Pradesh state forest department (UPFD) undertakes massive plantation activities on forest land as well as land owned by other department. On an average the UPFD has undertaken plantation of 37822.13 hectares per annum after 1994-95. Normally, the land which is other than recorded forest land fall in to different categories namely, Gram Samaj (village community), road side, canal side and the government institution, etc. Reports on estimation of carbon stock under plantation forest are rarely available in Indian context as well as state (U.P.) level. (Table 2.4) shows Year wise tree plantations raised by the forest department of Uttar Pradesh during last five years under various schemes.

Table 2.4. Tree plantations raised by forest department of Uttar Pradesh

Year	Forest Plantation (ha.)		No. of Plants (In lacs)	
	Target	Achievement	Target	Achievement
2009-10	66683.58	80597.40	597.08	812.81
2010-11	40300.00	67427.18	261.31	646.86
2011-12	41000.00	74181.85	266.50	564.72
2012-13	45000.00	51884.87	292.50	393.33
2013-14	49500.00	57097.29	321.75	456.67

Source: Uttar Pradesh State Action Plan on Climate Change 2014.

2.8. Bioenergy consumption scenario

2.8.1. Global scenario

Globally, solid biomass fuel remains an important source of energy for domestic cooking and space heating. It provides more than 11% of the world's total energy demand (Venkataraman *et al.,* 2010). It has been estimated that around 3 billion people in the world use solid biomass fuel for cooking (Suresh *et al*., 2016). More than half of this population lives in rural areas of developing countries. Villagers in developing countries use solid biomass such as twigs, wood, shrubs, crop residues, animal wastes or manure, etc., to meet their heating and cooking energy need. Traditionally, such biomasses are burned in a low-efficiency crude combustion device such as the three-stone fire stove to obtain the energy required for cooking. The combustion efficiency of this traditional type of cooking is very low and releases large amounts of harmful contaminants due to the incomplete combustion of the solid biomass fuel. The demand for local biomass energy can exceed the natural growth of local resources and cause deforestation from which environmental problems can arise. There is evidence that burned biomass fuels in traditionally inefficient cook stove contribute to the accumulation of greenhouse gases (GHGs) (Venkataraman *et al,* 2010). As well as other climate forces, including black carbon in the atmosphere (Alnes *et al*., 2014). Despite this knowledge, biomass remains the main fuel for cooking in developing countries.

(Figure 2.3) shows the percentage of people in developing world that use biomass fuel for cooking. It can be seen that the majority of people (more than 80%) in rural areas of the developing world depend mainly on biomass for cooking purposes. Two main approaches that can be used to improve energy security in developing countries, especially in rural areas are to promote more efficient and sustainable use of traditional biomass and encouraging people to switch to modern way of cooking and technologies. For many households, switching from traditional biomass to modern and clean biomass may not be feasible, in short term because of high capital costs coupled with high poverty levels (Singh *et al.,* 2014). Therefore, improving the way biomass is supplied and used for cooking purposes is an important way of improving the sustainability of its supply and use in developing world, while, at the same time, dealing with the energy security problems in those countries.

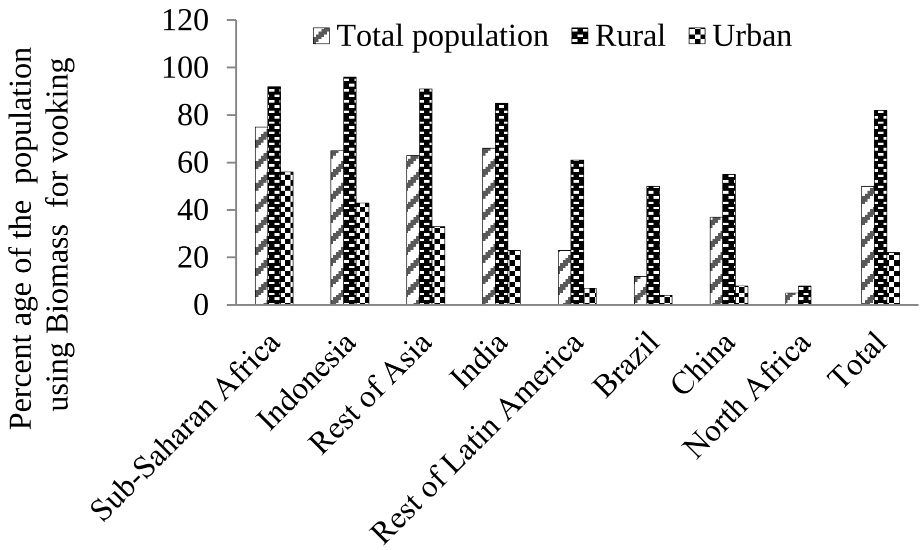

Figure 2.3. People of the developing world that depend on biomass resources as the main fuel for cooking purposes (Urmee and Gyamfi, 2014).

2.8.2. Indian scenario

The demand for energy increases with the increase in population and prosperity. The residential sector is one of the main energy-demanding sectors in India, where the thermal energy used for cooking contributes the highest percentage. Therefore, the use of a commercial and non-commercial energy source is required accordingly. It has been estimated that more than 170 million households depend on solid biomass fuel for cooking purposes in traditional inefficient cook stove that use solid biomass fuel (Singh *et al.*, 2014). Rural households depend to a large extent on locally available resources, such as forests and agricultural residue, to meet their daily energy needs. Among the various forms of biomass, firewood is the most attractive and occupies a predominant place in the rural energy budget of India (Dhanai *et al*., 2014). According to the 2011 Indian Census report, approximately 66% of households depended mainly on solid biomass as fuelwood to generate energy this includes 23% of urban households and 86% of rural households. Resulting in reduce local forest cover and contribute to the release of carbon by burning wood fuel (Anenberg *et al*., 2013).

The National Sampling Survey (NSS) showed that as of 2011-2012, around 80% of households in India used traditional fuels in the form of solid biomass to meet their cooking and heating (Jain *et al.,* 2015). However, commercial fuel has accelerated in the urban India, but the maximum population in the rural India consumes non-commercial solid biomass fuel (Narnaware and Pareek, 2015). Factors that the choice of fuel for cooking depends on the availability of biomass easily without any cost, income conditions of the households and tradition. The efficient use of fuel wood is much more eco-friendly than the use of efficient and conventional fuel like kerosene and LPG. The LPG emits 15 times more CO_2 per kg then wood and kerosene emits much as 10 times.

Knowledge of the energy mix in rural and urban areas has an important implication in the planning of energy sector policies. The impact of different policies and programs can be evaluated if the energy mix of both sectors is evaluated periodically. Two national level institutions in their studies (NCAER 1985-1993 and NSSO, 2007-2008) have analysed the energy mix in the domestic sector and has been reported that energy consumption pattern in rural and urban India differ a great deal.

Rural households use mainly firewood as the main source of energy for cooking, and more than two thirds represent around 67% of rural households, followed by LPG 15%. Only 10% of rural households use dung cakes and remaining 4 to 5 % households use other source of energy. In urban India fuel consumption pattern changed rapidly about 68 % of households use LPG as primary source of energy. And 15 % of households contribute fuel wood as primary source of energy only 1% households us cow dung cake as energy source. In urban house holds about 9% of households did not have any cooking arrangement. (Figure 2.4) shows percentage distribution of primary energy source use in rural and urban Indian households for cooking purposes.

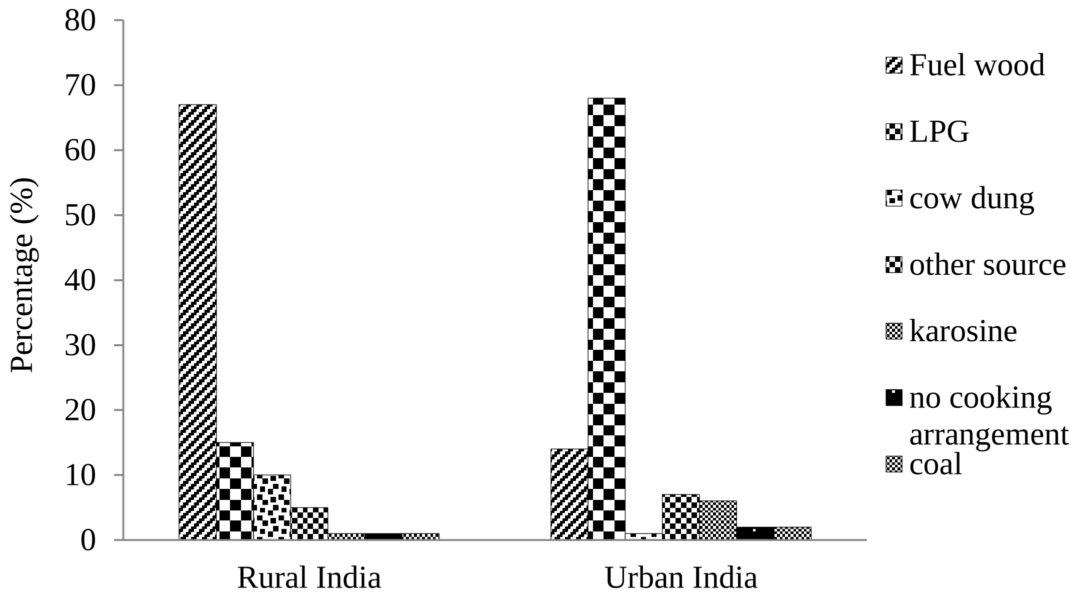

Figure 2.4. Percentage distribution of households by primary source of energy used for cooking in rural and urban India Source**:** NSS Report No. 567. Energy source of Indian house holds for cooking and lighting, 2011-12.

2.8.2.1. Forest fuel wood consumption status in India

If we look energy consumption in rural India many people especially poor rural households use fuel wood for energy purposes and contribution of fuelwood for energy purposes is viable from place to place and depends on easy availability. Collection of fuel wood is one of the most traditional activities which contribute to the forest degradation in the event of people adopting an unsustainable use of forests for these activities (Bhattacharya, 2010). Wood-based energy has been viewed as a means to reduce carbon emissions if biomass resources are sustainably managed and used with efficient bio energy systems (Richter *et al.,* 2009). Biomass fuels are preferred for reducing CO_2 emissions and reducing dependency on fossil fuel (Villeneuve *et al.,* 2012). Interest in using wood as biofuel are increasing with increase in population which may lead to further establishment of forest plantation of suitable tree species which are suitable for this purpose (Kole *et al.,* 2012). According to forest survey of India about 70% of Indian rural population depends on fuel wood to meet its domestic energy need. Fuel wood constitute one of the major energy source for cooking in India and it has been estimate that about 853 million people use fuel wood for cooking purposes in India (FSI, 2011). As per census of 2011 about 49 % of households in India use fuel wood for cooking purposes. However, in some state it is higher as 80 %. In order to meet the requirement for fuelwood, policy should be developed for mass scale afforestation program for meet the need of fuelwood and other ecosystem services from unused land, waste land or degraded land area to bridge the gap between demand and supply. In India major part of land contribute waste land and convert in woodland to fulfil the demand of fuel wood and timber for future. (Figure 2.5) Shows forest cover and dependence on fuel wood in some Indian states.

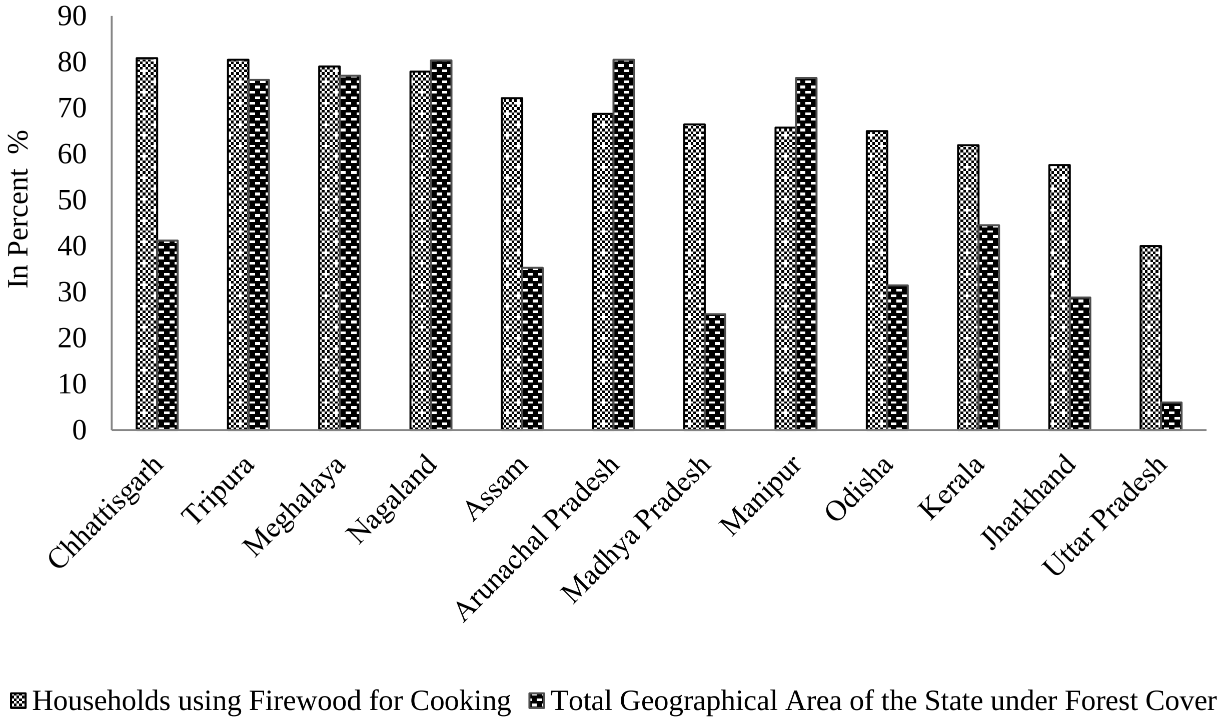

Figure 2.5. Forest cover and dependence on fuel wood in rural India. Sources: Census of India 2011 and India State of Forest Report 2011.

2.9. Cook stove technologies

Burning of biomass in the traditional cook stoves is one of the widely used biomass based appliance from incenting time till date. Traditional one pot or two pot mud chulha have low thermal efficiency and huge emission of smoke as compared to the improved cook stoves (Panwar and Rathore, 2008). Traditional cook stoves can vary from open fires of three stones to models of brick and mortar. These open fires are quite inefficient to convert energy into heat for cooking and the amount of biomass fuel needed each year for basic cooking purposes (WHO and UNDP, 2009). More than two thirds of all households in India (nearly 800 million people) cook in traditional stoves using solid biofuels such as wood, agricultural residue, coal and dry dung cake (IEA, 2012; Census of India, 2011). This practice can have an adverse impact on the health of people and local forests and contributing climate change (Desai *et al*., 2004; Anenberg *et al*., 2013). Traditional three-stone fires used in many households in rural areas of developing countries are inefficient in transforming biomass fuel into heat for cooking and not burn properly. Therefore, these types of cook stove are the major source of indoor air pollution. A possible solution to this complex set of problems is the use of cleaner combustion stoves, known as improved cook stoves (Anenberg *et al*., 2013).

In India the National Program of Improved Cook stove (NPIC 1985-2000) aims to achieve conservation of fuel wood and reduction of emissions in the indoor kitchen by the use of chimney system to make biomass combustion in improved cook stove as safe but the success has remained elusive. The National Biomass Cooking Initiative (NCI) was launched in late 2009 to extend the use of clean energy to all households in India through the development of next-generation of household cook stoves, biomass-processing technologies, and deployment models (MNRE, 2009). These programs provide a clean and affordable and reliable cooking energy option for the poorest households. Now it is expected that relying on traditional biomass technologies will generate huge gains in health and wellbeing for the weakest and most vulnerable sectors of society.

2.10. Problem associated with traditional cook stove

Exposure to indoor air pollution causes serious health risk especially women who cook food and children spend much time around the cook stove with their mother. According to (WHO, 2006) and (World Bank, 2011) reports, the premature death of around 2 million people worldwide may be directly related to household indoor air pollution due to the burning of solid biomass fuels in traditional inefficient cook stoves. Exposure to indoor air pollution has been linked to several diseases, like acute lower respiratory tract infection in children (Bates *et al*., 2013). Other diseases like decreased lung function, interstitial lung disease and respiratory symptoms such as runny nose, cough, shortness of breath and tightness in the chest (Khalequzzaman *et al*., 2007). In addition to health effects, other several implications associated with the use of the traditional cook stove include physical burdens, heavy work, maximum time consumption of time in the collection of firewood.

Traditional cook stoves can vary from open fires of three stones to models of brick and mortar. These open fires are quite inefficient to convert energy into heat for cooking and the amount of biomass fuel needed each year for basic cooking purposes (WHO and UNDP, 2009). More than two thirds of all households in India (nearly 800 million people) cook in traditional stoves using solid biofuels such as wood, agricultural residue, coal and dry dung cake (IEA, 2012; Census of India, 2011). This practice can have an adverse impact on the health of people and local forests and contributing climate change (Desai *et al.,* 2004; Anenberg *et al*., 2013).

Strategies to adopt an improved kitchen can help improve health conditions and reduce the consumption of firewood (Urmee and Gyamfi, 2014). Evidence suggests that the widespread deployment of improved cook stoves technology potentially help mitigate the adverse consequences for human health, energy and the environment (Tyagi, 2013). In India, almost 60 million people in rural areas do not have access to clean energy and rely on traditional unprocessed fuel. However, the pattern of energy consumption in rural India is changing with the absorption of clean energy. But traditional fuel such as wood, manure cake and agricultural residues remain the main source of energy for cooking due to inadequate and unreliable supply of clean energy (Balakrishna *et al*., 2013). Fuel such as biogas, natural gas, LPG, etc. they burn cleanly and should be promoted, but only LPG shows the only capacity to reach the rural population of the country, but due to its high price, which has been a barrier for the poor in rural areas (Sagar and Smith, 2014). Therefore, it is important to improve the existing traditional cook stove by making the following design improvement as maximum energy efficiency, reducing heat loss from the combustion chamber and decrease the level of emission in to the indoor kitchen environment. Two main approaches that can be used to improve energy security in developing countries, especially in rural areas are to promote more improved cook stove for poor rural households to sustainable use of traditional biomass and encourage people to switch to modern technologies and fuels for cooking. (Figure 2.6) shows important social, health and environmental implications associated with the combustion of solid biomass fuel in an inefficient biomass cook stove.

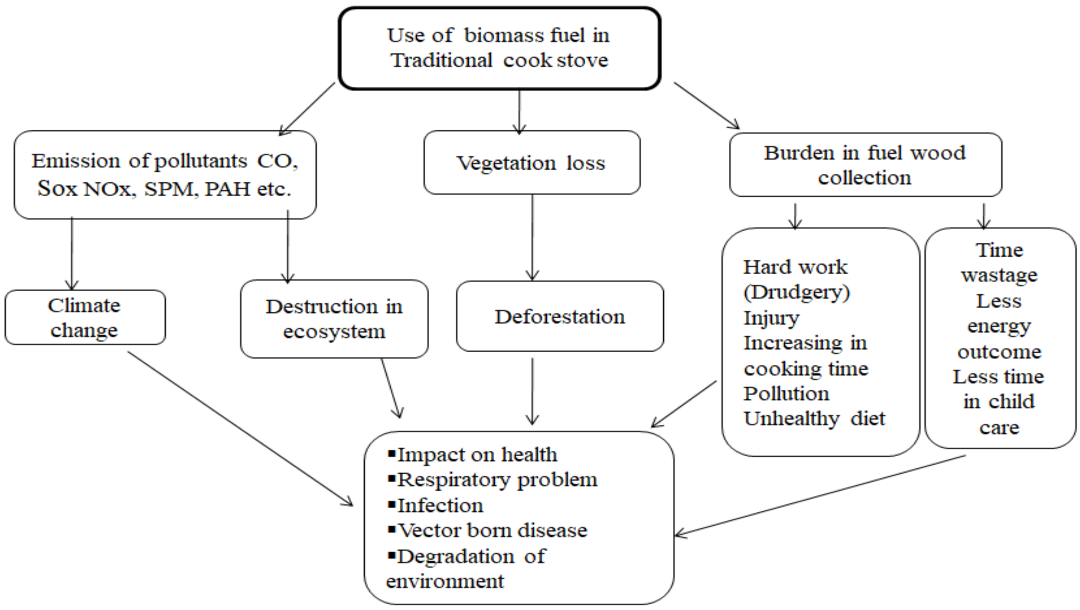

Figure 2.6. Pathway through which inefficient or traditional stove contribute in health and environmental impact. Source: (Ochieng *et al.*, 2013).

2.11. Improved cook stove (ICS)

The ICS can be designed and constructed in various ways, depending on local conditions, and is designed to maximize thermal and fuel efficiency, operate safely and minimize emissions that are harmful to human health (UNEP, 2010). The ICS not only improves the health and livelihood of the user, but also mitigates climate change by reducing the amount of emissions and rate of deforestation (Bhojvaid *et al.*, 2014).

Evidence suggests that the widespread deployment of ICS technology with certain improvements in energy efficiency and combustion could potentially help mitigate the adverse consequences for human health, energy and the environment (Suresh *et al.*, 2016). Replace traditional cook Stove with improved biomass cook stoves are simple, but are not easily acceptable by households. Many of the previous biomass cook stove programs have failed in different region of the world due to lack of adequate understanding of the needs of people using this technology (Legros *et al*., 2009).

By 1984, there were only few cook stove programs, distributing only a few thousand improved cook stoves. those countries with well-established programs that had distributed up to 5000 improved Cook stoves included Guatemala, southern India, Indonesia, Kenya, Nepal, Papua-New Guinea, Senegal, Somalia, and Sri Lanka (Lewis and Pattanayak, 2012). They concluded that current kitchen stoves were more efficient than open fire, and therefore, they emphasized providing more accessible fuel for households and the kitchen environment (Tukana and Lioyd, 1993). It has been reviewed that Chinese national improved cook stove program that introduced approximately 129 million improved biomass stoves in rural areas during 1982-1992 China's National Improved Stove program was a successful program for improved kitchens because more than 100 million improved stoves are still being used (Shen *et al*., 2015). The program focused on energy efficiency and the elimination of household smoke with the help of fire place-based cook stoves. Although this program was no longer funded, the private sector has produced stove components that lead the way to the development of more efficient and less polluting kitchen models (Panwar *et al*., 2009). The cooking needs of developing countries are not only less smoke or fuel efficiency, but they are diverse and sometimes broader than the benefits defined by clean Cook stove programmes implementers (Ashok and Gadgil, 2011).

The key feature of any improved cooking stove compared to traditional stoves is to use certain designs with scientific principles, to help better combustion and heat transfer, to improve emissions and efficiency performance. The improved technology of cooking stoves can be classified according to the material used in the manufacture of the stove and whether it is fixed or portable. It can also be based on whether the stove is equipped with chimneys and if it has grilles in the firebox to increase fuel combustion. The design of the stoves that are in use varies according to the location and the type of fuel available e.g., some stoves are specially designed to burn one fuel and others burn a range of fuels. (Figure 2.7) gives distribution of improved cook stove across the world. China has the largest distribution of improved cook stoves i.e. 70% all over the world and only 9% contributes India.

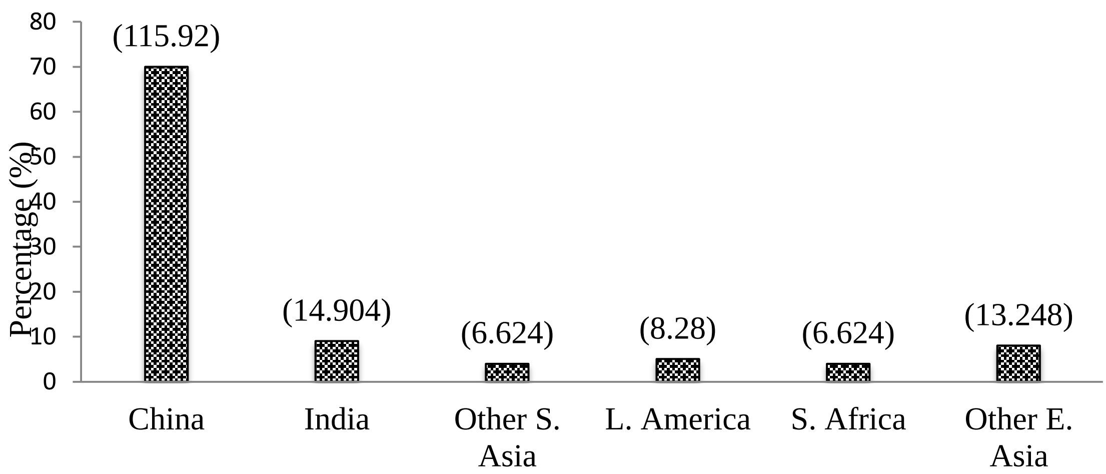

Figure 2.7. Percentage distribution of improved cook stove. Values in bracket are number of improved cook stoves in millions (UNDP and WHO, 2013).

2.12. Improved cook stove (ICS) technology in India

In India, the first improved cooking stove (ICS) was developed with technological attempts to improve the design of the cook stove due to the Smokey kitchen environment in which women had to cook. (Raju, 1957) introduced the first cook stove with multiple pots, which has a shielded fire type and chimney system to eliminate smoke from the kitchen. Systematic studies were conducted on measure the efficiency of cook stove by (Singer, 1961). During the 1970s and 1980s, several international donors had a very strong influence on the improved cook stove promotion and assistance of the development of kitchens throughout the world, particularly in Asia and Africa but unfortunately the impact of this aid program proved to be short lived due to inability of the programs to meet the expectations and active requirement of the user. However, during the late 80s again the emphasise begin shift words the important to the need of cook stove user based on cooking comfort, smoke free kitchen and thermal efficiency as well as safety in the use of cook stove were considered by the user to be as important as fuel saving. A large number of improved cooker models (ICS) have been developed over the last 10 to 15 years. The first program of the national program of the improved cooking program (NPIC) began in the year 1985-86 following a multi-model and multi-agency approach in the level of dissemination and adoption of improved cook stove for rural households and improved cook stove performance.

The NPIC was started with few good objectives including reduction of deforestation and smoke through fuel wood conservation, reduction in the drudgery tasks to be performed by women and children, health hazards due to exposure to smoke and the employment in the rural areas. More than 60 fixed and portable types of models with or without chimneys, single-pot or multi-pot, suitable for different fuels, cooking habits and local requirements, using different materials of construction were developed and installed under this program (MNRE, 2009). Since, the end-user wanted more versatility in the fuel usage and less time in cooking, while, the improved mud stoves were designed by the institutions on the objective of fuel economy and less smoke. Whereas, the rural people were not concerned much about the cooking fuels and deforestation at that time, as a result, the success was much below the expectation level with which it was started.

Table.2.5. Domestic size prominent portable improved biomass cook stove models in India.

Manufacturers	Model	Fuel used	Performance parameters as per test testing conducted in MNRE supported Test Centres			
Natural Drafts			TE (%)	CO (g/MJd)	TPM (mg/MJd)	Power Output
1. M/s Unicus Engineering Private Limited, Bhubaneswar, Dist.: Khurda	Harsha Cook stove	Multi-Fuel	28.6	3.75	338.33	2.0 kW
2. Vikram Stoves & Fabricators, Osmanabad	Bio-classic	Wood	26.01	4.54	315.38	1.49
3. M/s Ravi Engineering & Chemical Works New Delhi	FUELNZEL. ND no.1	Wood	26.62	4.54	315.38	1.49
4. Adarsh Plant Protect Ltd,604, GIDC, VitthalUdyognar, Anand, Gujarat.	Adarsh Domestic	Wood	22.40	0.041	1.92	0.74
5. Unicus Engineering Private Limited Bhubaneswar	Harsha(CSIR, IMMT Design)	Wood	26.7	3.81	303.02	0.89
6. Greenway Grameen Infra Pvt Ltd, Navi Mumbai	Greenway Jumbo Stove Model JS1	Wood	24.1	5.10	272.07	1.83
7. I Square D Charitable Trust Bangalore	Chulika	Wood	29.77	3.0	320	0.8
8. Energy Devices 7-2-1/a/22 balkampet, Sanathnagar hyderabad, Telangana	Urja Dix	Wood	29.00	3.69	314.08	1.28
Forced Draft						
1. First Energy Pvt. Ltd., Pune	Orja	Pellets	32.90	2.57	228.37	0.74
2. Alpha Renewable Energy Pvt. Ltd. Anand	Eco chulha – XXL	Wood	31.50	3.95	111.23	0.7
3. The Energy and Resources Institute (TERI), New Delhi	TERI SPT-0610	Wood	36.84	1.90	97.52	1.10
4. Ram Tara Engineering Company. Aurangabad	RAMTARA	Pellets	34.1	2.25	147.40	1.08
5. Sacks Right Energy Innovations Bangalore	OJAS	Pellets	35.33	1.0	86	1.0
Navdurga Metal Industries (Bharat), Faizabad,	Agni Star	Rice Husk	34.54	2.56	78.82	1.99

Source: TERRE Policy Centre, Pune, 2014

Apart from the traditional cooking practices, the non-replacement of traditional cook stoves with the improved cook stoves was also influenced by socio-cultural factors and other benefits such as, space heating by traditional cook stoves.

From the above experiences, it was learnt that the success of an improved cook stove program depends on the assessment, surveys, proper monitoring, evaluation and cultural barriers (Shen *et al*., 2015). A total of 33.8 million improved cook stove have been installed with varying degrees of success and, finally, this program was formally declared closed in 2004 (Kumar *et al.,* 2013). However, the findings of different dissemination projects showed that a strong political influence, an effective policy and a massive movement are required to facilitate the development of biomass stoves of the next generation for household and community cooking to get the benefits of health, mitigation of climate change and energy conservation (Kees *et al*., 2011). In 2010 government of India launched National Biomass Cook stoves Initiatives (NCI). At this time, there was a significant improvement in the design of cook stoves with effective dissemination programs in the country through private initiatives with limited penetration. One of the prominent models has been approved by the Ministry of New and Renewable Energy on the basis of their performance testing as per Bureau of Indian Standards (BIS) conducted by MNRE supported Test Centres. (Table 2.5) shows list of some main manufacturers of the improved cook stoves and differentiated on the basis of natural and forced draft.

2.13. Efforts for the improved cook stoves in India

In India, nationally and sub nationally organized efforts for improved cook stoves began almost 30 years ago, their widespread use and success have not been adequate and consistent (Vahlne and Ahlgren, 2014). Social scientists, voluntary organizations, academics and policymakers have done there bit and possible effort to improve cook stove. The National Programme on Improved Cook stoves (NPIC) and other efforts was started in 1983 to conserve and optimized the use of firewood, alleviate deforestation and to bring improved household sanitation and general living conditions, as a demonstration programme in India. National programme on improved cook stoves (NPIC) and ministry for new and renewable energy (MNRE), earlier known as department of non-conventional energy sources (DNES) launched a national program on improved chulhas (NPIC) in the year 1985–1986. The aim of this program was to provide quality life to women by reducing drudgery and saving fuel through improved efficiency of cook stove (Abeliotis and Pakula, 2013).

About 60 new designs were reported to evolve as a result of the research and development (R&D) activities. The average thermal efficiencies (TE) of the cook stoves developed during the NPIC were about 25%, nearly double than that of the traditional cook stoves (Venkataraman *et al.,* 2010). It is to be stated that though the improved cook stove developed during the NPIC period exhibited higher thermal efficiencies, however, the emission performances of all the cook stoves were not very impressive. Carbon monoxide (CO) and particulate matter (PM) emissions were higher than the prescribed limit of the WHO (Smith *et al.,* 2007). Government had planned for their dissemination and about 35 million stoves were distributed. However, the adoption rates were seemingly low, and ultimately the programme had to be discontinued. From April 2002, the Ministry of Non-conventional Energy Sources has discontinued its funding support to NPIC. Many of the concerns cantered on cook stove design. The emphasis was on use of materials and skills available in rural India and production at the cheapest cost as well as the delivery and maintenance approaches used in NPIC. In fact, independent studies revealed that improved cook stoves under NPIC often had higher emissions than traditional cook stoves and similar efficiency (kumar *et al.,* 2013). India's previous cook stove program in the late twentieth century, the National Program for Improved Chulhas (NPIC), was credited with the introduction of cook stoves to a few tens of millions of households before it ended, but it started in a completely different context in which fuel efficiency was the main criterion since the full benefits of clean combustion were not well understood and cook stove technologies to achieve it were not well developed.

2.14. Failure of improved cook stove technology and program in India

Installation of improved cook stove in contrast to any other large-scale improved cook stove program in the world, past or present, the new Indian National Cook stove Initiative has set itself a lofty goal for all Indian households (MNRE, 2009). Evaluations of the program, however, questioned the success in meeting its objectives largely because of the low durability, usage, and performance of the stoves in the field. Most improved biomass stove programs in India have failed to achieve the desired levels of adoption or goals of stemming deforestation rates, addressing fuel shortages, or curbing respiratory disease (Hana *et al.,* 2012). The most salient problems are low rates of initial household adoption and subsequent low usage rates. Even when initial adoption rates are adequate, there is usually a marked decline in use over time due in part to rapid deterioration of these products (Barnes *et al.,* 2012). In other cases, users modify the improved cook stove (ICS) in ways that compromise the stove’s performance (Palit and Bhattacharyya, 2014). Many studies reported that success of the programs depends on technology development and deployment with attitude of the user (Urmee and Gyamfi, 2014). Many of the ICS fail to reach their claim of performance. This may be because, when used in the household’s level, the cook stove is not actually more thermally efficient or smokeless compared to the traditional mud stove. It has been noted that many early improved cook-stoves were simply assumed to be more efficient than traditional systems. These judgement were often based on anecdotal accounts or unspecified data.

A frequently cited problem with ICS programs is that stove performance demonstrated in a laboratory setting could not be replicated in the field (Aung *et al*., 2016). In India traditional mud chulha not only have symbolic cultural or spiritual value in India but also easily built and repaired by women users or a local craftsperson making them a source of autonomy (Subramanian, 2015). In most NPIC programs efforts, effective awareness campaigns about the health benefits of improved cook stoves and hazards of indoor air pollution (IAP) had not been carried out. The demand for ICS and the actual adoption rates, therefore, remained relatively low (Dutta, 2012). Despite the lack of adequate campaigns, it was found that almost all users appreciated the benefits of smoke reduction in the kitchen, although there was little awareness of the adverse health effects of IAP (Bielecki and Wingenbach, 2014).

In India today many efforts to improve chulhas, cooking technologies, and poor villagers' health are managed by non-government organizations (NGOs). Two critiques of NGO-led development offer insight into ICS efforts, namely, the lack of coordination among NGOs and the uneven distribution of investments from region to region or even village to village. In India today, universities, NGOs, philanthro-capitalists, international development agencies, government researchers, and corporations work on different stove technologies, deploy these on different scales and rely on disparate models of social change, resulting in a fractured maze of ICS projects. There are little data to suggest that their efforts have resulted in significant rates of adoption or the promised improvements in health, household economies or local environments (Puzzolo *et al.*, 2011). (Figure. 2.8) shows other key reasons by different researcher to explain the failure of many ICS programs in India.

There is a robust debate among ICS researchers and promoters in India about the relative effectiveness of designing and distributing ICS through NGO and government subsidies or through market mechanisms (Smith *et al.*, 2005). Therefore, the unnat chulha abiyan (UCA) in India challenge of delivering clean cooking energy for the poor continues to loom large. Given the projected dominance of solid biomass as the cooking energy source for a majority of Indians, there remains the need for ensuring the availability of stove technologies that can deliver truly superior performance, both in terms of thermal efficiency and emissions as well as effective delivery mechanisms.

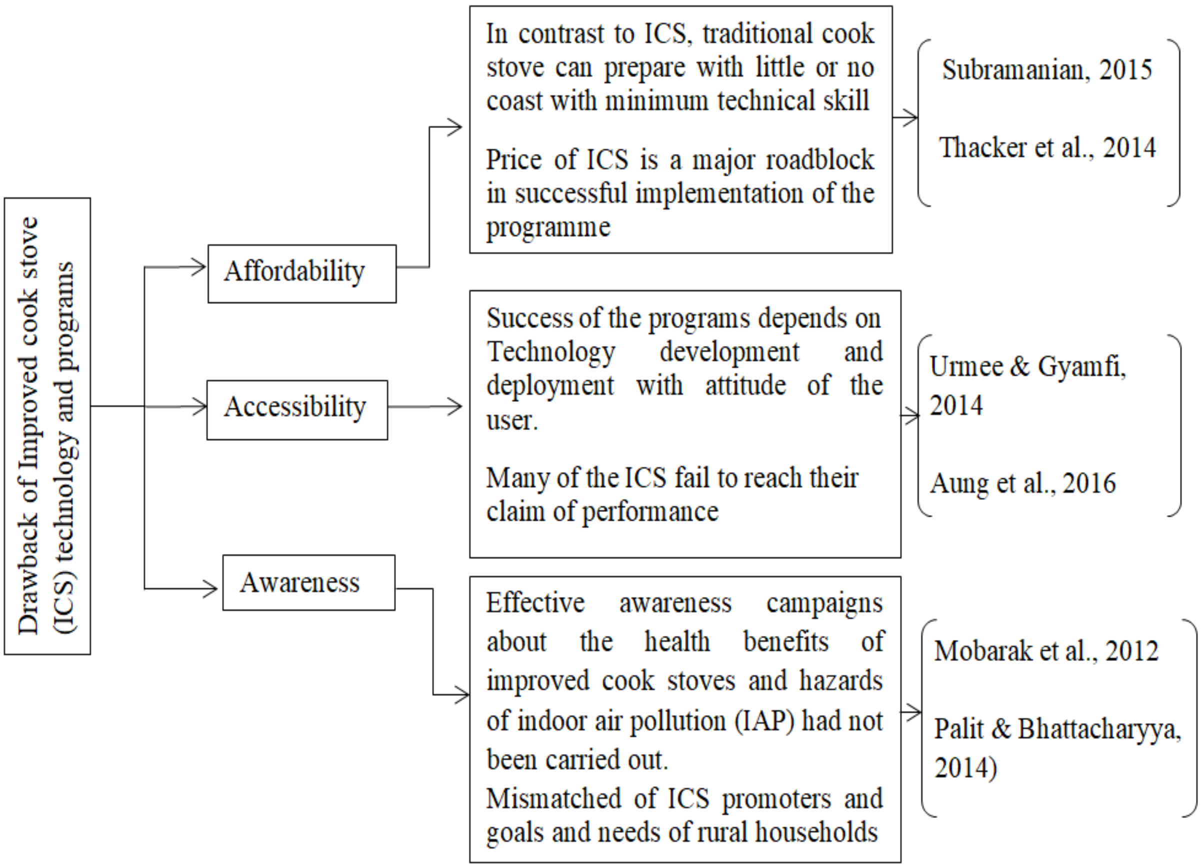

Figure 2.8. Drawback of improved cook stove technology and programs in India.

2.15. Recent developments in improved cook stove in India

2.15.1. National *Biomass Cook stove Initiative (NBCI)*

The India's national biomass cook stove initiative was launched in India in late 2009-10 to extend clean energy to all households in India through the development of the next generation households cook stove (MNRE, 2009). It is expected that the affordable and clean cook stove supply for poor rural households that now depend on traditional biomass technology will help achieve enormous health benefits and well-being of the weakest part of society. In contrast to another large-scale improved biomass cook stove program worldwide in the present or in the past, the new Indian national initiative has set a high target for all Indian households (MNRE, 2009). As follow up to consultations on biomass cook-stove and launch of NBCI, a project entitled "A New Initiative for Improved Cook stoves: Preparatory Activities for Launch" was taken up at Indian Institute of Technology, New Delhi. Subsequently, another project entitled "A New Initiative for Development and Deployment of Improved Cook-stoves: Pilot Field Testing and Evaluation of Community Sized Biomass Cook-stoves" was taken up recently and implemented by IIT Delhi in association with state nodal agencies (SNAs) and NGOs. The new initiative emphasizes improving the technical capacity in the country by setting up state-of-the-art testing, certification, and monitoring facilities and strengthening research and development programmes in key technical institutions. Fulfilling the commitments of the NBCI, during the year 2012-13 took a pilot-scale project for the demonstration of 12 lakh numbers of improved cook stove for the domestic and community size for cooking (MNRE Annual Report 2013–14). A proposed goal of 27.50 lakh of improved family-type and community-size cook stove, including earthen cook stove will be installed in the remaining period of the 12th Five-Year Plan period.

2.15.2. Existing policies and efforts on improved cook stoves

To follow up the above commitments the NBCI was reshaped into the unnat chulha abhiyan (UCA), the UCA was launched in 2014 with the aim of deploying 2.4 million ICS at households level and 350,000 ICS at community level by March 2017 with an amount of 294 crore budget (MNRE, 2014). Three distribution model proposed are Cluster level Federation Model (CLF), CSO/NGO Model and Government Schemes Model. Approximately, 24 Lakh improved cook-stoves at the household level and 3.5 Lakh improved cook stoves at the community level. These policies have tried to improve awareness of the ill health effects of traditional cook stove, subsidize clean fuel or technologies to improve affordability, increase the amount of investment in research and development to reduce current prices in the market and, finally, improve the penetration of such solutions by addressing the availability of fuels, technologies and after-sales maintenance services. However, The MNRE official associated with UCA confirmed that only 1.3 per cent of the target was met by the date of programme completion, with much of the budget having lapsed unutilised. Governments can assist in formulating a policy framework, which provides incentives to private sector operators, women's self-help group to engage in the production, distribution, and sale of improved stoves. The elements of such a policy framework may include; technical support, training, and assistance in market research same time the knowledge acquired can be passed on to the users which further reduces the chances of failure.

2.15.3. Testing of Improved cook stove (ICS)

Along with the advent of clean and efficient cook stove, several stove cooking test protocols were also developed to assess the degree of improvement in these new cook stove technologies. The water boiling test (WBT) is an international test protocol which was developed in year 1982 by volunteers in technical assistance (VITA) in 1982, with an aim to provide a set of guidelines to test cook stoves with a

Table 2.6. Studies conducted for thermal performance and emission parameter using water boiling test (WBT) protocol

WBT	fuel used	Parameters compared to tradition cook stove	Aim of the study	References
WBT Version 4.0	Red oak (*Quercus rubra)*	Time to boil, power, Thermal efficiency EFs for CO, CO2, THCs, and CH4, PM2.5, and UFP number MCE	Comparison of Cook stove designs and effect of moisture levels	Jettter *et al.*, (2012
Modified WBT	Wood	Thermal efficiency, boiling time, Energy use, Fuel use EFs for CO and PM	Comparison of Cook stove designs and benchmarking Performances	L'Orange *et al.*, (2011
WBT Version 3.0	Kiln-dried Douglas fir Kingsford charcoal Liquid	Thermal efficiency, boiling time, Energy use, Fuel use EFs for CO and PM	Comparison of Cook stove designs and benchmarking Performances	MacCarty *et al.*, (2010)
WBT Version 3.0	Kiln-dried Douglas fir Air-dried Red oak High-resin pine Charcoal Garment waste	Thermal efficiency, boiling time, Specific fuel consumption EFs for CO, CO/CO2 ratio, THC and PM2.5	Comparison of Cook stove designs	Jetter and Kariher (2009)
Modified WBT	Rice straw, maize, bean, Straw, fuelwood, branch, cotton stalk, wheat residue, kaoliang stalk	Thermal efficiency, firepower EFs for OC /EC and PM2.5	Comparison of Cook stove designs and fuels	Li *et al.*, (2009
VITA, 1985	Pine tree logs Charcoal (mangrove)	Thermal efficiency EFs for CO, CO2, CH4, TNMOC and NOx	Comparison of Cook stove designs; effect of fuel size, moisture content and ignition style	Bhattacharya *et al.*, (2002a)
Modified WBT	*Acacia nilotica*, dung cake, and biofuel briquettes	EFs for size resolved PM based PAHs	Comparison of Cook stove designs and fuels	Venkataraman *et al.*, (2002)
VITA, 1985	*Acacia nilotica*, dung cake, biofuel briquettes	Time of burn, Burn rate, Fire power, Thermal efficiency EFs for size resolved PM (0.056 – 10 µm) and CO	Comparison of Cook stove designs and fuels	Venkataraman *et al.*, (2001)
WBT (Version 4.1.2) and BIS test.	*Acacia nilotica*	Thermal efficiency, boiling time, Energy use, Fuel use EFs for CO and PM10 and PM2.5	Comparison of Cook stove performance, Estimation of CO, PM and black carbon emissions	Arora *et al.*, 2013

standardized procedure. The protocol was updated several times by different institutions over the years. In the year 2007, WBT version 3.0 was developed after certain conceptual improvements, while the latest version of WBT was published in the year 2013 with an integration of guidelines for emission testing along with testing of thermal performance parameters, (the WBT, Version 4.1.2).

However, the WBT base was established in 1965 when an Indian Standard test method (IS, Indian Standard: 2994, 1965) was developed for electric stoves. The first test protocol for biomass based cook stoves was developed by intermediate technology development group (ITDG) Reading, England in the year 1980. In India the first protocol for testing biomass cook stoves was developed in 1991 by bureau of Indian standards (BIS) titled as “standard on solid biomass chulha specification” and it has not been updated till date. The literature available on cook stove testing indicated that the WBT as the most widely used test to compare the performance of different cook stoves (Jetter *et al.,* 2012). However, it can be inferred from the literature that the performance of the cook stoves evaluated with the help of WBT is not representative of the actual field conditions (Berrueta *et al.,* 2008). Therefore, testing the performance of a stove is a challenging task as there are many factors that affect the performance of it, for instance, the properties of fuel and skills of the tester (Arora *et al*., 2013). Lately, the latest version of the WBT was published in year 2013 as version 4.2.3 by amalgamating the comments received from various research groups working in the cook stove sector on WBT Version 4.2.2.

The major differences in the test method between the different versions of WBT since its inception are presented in (Table. 2.6). The WBT developed principally to study the effect of designed on the performance of any cook stove through boiling of water. The WBT consists mainly of two phases, a high power phase and a low power phase. The high power phase is a simulation of the cooking activity, which requires a high power input for a rapid increase in temperature e.g., boiling of water. The low-power phase simulates cooking conditions where low temperatures are required. The methodological changes in the different versions of WBT were in terms of the boiling time during the cold start phase. In the first version of WBT, after reaching the boiling point, the boiling was continued for 15 minutes followed by the reconstruction of the fire during the slow cooking phase. However, in the updated version, the boiling phase of 15 minutes was omitted and the cold start was terminated as the water reached the boiling point. The first version of WBT recommended 60 minutes of slow cooking that decreased to 30 minutes in the second version and 45 minutes in the latest version of WBT. The increase in simmer time reduces the error that could induce biases in the efficiency calculations of the cooking stoves due to the accumulation of carbon (Bailis *et al*., 2007). In the third version of WBT, the high power phase bifurcated more in two steps i.e. cold start and hot start, which signified the heat take up by cook stove body. Hot start helps to assess the extent to which a cook stove can retain the temperatures gained during the cold start. The information available in the literature for laboratory-based cooking stove tests reveals WBT as the most commonly used test protocol in most studies. Therefore, review of lab based cook stove assessment methods based on thermal and emission parameters would be helpful in screening of improved cook stove performance and to predict their better compatibility with cooking practices epically for the poor rural households.

Chapter 3

Materials and Methods

Material and Methods

3.1. Study area

The study area is located in Uttar Pradesh (U.P) the largest state of Northern India with an area 243,286 km^2 constituting 7.33% of total geographical area of the country. It is the most populous state in India. The present study area is Kahinaure plantation forest at village Kahinaure, district Mau, Uttar Pradesh, India. District Mau is situated on the fertile plains of the Ganges–Ghaghara doab. It lies between 83°17’ to 84°52'E & 24°47' to 26°17'N. The recorded forest area of the state is 16,583 km2 which is 6.88% of its geographical area. Reserved forest constitutes 70.31%, protected forest 8.56% and unclassified forest 21.12%. Total area of the Mau district is 1716 sq. Km., out of which 1 sq.km dense, 15 sq km moderately dense, 17 sq. km open forest. Total 1.92% area of district Mau, Uttar Pradesh is covered by forest And following type of tree species available commonly in these forest are *Mangifera indica*, *Dalbergia sissoo, Madhuca indica*, *Prosopis juliflora*, *Azadriachta indica*, *Eucalyptus* sp. and *Butea monosperma* etc.

District Mau is very less cover area of forest. However, recently government of Uttar Pradesh carrying out massive tree plantation drive on waste land or degraded lands. This plantation drive is a sustained effort to increase the Green Cover in the state. The present study area is a subtropical deciduous forest developed by forest department of Uttar Pradesh under the plantation drive of mix culture of plant species during the year 1983 for commercial production of wood, non-wood products and environmental services. The dominant tree species in the plantation forest was *Prosopis juliflora*, *Alangium saluifolium, Alstonia scholaris*, *Terminalia arjuna, Berberis thunbergii* and *Tectona grandis*. The total area of the selected plantation forest is about 118 hectares and is located between 25^o 52′274′′N and 83^o30′578′′E.

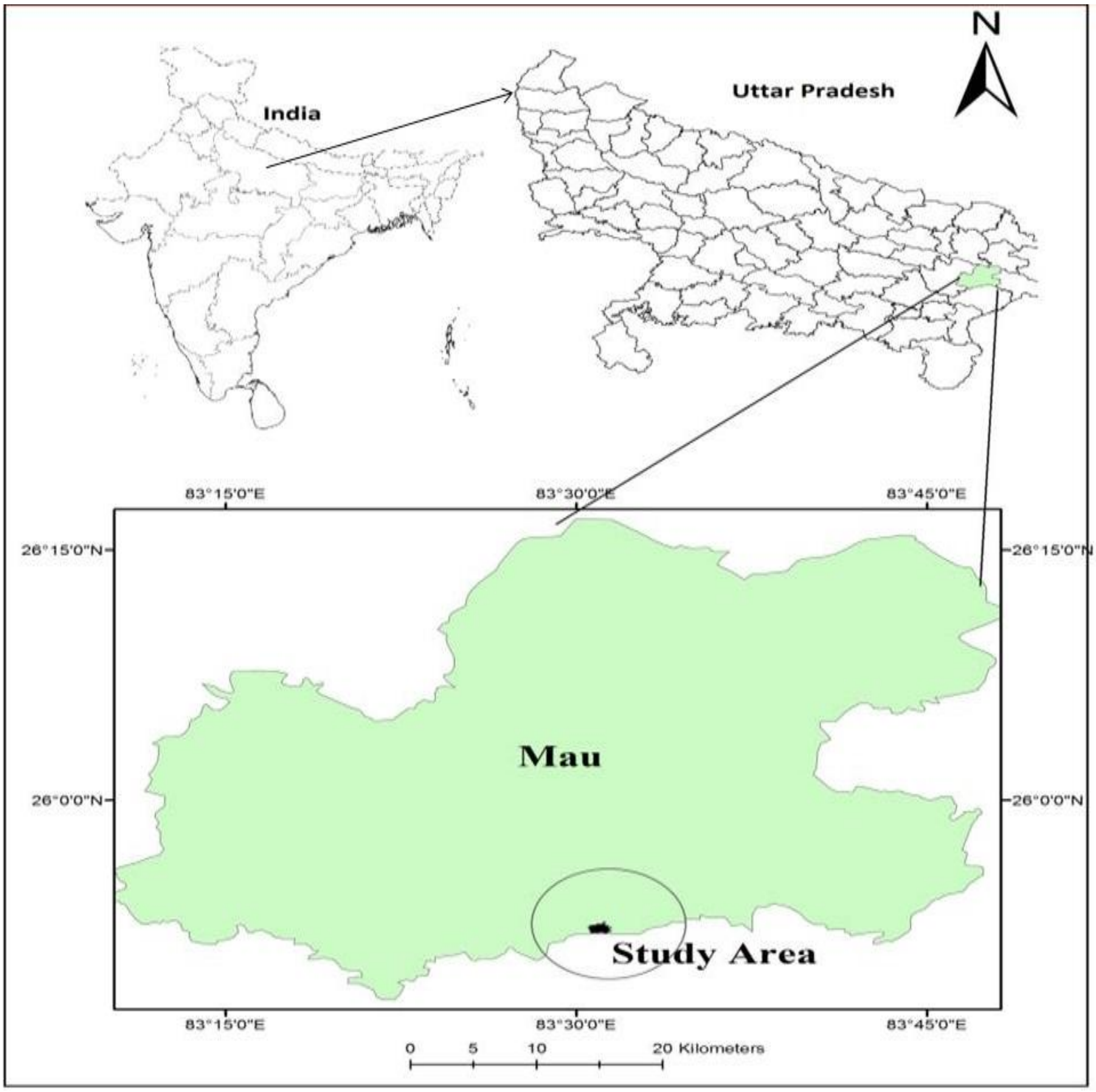

Figure 3.1. Map showing the location of the study site.

3.2. Climatic factors

The selected plantation forest is a subtropical deciduous forest having 36 plant species monitored by the forest department of Uttar Pradesh government. The study area experiences a dry and wet winter type, with average rainfall of 650 to 800 mm from June to September in every year. Like most of north India, it has a hot dry summer (April to June), followed by monsoon rains (July to September) and a cool and relatively dry winter. Temperature varied from maximum 42^{o}C in summer and minimum 7^{o}C in winter (Figure 3.2).

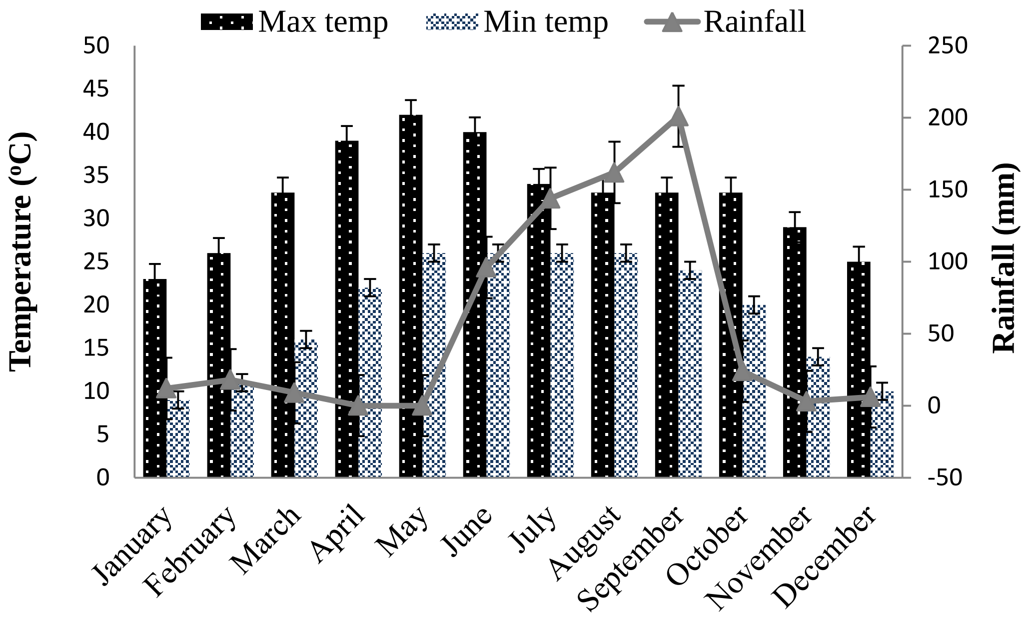

Figure 3.2. Climatic condition of the selected study area. Source: (SFR, 2015)

3.3. Methods for estimation of Above Ground Biomass (AGB) and Below Ground Biomass (BGB)

3.3.1. Sampling

Twelve sampling plots of size 25 m × 20 m were laid through stratified random quadrat sampling technique to determine the structure, composition and C-stock of the plantation forest covering a total area of 1 ha. For biomass estimation forest was divided into three compartments. Four of the sampling plots were selected from each compartment considering species composition, density and environmental conditions. Random number table was used to specify the geographical coordinates of these sites. All the woody plants greater than or equal to 10 cm girth at breast height (GBH) were measured (Baqir *et al.*, 2018) and individuals with less than 10 cm GBH (≥4.77 cm diameter at breast height (DBH) were categorized as saplings.

3.3.2. Diameter at breast height (DBH) measurement

To estimate biomass from selective tree species it is not advisable to cut them. The biomass can be measured by mathematical models by measuring Diameter at Breast

Height (DBH) directly and the girth at DBH. Girth considered is the DBH measured at breast height at approximately 1.3 meter and diameter of tree having diameter above >10 cm are treated as trees and are measured.

3.3.3. Estimation of above ground biomass (AGB) and below ground biomass (BGB)

In the present study, non-destructive approach of Above-Ground Biomass (AGB) and below ground biomass (BGB) estimation was used. The DBH measurements of each tree were subsequently converted into estimates of AGB using allometric equations for moist deciduous forest stands that relate tree diameter to biomass (Chave *et al.*, 2005). Two equations were explored in order to determine the biomass for dry and moist species independently.

For DM and MS tree stands the moist and dry allometric equation was used.

Dry $Y = \exp\{-1.996 + 2.32 * \ln(D)\}$ Range in DBH(cm)5–40 (1)

Moist $Y = 42.69 - 12.800(D) + 1.242(D2)$ Range in DBH (cm)5–148 (2)

Whereas,

Y is biomass per tree in kg, D = DBH in cm (Brown *et al.*, 1989).

Per tree biomass of all individuals within the plantation forest was summed for the respective tree species and total individual species biomass were calculated. Finally, we calculated total AGB from the plantation forest. For estimation of BGB the following relationship is used to estimate the root biomass developed by (FAO, 2000)

Belowground biomass = 0.30×aboveground biomass

3.3.4. Carbon content in different component of tree species

Samples of different tree components (stem, branch, leaf) were collected through an increment *borer*. For estimation of carbon content from stem, a wood sample was extracted from the place slightly above breast height; diameter at breast height (DBH). For estimation of carbon content from the branches, two branches of each species were chosen; one the lower most branch and the second branch just above the first branch while for estimation of carbon content from leaf, a quadrat of 1m×1m was laid out on the surface and the leaves falling in the quadrat were collected and weighed. Each sample of different components from trees species were taken to the laboratory and dried in oven at 80^{o}C for 70 hours to estimate dry weight and subsequently ground and passed through a 500 micron sieve. The carbon content in different tree components (stem, branch, leaf) was determined by IRMS (Thermo Scientific Inc.) at CSIR-NBRI, Lucknow.

3.3.5. Calculation of emitted carbon dioxide (CO_2) and deforestation due to burning of fuel wood

Annual rate of deforestation and emission of greenhouse gases (GHGs) as a result of burning of fuel wood was estimated. The volume of wood was used and expressed in cubic meter unit (m^3), which represents deforestation (m^3) per unit of time (World Bank, 1998). Conversion of fuel wood biomass data tonne dry biomass (t dm) into cubic meter by dividing the mass unit by an expression ratio of 1.90 (World Bank, 1998). Total emission of carbon was estimated by multiplying the amount of biomass burnt in t dm by fraction of biomass oxidized and biomass carbon content as shown in equation (1) (IPCC, 1994). The default value of 0.9 was used for the fraction of oxidized biomass and wood biomass; a conversion factor of 0.5 t C / t dm was used.

$$C_t = M_t \times M_f \qquad (1)$$

Whereas, C_t = total biomass burnt (t dm)

M_t = fraction of biomass oxidized (0.9)

M_f = Woody biomass carbon content (0.5 t C / t dm)

Estimation of CO_2 emission from burning of fuel wood can be calculated by conversion of total carbon content (t C) to carbon dioxide content (t CO_2) using conversion ratio of 44 t CO_2 / 12 t C shown in equation (2) (IPCC, 1994).

$$CO_2 = M_t \times M_f \times M_c \times (44 / 12) \quad (2)$$

Whereas, CO_2 = Total CO_2 (t CO_2) released from the burning of fuel wood

M_t = total biomass burnt

M_f = fraction of biomass oxidized (0.9)

M_c = Biomass carbon content (0.5 t C / t dm)

3.4. Soil analysis

3.4.1. Sample collection: Soil

Soil samples were collected by dividing the plantation forest into four compartments based on topographical feature of the study sites and physical feature of the soil. Four 30×30 m sampling plot were selected. From each sampling plot five sects of soil samples were collected at 0-10, 10-20 and 20-30 cm depth (IPCC, 1997). Soil sample were collected with soil core (6 cm diameter) during May, 2015 from all the four compartments. Five sects of soil samples from each compartment were collected in depth of 0-10, 10-20 and 20-30. All the five sects of soil sample with their respective soil depth were mixed together to form a composite soil sample and were brought to the laboratory for further analysis. One control soil samples were collected from the waste land which is adjacent to the plantation forest. Stones, plant and root debris were removed from the collected soil and stored at 4°C. After sieving (< 2 mm) the soil samples were analysed of SOC, soil microbial biomass carbon and soil enzyme activity. Collection of soil sample up to 30 cm depth for estimation of SOC and other soil properties was done in accordance with IPCC guideline (IPCC, 1997).

3.4.2. Details of standard protocols used in the soil analysis

3.4.2.1. pH: The pH was measured by the potentiometric method. 20 g of soil sample were taken in a 10 ml beaker to which 50 ml of distilled water was added. The suspension was stirred at regular intervals for 30 minutes and the pH was recorded using a pH meter (Maiti, 2003).

3.4.2.2. Electrical Conductivity (EC): 20 g of soil sample were taken in a 10 ml beaker to which 50 ml of distilled water was added. The suspension was stirred at regular intervals for 30 minutes and the EC was recorded by dipping the electrode using potable digital EC meter.

3.4.2.3. Bulk Density (BD):

Bulk density of soil is defined as the ratio of dry soil mass to bulk soil volume (including pore spaces). The BD was measured in grams per cubic meter (g cm^{-3}). Bulk density was measured using core method. A cylindrical metal or plastic coring tool of known volume was driven into the soil to a desired depth. The intact core was removed, dried in an oven at 105°C, and weighed (Gupta, 2004).

Bulk Density (g cm^{-3})

$$= \frac{\text{Dry weight of soil sample gram}}{\text{Volume occupied by the same soil sample } (\mathrm{cm}^3\ )} \ \mathrm{X}\ 100$$

3.4.2.4. Soil Organic Carbon (SOC): SOC was determined by method described by **(**Walkley and Black, 1934).

Reagents

1. Potassium dichromate, IN: dissolve exactly 49.04 g of AR (analytical grade) $K_2Cr_2O_7$ (dried at 105^{o}C) in 1 L of distilled water

2. Ferrous ammonium sulphate, 0.5N (approx.): Dissolved 196 g of the hydrated crystalline $FeSO_4$. $(NH_4)_2$ SO_4. $6H_2O$ per L containing 20 mL of Conc. H_2SO_4. This solution is relatively stable and convenient to work than that of ferrous sulphate.

3. **Diphenylamine indicator:** Dissolve 0.5g $(C_6H_5)_2$ NH in a mixture of 20 mL of water and 100 mL of Conc. H_2SO_4

4**. Conc. Sulphuric acid, H_2SO_4 (Sp. gravity 1.84, not less than 96%) containing 1.25% silver sulphate:** Add 15 g of Ag_2SO_4/L of H_2SO_4 In case of soil free from chlorides use of $Ag_2 SO_4$ can be avoided.

5. **Ortho-phosphoric acid (85%):** Chemically pure

Procedure

The rapid dichromate oxidation technique was used to estimate SOC. For this 1g of soil sample was taken in a 500ml conical flask and 10ml of 1N potassium dichromate solution and 20ml of concentrated H_2SO_4 was added and shaked very well. The flask was then allowed to stand for 30 minutes and 200 ml of distilled water, 10 ml of 85% of Ortho-phosphoric acid and 1ml of diphenylamine was added to that. It was then back titrated with ferrous ammonium sulphate and at the end point the violet blue colour changes to bright green. Value of blank was also noted. The readings were used for further calculations.

Calculation

Organic Carbon (%) = 10 (B-T) / B x 0.003 × 100/S

B= weight of ferrous ammonium sulphate varies for blank titration in ml.

T= Volume of ferrous ammonium sulphate needed for soil sample in ml.

S= weight of soil in g.

3.4.2.5. Total Kjeldahl Nitrogen (TN): Estimation of nitrogen was done by the Micro Kjhedhal procedure (Bremner and Mulvaney, 1982).

Dried and homogenized mixture of the soil sample (ground and sieved through 0.15) was used for estimation of total Kjeldahl nitrogen. To this 1.0 g of sample and 5 ml of distilled water was added along with 4 g of digestion catalyst (a mixture of 20 g cupric sulphate ($CuSO_4$. $5H_2O$), 2g selenium powder and 200 g potassium sulphate (K_2SO_4) and 7 ml of concentrated H_2SO_4. The mixture was then heated in a digestion block (Pelican Equipment) up to a temperature of 420^{o}C. The sample was then cooled and diluted with distilled water and mixed thoroughly. The mixture was then distilled under alkaline conditions using a distillation unit (Pelican Equipment) and the distillate was collected in 20 ml of Boric acid - mixed indicator solution. The distillate was then titrated against 0.01 N HCl and the end point was the change in colour from green to pink

$$\text{Kjeldhal Nitrogen mg/g } = \frac{(\text{T1} - \text{T2}) \times \text{N} \times 14}{\text{W}}$$

Whereas,

T1 = Volume of titrant used against sample (ml), T2 = Volume of titrant used against distilled water (blank) (ml), N = Normality of titrant (0.01N HCl), W = Weight of soil sample (g).

3.4.2.6. Available Phosphorus: Available phosphorus in soil was determined by the method of (Olsen *et al.,* 1954).

The available phosphorus was determined using Bray's method. For this Black Darco G-60 (2.0-3.0 g) and 50.0 ml of sodium bicarbonate (1/2 N) solution were added to 2.0 g dried powdered soil. It was shaken thoroughly for 30 minutes and then filtered through Wattman No. 40 filter paper. To 5.0 ml of filtered soil extract 5.0 ml of ammonium molybedate was added and this was diluted to about 20.0 ml with distilled water. Stannous chloride solution (working solution) (1.0 ml) was then added to it and the final volume was made upto 25.0 ml with distilled water and was shaken thoroughly. The colour intensity which was red was measured using the colorimeter at 660 nm after 10 minutes.

3.4.2.7. Available Potassium

Potassium was estimated by flame photometer (Perkin-Elmer model 52, flame photometer with acetylene of propane burner) method given by (Jackson, 1973).

Reagents

A. Ammonium acetate 1N: To 700 or 800 ml of water, 57.0 ml of concentrated acetic acid and then 68.0 ml of concentrated ammonium hydroxide was added. It was diluted to a volume of 1.0 litre and was adjusted to pH 7.0 by the addition of more ammonium hydroxide or acetic acid.

B. Potassium chloride 0.02N: Dry potassium chloride (1.49 g) in water was dissolved in distilled water and was diluted to a volume of 1.0 litre.

C. Potassium chloride: 0.02N KCl in 1N ammonium acetate: Dry potassium chloride (KCl) (1.49 g) was dissolved in reagent A and diluted to a volume of exactly 1.0 litre with additional A solution.

D. Lithium chloride, 0.05 N: Dry lithium chloride (2.12 g) was dissolved in distilled water and diluted to 1.0 litre.

Procedure

Reagents B and D were used to prepare a series of standard potassium chloride solutions, each containing the same concentration of lithium chloride. A similar series of standard potassium solutions using reagents C and D and which was diluted by reagent A were prepared. The concentrations of potassium chloride were 0.1, 0.2, 0.3, 0.4, 0.5, 1.0, 1.5 and 2.0 moles equivalent/L. The optimum concentration of lithium chloride varies with individual flame photometers but was usually 5.0 to 10.0 meq./L. Standard solutions were made in water employed for the analysis of water and water extracts of soils; whereas, those made up in ammonium acetate solution were used for the analysis of ammonium acetate extracts of soils. The flame photometer was calibrated for operation over the concentration range 0.0 to 0.5 meq./L. of potassium, using the first 6 standard solutions of the appropriate series. The first and the last 4 solutions of the appropriate series were used to calibrate the instrument for operation over the concentration range 0.0 to 2.0 meq/l of potassium.

An aliquot of the solution was pipetted out to analysis containing less than 0.1 meq. of potassium into a 50 ml volumetric flask. An amount of reagent D was added, which when diluted to a volume of 50.0 ml, gave a concentration of lithium chloride exactly equal to that in the standard potassium chloride solutions. It was diluted to volume with water or with A, and determined the potassium concentration by use of the flame photometer.

3.4.2.8. Soil microbial biomass carbon

Soil microbial biomass carbon was determined by method described by (Vance *et al*., 1987). For this soil was sieved through a mesh for equal particale size. 17.5 g of each sample in duplicate was transferred to bottles. One was fumigated by chloroform and the other was unfumigated. 1ml of chloroform was added and incubated for 24 hour at room temperature. The chloroform was evaporated at 50^{o}C for 24 hours.70 ml K_2SO_4 was added and shaken for 30 minutes. The extract was filtered through Whatman No 42. Optical density (OD) was recorded at 280 nm. Microbial biomass carbon per gram soil was calculated as follows:

OD of fumigated sample = OD of unfumigated sample × 15.487/17.5 (soil weight).

The microbial biomass carbon was expressed as µg C/g soil

3.4.2.9. Soil respiration (SR)

For estimation of Soil Respiration 50 grams of soil samples were kept in the 1 litter glass bottle. 10 ml of NaOH (0.1N) was kept in separate test tube lowered in the bottle with a thread. The bottle was tightly closed with a lid. The observation was taken on 1, 3, 5 days by removing the 0.1 N NaOH in test tube and titrating it with 0.1 N HCl (Stotzky, 1965).

3.4.2.10. Estimation of soil dehydrogenase (i.e. DHA)

Soil dehydrogenase was determined by method described by (Casida et al., 1964).

Reagents used:

Calcium Carbonate ($CaCO_3$), reagent grade and 2, 3, 5-Triphenyl tetrazolium chloride (TTC), 3%:

Dissolve 3 g of TTC in about 80 ml of water and adjusted the volume to 100 ml with methanol, analytical reagent grade.

Triphenyl formazan (TRF) standard solution:

Dissolve 100 ml of TPF in about 80 ml of methanol and adjust the volume to 100 ml with methanol mix thoroughly.

Procedure:

Twenty grams of air- dried soil (< 2mm) and 0.2 g of $CaCO_3$ were mixed thoroughly, and placed 6 g of this mixture in each three test tubes. To each tube, 1 ml of 3% aqueous solution of TTC and 2.5 ml of distilled water was added. Those samples were incubated at 37^{o}C for 24 hours. Then, 10 ml of methanol was added. The solution was filtrated through a glass plugged with absorbent cotton. Volume was made to 100ml with methanol. OD was recorded at 485 nm. The result was calculated with the standard curve.

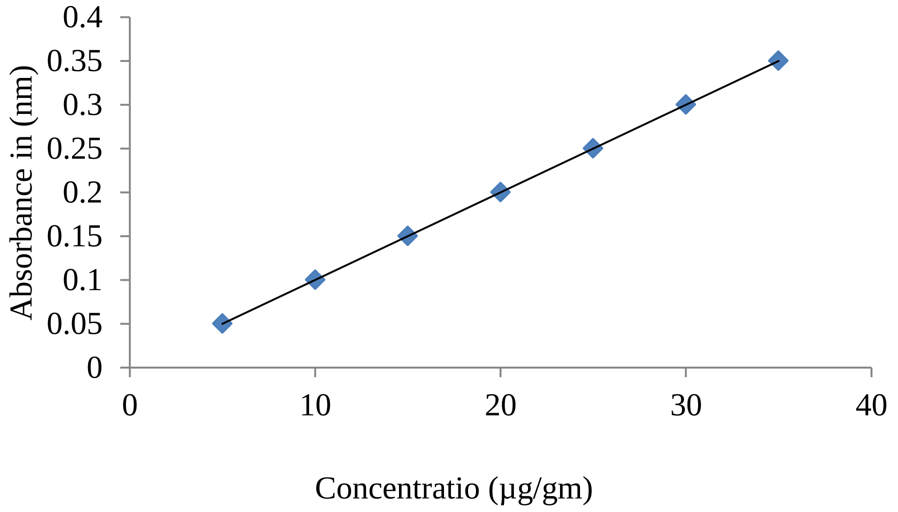

Fig 3.3. Standard curve for DHA Activity

3.4.2.11. Estimation of Phosphomonoesterase (Acid and Alkaline phosphatase)

For estimation of acidic phosphatase in soil was determined by the method of (Tabatabi and Bremner, 1969) and alkaline phosphatase was determined by method of (Eivazi and Tabatabi, 1977)

Reagents:

Toluene, Fisher certified reagent:

Modified universal buffer (MUB) stock solution:

Dissolve 12.1 g of tris (hydroxyl methyl) aminomethane (THAM), 11.6 g of maleic acid, 14.0 g of citric acid, and 6.3 g of boric acid (H_3BO_3) in 488 ml of 1N sodium hydroxide (NaOH) and dilute the solution to litre with water. Store it in a refrigerator.

Modified universal buffer (MUB), pH 6.5 and 11:

Place 200 ml of MUB stock solution in a 500 ml beaker containing a magnetic stirring bar, and place the beaker on a magnetic stirrer. Titrate the solution to pH 6.5 with 0.1 N HCl and adjust the volume to 1 litre with water. Titrate another 200 ml of the MUB stock solution to pH 11 by using 0.1 N NaOH, and adjust the volume to 1 litre with water.

p-Nitrophenyl phosphatase tetrahydrate in about 40 ml. modified universal buffer (MUB) pH 6.5 (for assay of acidic phosphatase) or pH 11 (for the essay of alkaline phosphatase), and dilute the solution to 50 ml with MUB of the same pH. Store the solution in a refrigerator. **Calcium chloride ($CaCl_2$) 0.5M**: Dissolve 73.5 g of $CaCl_2$. H2O in about 700 ml of water and dilute the volume to 1 litre with water.

Standard p-nitrophenol (PNP) solution: Dissolve 1.0 g of p-nitro phenol in about 70 ml of water and dilute the solution in a refrigerator

Procedure:

One g of soil sample was placed in a 50 ml Erlenmeyer flask, 0.2ml of toluene was added 1 ml of MUB (pH 6.5 for the assay of acid phosphatase or pH 11 for the essay of alkaline phosphatase), 1ml of p-nitrophenyl phosphate solution made in the same buffer, and swirl the flask for few second to mix the content. The sample was incubated at 37^{o}C for 1 hour. Then, add 1 ml of 0.5 M CaCl2 and 4ml of 0.5 M NaOH. Swirl the flask for a few seconds and filter the soil suspension through whatman No. 2. O.D. was recorded at 420 nm.

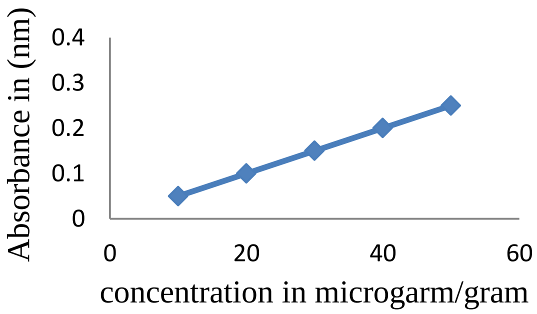

Fig.3.4. Standard curve for Alkaline phosphatase activity

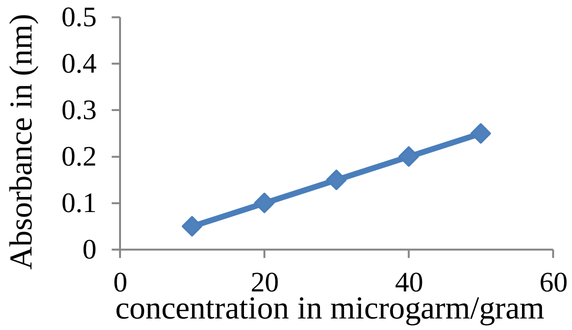

Fig.3.5. Standard curve for acid phosphatase activity

3.5. Data collection and analysis for fuel wood assessment

An extensive field survey was conducted to study the pattern of fuel wood consumption of rural households and collection of fuel wood from the selected plantation forest. To carry out the smooth survey, permission was first taken from the forest department and the village leader. A preliminary survey was conducted using the questionnaire method. Out of 450 households, 90 households were randomly selected for the study of fuel wood consumption. Respondents provide information about socioeconomic status of households, fuel wood consumption status and preferred fuel wood species of households. The respondents were asked to specify their preference of fuel wood species and other informal discussion and observation following (Baqir *et al.*, 2017). The quantity of fuel wood collection was estimated on the bases local people carry bundle of fuelwood on their head (head load). We used the head load as a standard term and asked respondents to estimate the amount of head load they collected per day. Fuel wood collected from different sources but majority of households collected fuel wood from the plantation forest. The collection of fuelwood is carried out on the head, especially by women and children to transport them at home (Photo 5.1). Questions were added about the effect of season of the year on the extraction and use of firewood. The amounts of daily collection of fuel wood from the PF and the pressure on the forest were estimated. The questionnaire used to collect the information was translated into Hindi language.

3.5.1. Sampling and analysis

Randomly, 12 tree species between the age group of 10-20 year were selected for sampling. Wood samples were collected from the stem of each species slightly above from the diameter at breast height (DBH). About 10 cm in length and 8 cm in width of wood sample were harvested before the removal of bark from each species and wood samples collected in polyethane bag and sealed to avoid the loss of moisture content with proper labelling. All samples were taken to the laboratory of Department of Environmental Science at university campus, Lucknow, India for determining the fuel wood properties and other elemental analysis.

3.5.2. Physical properties

3.5.2.1. Moisture content

For moisture content, freshly cut wood samples were collected in triplicate and oven dried at $103^o \pm 3^oC$ until they attained constant weight (Valter *et al*., 2008).

Moisture content (MC) = $W_F - W_O / W_O \times 100$

Whereas, W_F = fresh weight, W_O = Oven dry weight

3.5.2.2. Bulk density

Bulk density (BD) or wood density was determined by mercury displacement technique (Walker et al., 1993). The BD was determined by using the equation:

Bulk density (BD) = W_{OD} / V_G

Whereas, W_{OD} = is the oven dry biomass; V_G = is the green volume of biomass

3.5.3. Energy analysis

3.5.3.1. Calorific value

To estimate the calorific value of wood samples on the basis of dry weight, 2 gm of oven-dried powdered material were burnt in Rajdhani bomb calorimeter (Bhatt and Todaria, 1990). There were three replicate for each sample.

3.5.3.2. Proximate analysis

Ash content (at dry basis) was determined by burning of 2gm wood sample in a platinum crucible in a muffle furnace (Lenton Thermal Designs EF 11/8B) at temperature 550 ± 10^{o}C for 2 hours. Subsequently the ash was weighed and the ash content was determined using the equation as

$$\text{Ash content } \mathrm{AC} = \frac{\text{mass of ash}}{\text{mass of oven dry wood sample}} \times 100$$

Volatile matter (at dry basis) content was determined by burning of 2gm wood sample in a fused silica crucible with lid in a muffle furnace (Lenton Thermal Designs EF 11/8B) at temperature 900 ± 10^{o}C for 2 hours. All analyses were done in duplicate and the results were expressed on a dry weight basis. Fixed carbon content (FCC) was determined by using the equation below.

FCC (%) = [100 - (A_C % + V_C %)]

Whereas, FCC = Fixed carbon content; A_C = Ash content; V_C = Volatile matter content

3.5.3.3. Ultimate analysis

Elemental analysis or ultimate analysis (carbon, hydrogen, nitrogen and sulfur) were analysed by using CHN analyser (LECO-CHN-200). Oxygen was calculated by subtracting the sum of CHN, S and ash percentage from 100% (Kumar and Chandrashekar, 2014).

3.5.3.4. Fuel wood value index (FVI)

For estimation of suitable tree species for fuel wood, FVI was calculated as determined by (Purohit and Nautiyal, 1987). Taking into account, the calorific value and wood density of the fuel wood as positive character on the other hand ash and moisture content as negative character. However, moisture content of the fuel wood varies with dimension of branches and in different seasons. Therefore, moisture content cannot be considered as part of the intrinsic value of tree species for fuel wood. Therefore, the modified formula for calculation of FVI was given by (Bhatt and Todaria, 1990):

$$\text{Fuel wood value index FVI} = \frac{\text{Calorific value (MJ/Kg)} \times \text{wood density(g/cm}^3\text{)}}{\text{Ash content (\%)}}$$

Over all rank of the fuel wood properties and elemental composition of the selected tree species was assessed on the basis of characteristic of fuel wood and elemental composition. For each attribute, rating of species was made using 1–12 number (1 is for best and 12 is for worst). Based on the total score obtained for each species, was then divided by the number species was selected for the present pool value (Simonne *et al.*, 1999).

3.5.4. Performance Evaluation of Improved metal Chulha

3.5.4.1. Testing site

Testing of IMC over TMC was carried out in a simulated village kitchen (length × width × height: 4.5 m × 3.5 m × 3.2 m) set up in the Kahinaur village (25° 52' 274' ' N and 83°30' 578" E) of district Mau, Uttar Pradesh, India. The testing site was about 3 km away from the city and 1 km from the state highway. Collection of air samples from indoor kitchen was taken during the cooking process. The reason for choosing indoor kitchen sampling method for emission sampling was as majority of the households was using indoor kitchen for cooking daily meals. The air sampler was placed in the kitchen at a distance of one and a half meter away from the combustion zone. Concentration of a pollutant in the kitchen environment was monitored during the cooking processes. Average time taken to monitor the indoor air quality during the cooking hour was three and half hour because this time is an average time taken to cook the single meal by Indian rural women's in the indoor kitchen. One control test (CT) was performed without any cooking Activities.

3.5.4.2. Fuel used

The most commonly available fuel wood in the study area was *Alangium salvifolium*, *Prosopis Juliflora,* and *Terminalia arjuna*. However, for the present study *Prosopis Juliflora* was used as fuel wood. This species was the most preferred species as firewood in the selected region and its gross calorific value was higher compared to other commonly available species studied. Testing of IMC over TMC was done by using the same size of fuel wood. Before using as fuel the moisture content of fuel wood was measured by oven dry method and it varied from 5 to 12%. The average size of wood pieces was made uniform i.e. 3×3×20 cm as per specification of IMC and size of burning chamber of the IMC manufactured. The gross calorific value of fuel wood used for WBT was estimated by digital oxygen bomb calorimeter and was found to be 19.56 MJ/kg.

3.5.4.3. Measurement of Different Parameters during the Experiment

3.5.4.3.1. Measurement of PM_{10}, $PM_{2.5}$, CO, SO_X and NO_X

The suspended particulate matters were collected onto glass fiber filters of 8 ×10 inches using the Respirable dust sampler (Model- APM 460 BL, Envirotech) at a flow rate of 1.3 $m^3 min^{-1}$ and fine particulate matter was collected on glass microfiber filter paper of 47 mm using fine particulate sampler (FPS, Envirotech, APM 550) which runs at a constant flow rate of 16.67 L min^{-1}. Each filter is weighed before and after sample collection to determine the net gain due to the particulate matter. The mass concentration in the ambient air is computed as the total mass of collected particles was divided by the actual volume of air sampled, and expressed in μgm^{-3} (Pandey *et al.,* 2012). For measurement of carbon monoxide (CO) a portable electrochemical cell based CO monitor (Model: Drager Pac III, Draeger Safety Inc., Pittsburgh, USA) was used to measure the concentration of CO during the cooking hour in the indoor kitchen. The minimum detectable limit of the instrument was 0.02 µg m^{-3} with 0.01 µg m^{-3} resolution. The instrument was calibrated before the starting of experiment with 910 µg m^{-3} CO in nitrogen standard (MSC-307; Master Standard, Mumbai, India) (Suresh *et al.,* 2016). Analysis of SO_x and NO_x was performed according to the method of Bureau of Indian Standard (BIS) Indian Standard (2001): IS: 5182 (Part II) and Indian Standard (1975): IS: 5182 (Part VI), respectively (Barman *et al*., 2008).

3.5.4.3.2. Trace metal analysis

The extraction of metals from filter paper was carried out in digestion mixture of nitric acid and perchloric acid (3:1) on the hot plate until the solution becomes clear and reduced to 2-3 ml. Digested samples were filtered through Whatmann filter no. 42 and final volume was made up to 50 ml by 0.1N nitric acid. The filtrate was examined for the concentration of trace metal by AAS (Varian Spectra AA- 250 Plus). The atomic absorption spectroscopy (AAS) values of blank filter papers of each metal were deducted from the sample value for final calculations. The AAS was calibrated for each metal using known CRM (Qualigens make) before analysis (Barman *et al*., 2008).

3.5.4.3.3. Water Boiling Test (WTB)

The thermal efficiency of IMC over TMC was evaluated by following the well-defined protocol the WBT protocol version 4.1.2 was used (Lombardi *et al.*, 2017). While there are many other methods for testing cooking stoves used by governments and organizations around the world, the Water Boiling Test was chosen because it has been written and continually revised by the cooperation of international experts in the field. The WBT performed in three phase i.e. cold start (high power phase) is the first phase begins with the stove, standard test pot, and water at room temperature, and the stove is operated until the water reaches boiling temperature, hot start (high power phase) is the second phase begins immediately after the first phase with the stove hot and with the pot refilled with water at room temperature. The stove is operated until the water reaches boiling temperature. Results for the cold start and hot start can be compared to identify differences in performance between a cold and hot and simmered test (low power phase) is the third phase begins immediately after the second phase with the stove, pot, and water hot. The stove is operated to maintain the water temperature just below the boiling point, and results can be compared to identify differences in performance between low-power and high power operation of the stove. (Figure 3.6). Prior to starting the test approximately 10 liters of water and 15 kg of dry fuel wood with uniform size must be needed for WBT. Between each of the three phases, the wood, water, temperature, and charcoal are weighed by quickly removing and extinguishing the fuel. Burning of biomass in cook stove is a highly variable. Therefore, a number of replicates required for the overall performance of cook stove. In the present study, five replicate of WBTs were performed for both types of chulha to calculate the average performance metrics. These measurements of the cook stove performance at both high and low power phase help to simulate what is likely to occur when cooking foods that involve boiling and simmering. This type of cooking is believed to be the most common type of cooking.

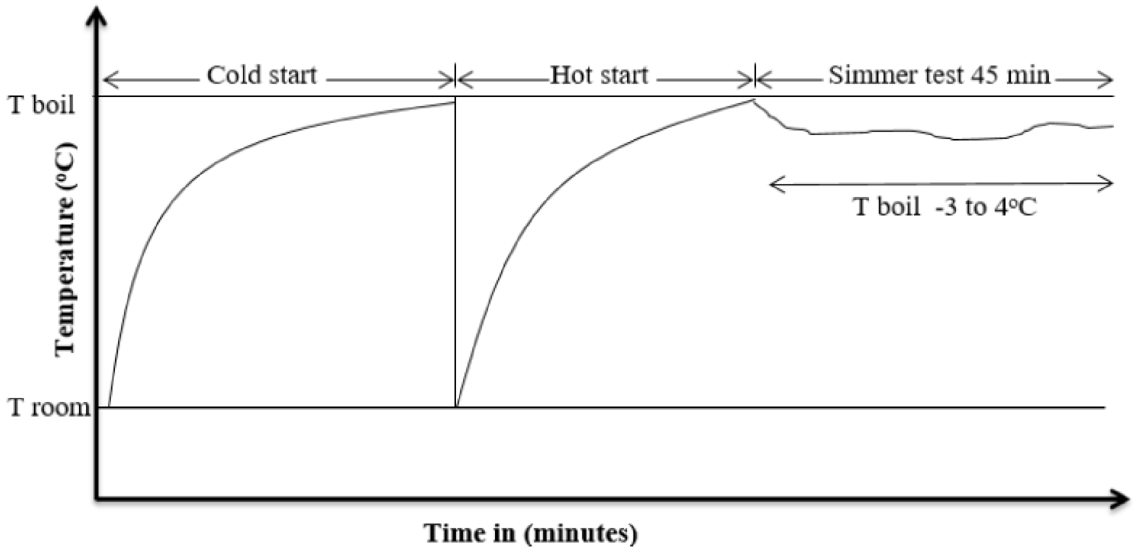

Figure. 3.6. Water boiling test procedure.

3.6.2.4. Scanning Electron Microscope Energy dispersive X-ray (SEM EDX) Based Analysis

Morphological and elemental characterization of airborne particulates were performed by SEM (JSM 6490LV, JEOL) coupled with EDX (Oxford INCA x-act). Dry and particle loaded filters were cut into approximately 1 mm^2 size and mounted on aluminium stubs with double sided sticky carbon tape. A very thin film of gold and palladium was deposited on the surface of the samples to make them electrically conductive using vacuum coating unit. Samples were examined and photographs were taken at different magnification by stereo SEM at 30 tilt and 10 KV. Three images of the single sample were taken at different magnifications to highlight the morphological characteristics. EDS spectra of the individual aerosol particle were obtained by scanning an electron beam with an accelerating voltage of 15–30 kV (Sielicki *et al*., 2011; Pipal *et al.*, 2011; Srivastava *et al*., 2009).

3.6. Statistical analysis

Study results were statistically analysed by using SPSS-20 software. Pearson correlation coefficient was used to calculate the relationship between different parameters. An analysis of variance (ANOVA) was performed for statistical comparison of means. The mean differences between species were evaluated using Tukey test ($P < 0.05$).

Chapter 4

Characterization of mix plantation forest for soil quality and carbon sequestration potential

Chapter 4. Characterization of mix plantation forest for soil quality and carbon sequestration potential

4.1. Introduction

The concentration of CO_2 in the atmosphere has risen from 277 ppm in 1750 (Joos and Spahni, 2008) to 406.42 ppm on February, 2017 (NOAA, 2017), and it is predicted to continue to increase than the present levels. Therefore, it is important to manage the carbon pool in soils and plants to reduce atmospheric carbon concentration. This could be achieved by better management of plantation forests which acts as a sink for carbon (Brahma *et al.,* 2016). Recently, the role of forest ecosystem in storing soil organic carbon (SOC) stocks and its dynamics for mitigating climate change has highlighted the need for developing knowledge databases of different tree species for their carbon stocks that can act as a potential measure for mitigation of atmospheric CO_2 concentration in national GHG budgets (Jandl *et al.,* 2007).

Developmental activities lead to deforestation and disturbance which in turn led to degradation of soil quality and reduction in terrestrial carbon stocks (Sexena and Choudhary, 2015). Plantation forests are recognized as sequesters of greenhouse gases as well as enhancing terrestrial carbon stocks (Arora and Choudhary, 2014). It has been estimated that about two third of the terrestrial sequestration of carbon is done by forests and forest soil (IPCC, 2007; Kailes *et al.,* 2016). Soil microbial biodiversity helps in maintenance of soil organic carbon (SOC) and nutrient recycling in soil (Song *et al.,* 2016). Increased levels of soil microbial biomass carbon (SMBC) and SOC indicate sequestration of carbon into the soil (Shao *et al.,* 2015). Soil enzyme activities like decomposition of organic matter; transfer of energy and recycling of soil nutrients reveal soil fertility characteristics (Sharma *et al*., 2015), that have been attributed to the dynamics of soil microorganisms (Das *et al*., 2014).

Evaluation of SMBC in soil is an indicator of soil quality and productivity (Shao *et al*., 2015). Management options for carbon sequestration, afforestation have been recognized as a profitable and beneficial strategy for the sequestration of environmental carbon (Ostadhashemi *et al*., 2014). Measuring the impacts and storage capacity in short and long term of the forest to sequester CO_2 would allow the development of informed measures aimed at reducing net CO_2 emissions.

In the present study variability in carbon sequestration efficiency of different tree species and improvement in soil organic carbon stock and other soil physicochemical properties of plantation forestry were evaluated in comparison with non-forest area i.e., wasteland of our selected study area Kahinure district Mau, Uttar Pradesh, India. Reports on estimation of carbon pool in soils and plants of plantation forests are rarely available in Indian context (Singh *et al.*, 2015; Sharma *et al*., 2017). Certain plantation forests with mixed culture of tree species have been developed by forest department of India as part of plantation drives. Assessment of the potential of these plantation forests for their carbon sequestration and subsequent amelioration in soil physicochemical characteristics will help in developing a database of trees as best carbon sequesters, thereby providing environmental services. Keeping the above facts in consideration, the present study was aimed: (1) to estimate the potential of above and below ground carbon sequestration of the mixed plantation forest in a semi-arid zone of India and impact of plantation forest, if any, on enhancement of soil organic carbon, soil microbial activity and other soil nutrients; (2) interrelationship between soil carbon content, soil microbial biomass carbon, soil enzyme activity and soil respiration at different soil depth; (3) quantify inter and intra specific variation in carbon concentration in tree species to evaluate better tree species as atmospheric carbon sequesters.

4.2. Material and Methods:

To Carrey out the above said objectives for this study, methodologies for estimating above and below ground biomass carbon stock, soil sample collection, its analysis with emphasis on soil organic carbon stock, soil microbial biomass carbon, soil respiration, soil enzyme activity and carbon content in different component of tree species already discussed in detail in chapter 3.

4.3. Statistical analysis

One Way ANOVA was used for statistical comparison of means using SPSS-16 software. Pearson Correlation coefficient was used to calculate the relationship between various soil physicochemical parameters.

4.4. Results and Discussion

4.4.1. Physicochemical characteristics of soils from plantation forest and wasteland

The physicochemical characteristics of soils of plantation forest and its comparison with non-forest area i.e., wasteland are presented in (Table 4.1). Statistically significant differences were observed between the mean values of the parameters at selected sites ($p \leq 0.05$). In the present study, pH of plantation forest (PF) of top soil (0-10cm) ranged from 6.78 to 6.80 and in wasteland 7.68 to 8.85. However, pH increased with increasing soil depth in both the plantation forest (PF) and in wasteland. In PF, pH at 10 to 30cm depth ranged from 6.78 to 8.21, while in wasteland (WL) it ranged from 7.95 to 8.25. In the present study there is no consistent relationship between soil pH and EC with soil depth in both forest and wasteland area, however, variation in EC between forest and non-forest soil was reported. EC ranged from 0.86 to 0.31mS/cm in PF and 0.44 to 0.58 mS/cm in WL. Bulk density (BD) varied from 0.63 to 1.75 g cm^{-3} in PF and 1.78 to 1.98 g cm^{-3} in WL. BD increased with increasing soil depth. BD was observed to be higher in WL as compared to PF soil (Table.4.1). SOC was reported to show a decreasing trend with increasing soil depth in both PF and WL. However, the soil from plantation forest showed higher SOC as compared to non-forest soil. In PF SOC ranged from 0.91 to 2.48 percent and in WL it was 0.34 to 0.95 percent (Table.4.1). Nutrients in soils are present in different chemical forms, which can remain in solution or combined with soil particles. The exchange of nutrients between different forms or soil pools is governed by physical, chemical or biological processes. All these processes are included in the concept of "nutrient cycle" in soils. In the present study higher concentration of NPK was found in PF as compared to WL with the levels of NPK decreasing with increasing soil depth in both PF and non-forest land (WL). NPK in the PF was higher as compared to WL with Nitrogen (N) ranging from 0.03 to 0.39 percent, Phosphorus 5.12 to 51.29 $kgha^{-1}$ and Potassium 125.56 to 248.90 $kgha^{-1}$, while in WL the values ranged from 0.01 to 0.04 percent N, 5.01 to 20.51 $kgha^{-1}$ P, 65.10 to118.20 $kgha^{-1}$ K (Table.4.1). Changes in land use and vegetation cover on degraded or waste land could have an impact on some important soil properties. In the present investigation with the increase in soil depth, the nutrient content of the soil is reduced, the soil becomes tight and the acidity of the soil gradually increases. Afforestation efforts on degraded lands positively affect several soil properties. Soil properties substantially affected by vegetation change include SOC, other soil physicochemical properties. The soil organic carbon value of the plantation forest soil is generally higher than in the soils of waste land lands. Therefore, land use and management strategies can have a profound impact on many soil properties, which indirectly affects the quality of the soil. The current study was aimed at evaluating the prospective use of plantation forest as carbon sequesters and subsequently enhancing the soil nutrient status and other properties. Generally, soil pH (5.9 to 7.2) is considered as a fertile soil providing nutrients and essential elements to the plants. In the present study, the lower value of pH observed in top soil layer may be due to addition of more organic matter, microbial activity and less disturbance

Table 4.1. Physicochemical characteristics of soil at selected sites (± is standard deviations)

Sites	Depth (cm)	pH	EC* (mS/cm)	BD* (g/cm^{-3})	SOC* (%)	TKN* (%)	Available P* ($kgha^{-1}$)	Available K*($kgha^{-1}$)
PF Site -1	0-10	7.45^a ±1.08	0.52^a ±0.08	1.33^a ±0.03	2.20^a ±0.02	0.38^a ±0.02	41.03^a ±1.03	223.97^a ±9.79
	10-20	8.21^a ±0.06	0.86^b ±0.02	1.37^a ±0.02	1.94^b ±0.01	0.20^a ±0.03	20.51^b ±1.24	222.35^a ±7.09
	20-30	7.20^a ±0.10	0.42^a ±0.05	1.54^a ±0.03	1.68^c ±0.04	0.08^a ±0.48	15.38^c ±0.89	220.91^a ±2.16
PF Site -2	0-10	6.80^a ±0.10	0.84^b ±0.01	1.46^a ±0.02	2.48^b ±0.15	0.39^b ±0.01	35.90^c ±0.12	248.90^b ±1.96
	10-20	7.10^a ±0.00	0.31^a ±0.03	1.73^b ±0.01	1.69^a ±0.12	0.09^a ±0.01	20.15^b ±0.01	130.13^a ±3.12
	20-30	7.01^a ±0.44	0.67^b ±0.11	1.75^b ±0.03	1.43^a ±0.01	0.06^a ±0.01	5.12^a ±0.04	125.56^a ±3.48
PF Site -3	0-10	6.78^a ±0.26	0.76^b ±0.05	0.63^a ±0.03	1.24^b ±0.01	0.09^b ±0.01	10.25^b ±0.02	136.54^a ±5.63
	10-20	8.14^b ±0.20	0.54^a ±0.06	0.67^{ab} ±0.02	1.22^b ±0.01	0.06^{ab} ±0.02	5.12^a ±0.03	132.56^a ±4.91
	20-30	8.13^b ±0.05	0.82^b ±0.02	0.72^c ±0.02	0.91^a ±0.02	0.03^a ±0.01	15.38^c ±0.02	131.61^a ±3.08
PF Site –4	0-10	7.25^a ±0.07	0.80^a ±0.01	1.13^a ±0.03	1.54^a ±0.64	0.12^a ±0.05	51.29^c ±0.08	179.84^b ±1.94
	10-20	7.20^a ±0.20	0.78^a (±.04	1.19^{ab} ±0.03	1.44^a ±0.04	0.07^a ±0.02	41.03^b ±0.04	248.93^c ±3.46
	20-30	8.21^b ±0.10	0.76^a ±0.03	1.26^b ±0.04	1.34^a ±0.01	0.08^a ±0.02	25.64^a ±0.03	159.96^a ±1.50
WL	0-10	8.25^a ±0.03	0.58^a ±0.06	1.78^a ±0.04	0.95^c ±0.02	0.04^a ±0.01	20.51^a ±0.03	118.20^c ±2.26
	10-20	8.10^a ±0.08	0.51^a ±0.02	1.81^a ±0.02	0.64^b ±0.03	0.03^a ±0.01	9.12^b ±0.03	96.61^b ±0.15
	20-30	7.95^a ±0.30	0.44^a ±0.16	1.98^a ±0.02	0.34^a ±0.01	0.01^a ±0.03	5.02^c ±0.01	65.10^a ±0.83

One way ANOVA was performed to compare the mean of soil samples at different depths using Duncan Multiple Range Test ($P \leq 0.05$). Different letters signify statistical differences among different soil parameter at the selected sites. *(EC= electrical conductivity, BD= bulk density, SOC= soil organic carbon, OM= organic matter, TKN= Total Kjeldahl nitrogen, P= phosphorus, K=potassium, PF= plantation forest and WL= waste land).

(Gupta and Sharma, 2009) and increase in pH with the increase in soil depth may be due to decrease in organic matter with soil depth (Sundarapandian *et al.,* 2016). Contrary to this, other studies have reported that lower value of pH in PF compared with non-forest areas may be due to higher organic matter decomposition in the PF (Yaqoob *et al.*, 2015). It has been reported that higher pH of soil may be attributed to the mixing of herbaceous litter with the soil (Xu *et al*., 2006). Electrical conductivity is directly related to the soluble salt concentration in the soil which effects the plant growth (Wani *et al.*, 2014). It has been reported that soil with high value of pH shows higher electrical conductivity (Goel and Behl, 2008). The reason for increased bulk density in wasteland soil may be due to the lower amount of organic matter and the degradation of soil quality. Concurrently in other studies BD of 1.4 to 0.7g cm^{-3} was observed in the plantation forest soil of Taiwan (Tsai *et al*., 2009). Decrease in BD of top soil of plantation forest as compared to the barren land may be due to higher accumulation of organic matter and with the increasing in soil depth, there is a stronger mixing of mineral material in the soil profile and therefore, higher bulk density (Dar and Somaiah, 2015).

Soil Organic Carbon pool plays an important role in soil quality and productivity which act as strong indicator of soil quality in addition to other soil parameters (Gandhi and Sundarapandian, 2017). The higher value of SOC under the plantation forest may be due to addition of more leaf litter fall on the surface of forest which keeps decomposing and adds more organic carbon into the soil (Wani *et al*., 2014). Variation in SOC stock within the forest may be due to composition of species, soil type and texture (Gandhi and Sundarapandian, 2017). Higher SOC stock in top soil and its increase with increasing depth indicated that proper management and fewer disturbances could enhance the infiltration of SOC up to the deep soil layer

(Rumpel, 2014). Contradictory to this, decreasing levels of SOC with increasing soil depth have also been reported which may be attributed to slow cycling of nutrients and carbon pool and may also be due to compaction of soil (Semwal *et al.*, 2009; Dar and Somaiah, 2015). Therefore, top soil of the plantation forest should be protected to minimize the risk of large scale carbon release. Higher value of NPK in the top layer of the soil (0-10 cm) in PF may be attributed to heavy leaf litter and humus contents (Bharali *et al.*, 2014). It has been reported that soil under plantation forest with minimum disturbance had improved considerably as compared to non-forest land (Haque and Barue, 2013). Therefore, minimum disturbance of the surface soil and slow rate of decomposition may store maximum NPK and carbon into the soil (Paz *et al.*, 2016). Soil under *Gmelina arborea* plantation in India showed significantly higher total nitrogen as compared to non-forest land with maximum concentration in the upper surface of 0-20 cm (Nath *et al.*, 2015).

4.4.2. Soil microbial biomass carbon (SMBC), Soil respiration (SR) and Soil enzyme activity

In the present study SMBC, soil dehydrogenase activity, acidic and alkaline phosphatase and soil respiration showed higher value in the plantation forest as compared to wasteland soil and the value decreased with increasing soil depth in both PF and WL (Table 4.2). The SMBC was significantly affected by plantation trees as PF showed higher SMBC as compared to non-forest sites. The value ranged from 96.65 to 114.47 $\mu g\ g^{-1}$ soil per 24 h^{-1} SMBC in PF and 46.95 to 56.65 $\mu g\ g^{-1}$ soil per 24 h^{-1} in WL. In the present study, SR showed higher value in PF as compared to WL ranging from 13.53 to 39.13 mg CO_2 $(100g)^{-1}$ soil per 24^{-1} in PF and 10.79 to 14.42 mg CO_2 $(100g)^{-1}$ soil per 24^{-1} in WL. SR also decreased with increasing soil depth in both PF and non-forest sites (Table 2). Soil dehydrogenase activity was also greater in PF and it ranged from 0.35 to 2.74 $\mu g\ g^{-1}$ soil h^{-1} and in WL the value was 0.43 to

0.82 μg g^{-1} soil h^{-1}. Acidic phosphates (ACP) and alkaline phosphates (ALP) varied significantly both in plantation forest and non-forest land.

Table 4.2. Soil microbial biomass carbon (SMBC), soil respiration (SR), dehydrogenase activity (DA), Acidic phosphatase (ACP) and Alkaline phosphatase (ALP) of soil samples at selected sites (± is standard deviations).

Sites	Soil depth in cm	SMBC (μg g^{-1} soil per 24 h^{-1})	SR (mg CO_2 $(100g)^{-1}$ soil per 24^{-1})	DA (μg g^{-1} soil per h^{-1})	ACP (μg PNPP g-1 soil h^{-1})	ALP (μg PNPP g-1 soil h^{-1})
PF	0-10	107.21^{c} ±0.90	34.21^{c} ±0.11	1.23^{b} ±0.03	36.01^{c} ±0.43	68.42^{c} ±1.40
Site-1	10-20	102.43^{b} ±2.78	31.64^{b} ±0.30	1.12^{b} ±0.24	28.25^{b} ±1.10	48.44^{b} ±1.85
	20-30	96.56^{a} ±0.52	26.45^{a} ±0.43	0.35^{a} ±0.05	25.32^{a} ±0.69	39.61^{a} ±1.85
PF	0-10	114.47^{c} ±1.05	39.13^{c} ±0.55	2.74^{c} ±0.03	26.45^{b} ±2.12	56.35^{c} ±1.63
Site-2	10-20	107.55^{b} ± 0.17	35.47^{b} ±1.08	2.22^{b} ±0.01	18.57^{a} ±0.36	48.33^{b} ±0.36
	20-30	105.32^{a} ±0.60	26.64^{a} ±0.70	2.07^{a} ±0.03	17.45^{a} ±0.62	42.41^{a} ±0.75
	0-10	116.38^{c} ±1.00	24.22^{b} ±0.95	1.91^{a} ±0.03	21.22^{a} ±1.49	48.96^{c} ±1.35
PF	10-20	103.32^{a} ±0.43	20.25^{a} ±1.27	1.60^{a} ±0.34	18.65^{a} ±1.05	40.48^{b} ±0.85
Site-3	20-30	111.74^{b} ±2.56	21.73^{a} ± 0.26	1.80^{a} ±0.10	19.78^{a} ±1.57	29.65^{a} ±1.27
PF	0-10	102.51^{c} ±1.20	22.11^{c} ±0.70	1.85^{b} ±0.03	24.33^{c} ±0.26	39.64^{c} ±1.31
Site-4	10-20	96.65^{b} ±2.25	16.42^{b} ±0.96	0.62^{a} ±0.02	18.44^{b} ±0.88	31.12^{b} ±1.40
	20-30	81.28^{a} ±0.17	13.53^{c} ±0.26	0.58^{a} ±0.02	16.76^{a} ±0.20	25.26^{a} ±0.20
WL	0-10	56.65^{c} ±0.26	14.42^{b} ±1.68	0.82^{c} ±0.01	19.37^{b} ±1.00	31.59^{b} ±1.12
	10-20	51.24^{b} ±0.72	09.64^{a} ±0.43	0.71^{b} ±0.01	15.69^{a} ±1.10	32.42^{b} ±0.70
	20-30	46.97^{a} ±0.65	10.79^{a}±0.17	0.43^{a} ±0.02	16.41^{a} ±0.79	26.51^{a} ±0.34

Different letters show significant differences among different soil parameters. One Way ANOVA was performed to compare the means at different depths using Duncan test ($P<0.05$); whereas PF= Plantation forest; WL= Wasteland and PNPP= para-Nitro phenyl phosphate.

The values ranged from 16.76 to 36.01μg para-Nitro phenyl phosphate (PNPP) g^{-1}soil h^{-1} ACP and 25.26 to 68.42μg PNPP g^{-1}soil h^{-1} ALP in PF and15.69 to 19.37μg PNPPg^{-1}soil h^{-1}ACP and 26.51 to 32.42μg PNPPg^{-1}soil h^{-1} ALP in WL (Table 4.2). The SMBC is highly influenced by higher organic inputs than total change in soil organic matter (Chander *et al.*, 1997). The higher SMBC in the plantation forest may reflect more addition of organic matter due to decomposition of leaf litter into the soil. Soil respiration (SR) signifies efflux of CO_2 from the soil and is considered as a measure of total soil microbial activity of the soil system. It has been reported that the rate of SR was affected by tree species (Wang *et al.,* 2013) and SR had a linear significant relationship with the forest canopy and soil temperature (Sun *et al*., 2009). Our study indicated that SR from the plantation forest was almost two-fold higher than the WL. The reason behind this may be due to higher availably of organic content due to leaf litter decomposition on the upper surface and maximum microbial population (Kara *et al.,* 2016). Estimation of soil dehydrogenase activity depicts the involvement of soil microbes for their role in electron transport system (Kandeler and Dick, 2007). It has been reported that dehydrogenase activity in natural forest showed higher value (0.42 to 1.02μg g^{-1} soil h^{-1}) than dump soil (0.05 to 0.163μg g^{-1} soil h^{-1}) (Verma *et al.*, 2014). Enzyme activity such as ACP, ALP and dehydrogenase in soil is more affected by the biological activity of soil and population of soil microbes (Sharma *et al.,* 2014). While comparing soil enzyme activity with soil depth it has been observed that with the increase in soil depth, the enzyme activity decreases which corresponds to the microorganism distribution in soil profile (Khazirev and Burangulova, 1965) and total organic matter (Arutyunyan and Simonyan, 1975). Earlier studies reported that the soil enzyme activity and soil microbial population were higher in soil covered with broad leaf forest as compared to coniferous plantation (Xing *et al*., 2010).

4.4.3. Correlation studies among parameters of soil

Analysis of Pearson correlation coefficient between different soils parameters of the present study is shown in (Table.4.3). It is concluded that SOC showed a positive correlation with TKN (0.648), SMBC (0.675), SR (0.704), ACP (0.735), ALP (0.685); ($p< 0.01$), and with K (0.533) and DE (531); ($p< 0.05$). TKN in soil showed positive correlation with P (0.739), K (0.709), SR (0.733), ACP (0.735), ALP (0.685);

(p< 0.01). Available P in soil showed a positive correlation with K (688); (p< 0.01). Available K showed positive correlation with SR (0.646); (p< 0.01). SMBC shows positively correlation with SR (0.751), DE (0.678), ALP (0.609); (p< 0.01) and with ACP (0.488); (p< 0.05). Among the soil enzyme activity, SR shows positive correlation with DE (0.566), ACP (0.655) and ALP (0.742); (p< 0.01). DE shows positive correlation with ALP (0.583); (p< 0.05) and ACP shows positive correlation with ALP (0.797); (p< 0.01).

Table.4.3. Pearson correlation coefficient matrix between soil physicochemical characteristics and enzyme activities of the selected sites

	PH	EC	BD	SOC	TKN	P	K	SMBC	SR	DA	ACP	ALP
PH	1											
EC	.113	1										
BD	.127	-.031	1									
SOC	-.388	.363	.188	1								
TN	-.473*	.012	-.257	.648**	1							
P	-.454	-.006	-.423	.353	.739**	1						
K	-.492*	.088	-.386	.533*	.709**	.688**	1					
SMBC	-.549*	.335	-.363	.675**	.458	.293	.571*	1				
SR	-.588*	-.055	-.110	.704**	.733**	.385	.646**	.751**	1			
DA	-.407	.360	-.013	.531*	.297	.046	.015	.678**	.566*	1		
ACP	-.242	.157	-.039	.735**	.735**	.423	.570*	.488*	.655**	.197	1	
ALP	-.412	.098	.089	.816**	.685**	.235	.341	.609**	.742**	.583*	.797**	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

In the present study SOC showed significant positive correlation between TN, K, SMBC, SR, ACP, ALP and DE except available P. A positive correlation between SOC, TKN and available K in soil has also been reported by (Gupta and Sharma, 2009; Gairola *et al.*, 2012). It was also reported that available P showed negative correlation with SOC and showed positive correlation with soil pH (Haque *et al.*, 2013). Positive correlation among these characteristics may be attributed with soil humus (Bharali *et al.*, 2014).

4.4.4. Carbon percentage in different tree species and its components

In the present study, percentage of carbon in different tree species and its components (branch, stem and leaf) of the selected tree species is presented in (Table 4.4). Inter and intra specific variation in carbon concentration showed significance difference ($p \leq 0.05$). One way ANOVA showed significant differences among the carbon content of stem, branches and leaves of all studied plant species. With the help of loss of ignition method, generally it was observed that ash content showed increasing trend in different tree components (stem < branch < leaf) of the tree species. Individually, maximum carbon percent in different tree components was recorded in certain species like *Prosopis juliflora* with stem showing (52.01%), branch (49.23%) and leaf (47.78%), *Putranjiva roxburghii* with stem (50.48%), branch (47.43 %) and leaf (45.16 %), *Pithecellobium dulce* in stem (50.31%) branch (48.04%) leaf (46.72 %) and *Artocarpus heterophyllus* in stem (49.13%) branch (48.21 %) and leaf (44.52 %) respectively.

Carbon percentage in different tree species and its components depends upon ash content and the ash content depends upon the structural components. Higher the structural tissue higher will be the ash content and lower will be the carbon percentage in wood sample (Negi *et al*., 2003). Thus, carbon percentage showed decreasing trend in different tree components (leaf < branch < stem). Several other studies have reported that variation of carbon content in intra and inter species is also influenced by stand characteristics, site condition and management practices (Guan *et al*., 2015). While comparing hard tissue and soft tissue, it has been observed that woody tissues like stem, root and branch shows higher percentage of carbon stock than the soft tissues like leaf, flower and fine root (Kraenzel *et al*., 2003).

Table 4.4. Comparison of the carbon percentage (%) of Stem, Branch and leaf for the 15 tree species having most frequent occurrence (± is standard deviations).

Name of species	Vernacular name	Carbon percent (%)		
		Stem	Branch	Leaf
Prosopis juliflora (Sw.) DC	Vilayati Babul	52.01^{ef} ±0.55	49.23^{e}±1.58	47.78^{g} ±0.89
Putranjiva roxburghii Wall.	Putranjiva	50.48^{g} ±1.96	47.43^{cd}±1.63	45.16^{de} ±0.72
Pithecellobium dulce (Roxb.)B	Jungle Jalebi	50.31^{fg} ±0.69	48.04^{e} ±1.67	46.72^{e} ±0.87
Artocarpus heterophyllus Lam.	Katahal	49.13^{g} ±0.24	48.21^{e} ±1.59	44.52^{fg} ±1.24
Ficus benghalensis (L.)	Bargad	48.27^{de}±2.44	46.32^{de}±1.85	45.67^{fg} ±0.38
Madhuca indica J.F. Gmel.	Mahva	47.86^{cde} ±1.42	38.32^{a} ±0.94	33.44^{a} ±1.70
Mangifera indica (L.)	Mango	47.33^{bc} ±2.22	45.32^{cd}±0.72	43.58^{f} ±2.57
Alstonia Scholaris (L.) R. Br	Saptaparni	47.16^{be} ±3.68	48.42^{e} ±2.70	44.07^{fg}±0.52
Terminalia arjuna (Roxb. ex DC.)W& A	Arjun	45.95^{bc} ±0.77	42.42^{ab}±1.54	35.59^{ab} ±1.77
Tectona grandis (L. f.)	Teak	48.38^{ab} ±0.97	47.24^{e} ±0.45	45.03^{de} ±2.14
Eucalyptus sp. (L'He´r.)	Safeda	43.17^{ab} ±4.38	44.23^{cd}±2.01	51.44^{i} ±0.40
Acacia nilotica (L.)	Babul	49.05^{ab} ±3.09	48.24^{a} ±0.73	46.00^{be} ±0.50
Alangium salvifolium (L. f.) W	Ankol	42.25^{ab} ±4.85	41.24^{ab}±2.14	37.95^{cd} ±1.97
Eugenia jambolana (Lam.)	Jamun	42.12^{abc} ±1.80	38.32^{a} ±1.33	34.54^{ab} ±0.70
Holoptelea integreifolia (Planch.)	Chilbil	40.01^{a} ±0.65	42.62^{ab}±0.74	38.34^{cd} ±2.40

One way ANOVA was performed to compare the mean of using Duncan Multiple range tests ($P<0.05$). Different letters shows significant differences among different fuel wood parameters of the selected tree species.

4.4.6. Distribution of planted tree species and Biomass carbon stock

A total of 62,658 trees of 36 species of the selected plantation forest (PF) were reported (SFR 2015). The number of dominant tree species in the PF was *P. juliflora* (26481), *A. scholaris* (7902), *A. salviifolium* (6680), *S. asper* (5318), *T. arjuna* (6151), *T. grandis* (4318). The DBH of the tree species was ranged from 3.5 to 44 cm. (Table 4.5) provide the average DBH and average biomass carbon stock of the standing tree species of the forest has been summarized. On the basis of the allometric equation, tree species with higher DBH increase their biomass and carbon stock due to increased accumulation of biomass with increasing tree age. The observed mean biomass and carbon stock of PF was 88.87 Mg C ha^{-1} (carbon stock of 44.43 Mg C ha^{-1}). The carbon budget of the PF covers 118 hectares of area that has approximately 5,500 Mg C stock. The carbon stock of the above ground biomass of a forest ecosystem is one of the fundamental parameters that describe its functioning (Behera *et al*., 2017). (Figure 4.1) Shows overall above ground biomass carbon stock (AGBC) of the PF was 37.60 Mg h^{-1} C, which is greater than tropical Savanna forest of Australia (34 Mg C ha^{-1}), tropical dry deciduous forest of India (27 Mg C ha^{-1}), tropical dry deciduous forest of Mexico (33 Mg C ha^{-1}) (Chaturvedi *et al*., 2011). In comparisons to other type of PF like Sal and teak PF the carbon stock was reported as 25 to 30 Mg C ha^{-1} which is also lesser then the present results (Kaul *et al*., 2010). The findings imply that plantation forests with mixed culture have a better potential in carbon sequestration and tree plantation should be enhanced on the unused land with management strategies. The below ground carbon stock contributes approximately 18% of the total carbon accumulated. Therefore, the below ground carbon stock was 765.86 Mg. However, the total carbon stored both above and below ground (AGC + BGC) of the present study was not much higher as earlier reported from India's natural forest and some natural forest of different Asian countries as Thailand (98.76 t ha^{-1}), Malaysia (100 t ha^{-1}), and Philippines (86 t ha^{-1}) (Pibumrung *et al*., 2008). Number of studies reported that potentiality of the forest for carbon sequestration depends on the type of forest, age of the forest and size of the trees (Terakunpisut *et al*., 2007). However, fast-growing tree species accumulated more carbon in their biomass than other plantations of the same age. It has been reported that an increase in the size of the individual tree does not necessarily increase the level of biomass and carbon stock (Khum *et al*., 2015).

In (Figure 4.2) provides the five main species that contribute to a better carbon sequestration potential over the ten dominant tree species in the present investigation as a species *P. juliflora* (52.01% C), *T. arjuna* (45.95 % C), *A. nilotica* (48.45 % C) and *T. grandis* (46.38 % C) and *Eucalyptus* sp. (45.34% C). *P. juliflora* is a dry species resistant to drought and can be planted in dry areas. Its roots can penetrate deep soil and can improve the organic carbon stock of the soil and play an important role in erosion control. Growth rate is very fast and can sink more atmospheric carbon per unit of biomass. Currently, arid zones contain the lowest level of carbon in the world per hectare (Tewari *et al*., 2000). Therefore, it is necessary to consider the role of the arid zone forest in capturing carbon at a regional and global level. *T. arjuna* is a tropical species, both dry and moist species, commonly found throughout India, especially along the banks of rivers, streams and old irrigation canals that help reduce soil erosion. It is a large evergreen deciduous tree with very strong and long roots, and reaches a height of up to 20-30 meters with smooth gray bark, spreading crown and drooping branchlets. The growth rate of this species is higher as other species and life expectancy of the tree are 50 years old or more. In India, *T. arjuna* is one of the most religious and sacred trees and also possesses versatile medicinal properties. This species is a characteristic component of tropical dry riverine forests and tropical dry and moist deciduous forests. *T. grandis* is a species of tropical hardwood tree and is an indigenous of India, its growth rate is very fast. It is a valuable species that produces timber in the tropics, especially in India, Indonesia, Malaysia, Myanmar, northern Thailand and north western Laos (Sreejesh *et al*., 2013). This species can survive in a variety of habitats and climatic conditions of arid areas with only 500 mm of rain per year to very humid forests up to 5,000 mm of rain per year. The area of the leaves is very large and can sink the maximum CO_2. *Eucalyptus* sp is a moist species and can grow anywhere from 33 feet to 300 feet tall. This species are much faster growth rate than most other *trees* in cultivation. This species can live until it is 200 years old. *A. nilotica* is a dry species can grow almost anywhere in dry, water less and on the marshy banks of lakes. Growth rates varied considerably depending on the sites. This species is an excellent for fuelwood and better carbon sequester.

Table 4.5. Above and below ground biomass carbon stock of the selected plantation forest in Mega gram (Mg)

S. No.	Species name	Number of individual	Average DBH (cm)	Average biomass carbon (Kg / individual)			Total biomass and carbon in Mg / tree species	
				TAGB	TBGB	Total	TB	TC
1	*Prosopis juliflora*	26481	10.5	0.0452	0.0104	0.0556	1472.34	736.435
2	*Alangium salviifolium*	6680	23.7	0.4369	0.10049	0.5374	3590.03	1795.01
3	*Streblus asper*	5318	14.1	0.1091	0.0251	0.1342	713.83	356.915
4	*Butea monosperma*	115	20.3	0.2946	0.06777	0.3624	41.67	20.835
5	*Tectona grandis*	4318	18.7	0.2376	0.05465	0.2922	1262.10	631.05
6	*Holoptelea integrifolia*	32	19.3	0.2582	0.0594	0.3176	10.16	5.08
7	*Acacia nilotica*	1014	11.8	0.0645	0.01485	0.0794	80.54	40.27
8	*Pithecellobium dulce*	462	11	0.0521	0.01199	0.0641	29.64	14.82
9	*Alstonia scholaris*	7902	11	0.0521	0.00894	0.0611	482.89	241.445

10	*Cassia fistula*	349	10	0.0388	0.17859	0.2174	75.90	37.95
11	*Eugenia jambolana*	1	30	0.7764	0.15528	0.9317	0.93	0.465
12	*Mangifera indica*	12	28.3	0.6751	0.17859	0.8537	10.24	5.12
13	*Ficus benghalensis*	1	30	0.7764	0.17859	0.9550	0.955	0.4775
14	*Syzygium cumini*	1	30	0.7764	0.0141	0.7905	0.79	0.395
15	*Azadriachta indica*	3	11.6	0.0613	0.06777	0.1291	0.38	0.19
16	*Terminalia arjuna*	6151	20.3	0.2946	0.0652	0.3598	2213.49	1106.74
17	*A. heterophyllus*	1	20	0.2834	0.0652	0.3486	0.34	0.17
18	*Putranjiva roxburghii*	18	20	0.2834	0.0652	0.3486	6.27	3.135
19	*Buschanania lanzan*	3	20	0.2834	0.1037	0.3871	1.16	0.58
20	*Peltophar pterocarpum*	7	24	0.4508	0.0652	0.5160	3.61	1.805
21	*Neolamarckia cadamba*	4	20	0.2834	0.0652	0.3486	1.39	0.695
22	*Sapindus mukarosse*	17	20	0.2834	0.05236	0.3358	5.70	2.85
23	*Eucalyptus* sp.	28	18.4	0.2276	0.0652	0.2928	8.20	4.1
24	*Callistemon viminalis*	18	20	0.2834	0.05621	0.3397	6.11	3.055
25	*Saraca asoca*	121	18.9	0.2444	0.05621	0.3006	36.37	18.185
26	*Madhuca indica*	12	14	0.1065	0.0241	0.1306	1.56	0.46
27	*Liriodendron tulipifera*	15	19	0.2478	0.057	0.3048	4.57	2.285
28	*Berberis thunbergii*	3316	13.1	0.0881	0.02027	0.1084	359.48	179.74
29	*Ficus religiosa*	1	30	0.7764	0.17859	0.9550	0.95	0.475
30	*Phyllanthus emblica*	7	18.2	0.2211	0.05085	0.2719	1.90	0.95
31	*Aegle marmelos*	33	11.9	0.0662	0.01523	0.0814	2.68	1.34
32	*Echinops ritro*	35	21.4	0.3375	0.07763	0.4151	14.53	7.265
33	*Cordia dichotoma*	151	18.7	0.2376	0.05465	0.2922	44.13	22.065
34	*Ziziphus mauritiana*	22	8.5	0.0236	0.00543	0.0290	0.63	0.315
35	*Psidium guava*	6	7.5	0.0165	0.0038	0.0203	0.12	0.06
36	*Groot schildmos*	3	20	0.2834	0.0652	0.3486	1.04	0.52

DBH= diameter at breast height; TAGB= total above ground biomass; TBGB= total below ground biomass; TB= total biomass; TC= total carbon.

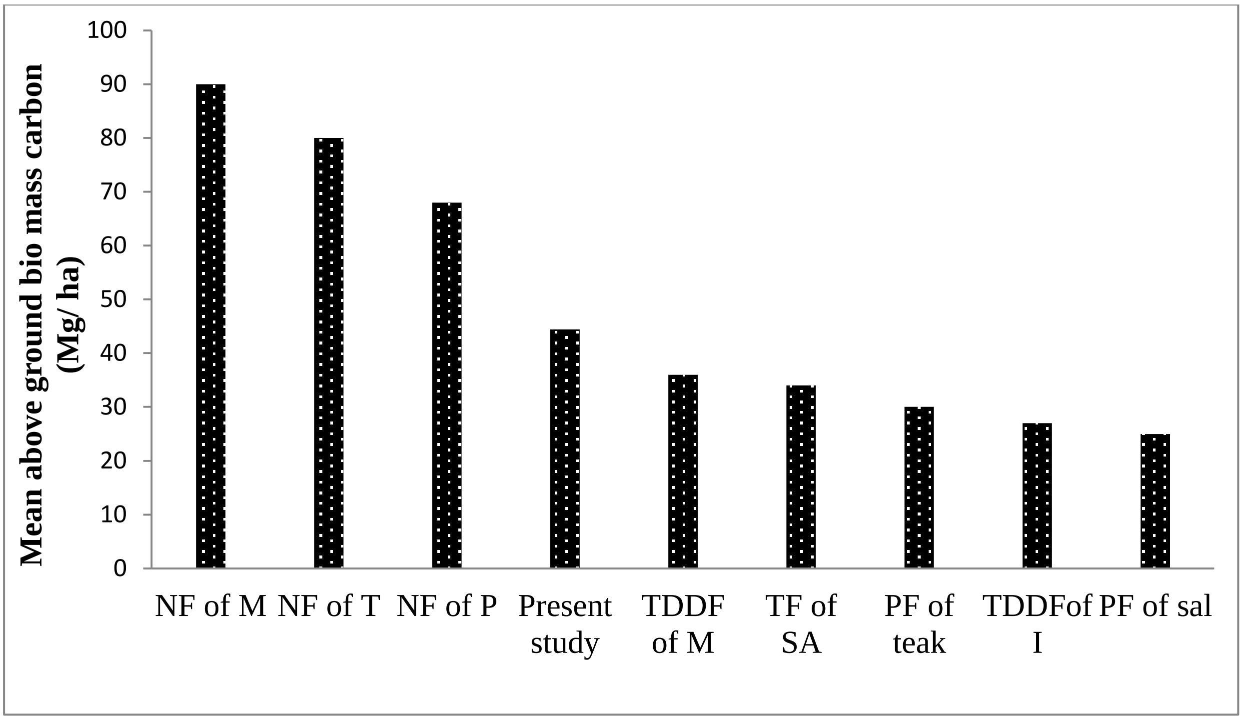

Figure 4.1. Comparing of above ground biomass carbon different type of forest, including present study. Whereas, NF of M = Natural forest of Malaysia; NF of T = Natural forest of Thiland; NF of P = Natural forest of Philippines; TDDF of M = Tropical dry deciduous forest of Maxico; TF of SA= Tropical forest of savanna Australia; TF of Teak = Plantation forest of Teak; TDDF of I = Tropical dry deciduous forest of India; PF of Sal = Plantation forest of Sal.

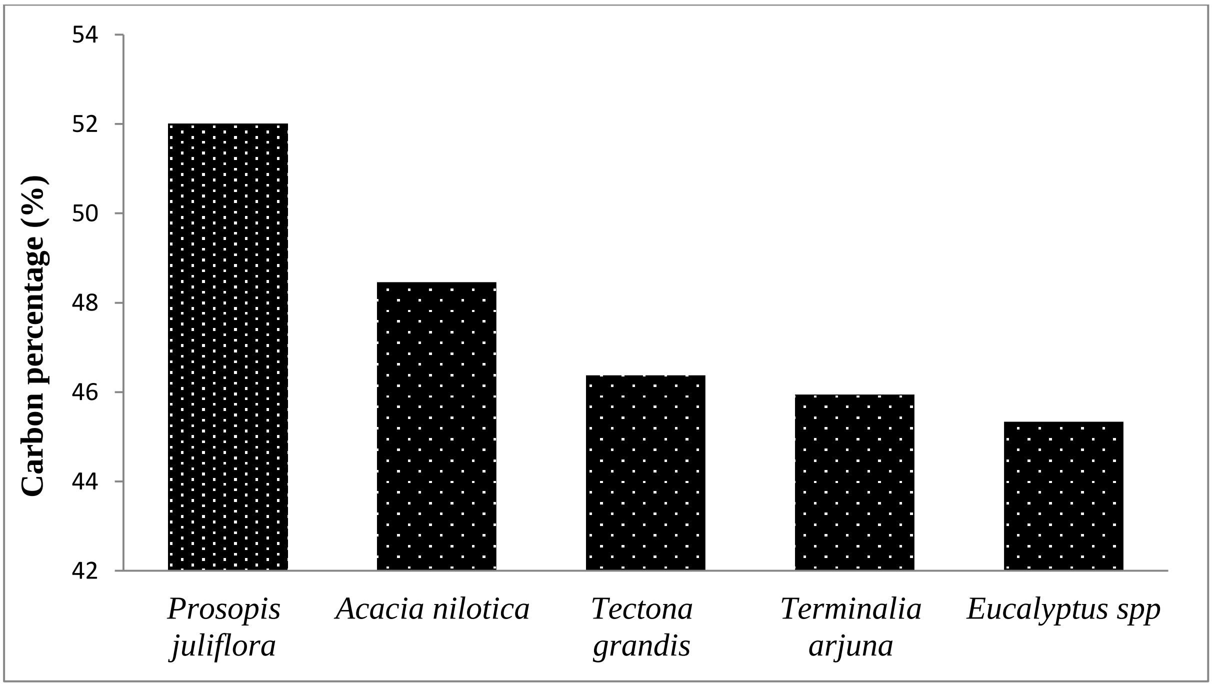

Figure 4.2. Top five potential carbon sequestration tree species.

The government should encourage the planting of these types of tree species because of their better potential for sequestering and storing carbon from the atmosphere. The present study suggested that these species have the better capacity to accumulate carbon and other ecosystem services and can be used for afforestation program in future. The reduction of atmospheric carbon is a benefit to reduce the current atmospheric carbon stock and allow the rapid sequestration of carbon in the future, which ultimately avoids the coast of climate change. Therefore, creation of new plantations with these species on unused land or degraded land is a better option for high carbon accounting and credit to mitigate climate change

4.5. Conclusion

The current study revealed that forest plantations enhance soil organic carbon stock and improved the soil fertility in addition to providing a good sink for atmospheric carbon. Soil from plantation forest showed higher concentration of SOC, soil nutrient, soil microbial biomass carbon and soil enzyme activity as compared to the adjacent wasteland. Increase in soil microbial biomass carbon reflects an increase in soil microbial population which is essential for long term soil productivity and fertility. Improvement in SOC stock in the PF soil reflects that afforestation or forest plantation is a viable option to increase SOC stock in soil. Variability in carbon percentage in different tree species within their components showed differential ability of these species. However, certain species such as *Prosopis juliflora, Putranjiva roxburghii*, *Pithecellobium dulce*, *Artocarpus heterophyllus* have more potential to sequester atmospheric carbon over the other species and these species should be planted on priority basis for their potential as atmospheric carbon sinks.

Mitigating climate change through carbon sequestration by forests is the low-cost method and will open a door for development activities because it is a very easy and simple way of receiving funds for carbon sequestration. The results of the study indicated that the plantation forest has a large carbon storage capacity if the forest area is managed in a sustainable manner. It is time to give emphasis not only to trees, but also to understory and soil to capture more carbon from the atmosphere and to determine forests as a more effective carbon sink. Further, biomass studies of the plantation forest stands revealed that the stand areas are still having potential for re-growth and can be developed into good plantation forest if proper protection measures are taken up. Participation of local communities in the management process of these forest stands has yielded better results.

Chapter 5

Fuel wood consumption pattern of Kahinaure village and emission potential from fire wood burning

Chapter 5. Fuel wood consumption pattern of Kahinaure village and emission potential from fire wood burning

5.1. Introduction

Consumption of firewood is society's oldest source of household energy and is still used around the globe, even in technologically advanced countries with high energy consumption (Lindroos, 2011; Kandel *et al*., 2016). In many countries, fuel wood consumption is now one of the most important reasons for forest degradation. It has been estimated that biomass in the form of fuel wood only accounts for approximately 9% of total global energy consumption (Lauri *et al*., 2014). For several decades, forest degradation has been one of the development agenda worldwide in an effort to find a compromise between the lifestyle of forest dwellers and forest conservation. However, due to unsustainable way of utilization forest resources due over exploitation resulting forest degradation.

Indian Forest Survey reports that about 70% of the Indian rural population depends on firewood to meet their household energy needs (FSI, 2011). According to the 2011 census, approximately 49% of households in India use firewood for cooking. However, in some states it is higher than 80%. Poor rural households collected fuel wood from locally available resources like forests to meet their domestic energy needs. Fire wood is the most attractive among the various forms of biomass and occupies a predominant place in the rural energy budget in India (Baqir *et al*., 2017). To meet the requirement for fuel wood, a policy for the large-scale afforestation program should be developed to meet the need for fuel wood and other ecosystem services from unused land or degraded land area to close the gap between demand and supply. Collection of unsustainable fuel wood and inefficient conversion technology have serious implications for the environment (Chen *et al*., 2005; Hussain *et al*., 2017). Burning of fuelwood produces large amounts of carbon dioxide (CO_2), but fuelwood emissions are considered to be carbon neutral if fuelwood is harvested sustainably. Due to incomplete and inefficient way of combustion, the use of fuelwood may not be carbon neutral because excessive carbon is released in other forms of CO, methane, nitrous oxide, carbon monoxide, and non-methane hydrocarbons, which have more global warming potential than CO_2 (Smith, 2005).

Wood biomass accounts for about 14% of total energy used globally and is the largest energy source for three-quarters of the world's population living in the developing countries (Sedai *et al*., 2016). The total average annual production of wood fuel for energy in the developing countries increases nearly 17.6% over the last decade (Simon and Singh, 2015). In India, over 170 million households and almost 800 million people depends on traditional chulha using solid biofuels such as wood, agricultural waste, coal and dried cattle manure (Singh *et al*., 2014). Rural areas largely depend on locally available resources like forests and agriculture crops to meet their domestic energy needs. Among the various forms of biomass, firewood is the most attractive and occupies a predominant place in the rural energy budget of the country (Jaiswal and Bhattacharya, 2013). Fuel wood is the only source of energy for many people living in the rural areas due to the lack of other available energy sources.

The quality of fuel wood is recognised by their calorific value, which is normally governed by the availability, time duration of burning, maximum temperature and the ash content (Lisardo *et al*., 2003). Generally, species burn for longer time and emit less smoke is considered more preferred. However, majority of rural people consume fuel wood as whatever fuel wood is available without considering energy value, ecological factor and sustainability. Factors responsible for performance of fuel wood are calorific value, moisture content, bulk density and ash content (Todaro *et al*., 2015). Higher the moisture content, results decrease in the combustion efficiency of the fuel wood. Important attempts have established the negative effect of moisture content on its calorific value (Kumar *et al*., 2009).

At present, biomass is drawing interest at global level as a renewable feed stock for energy production and reducing dependency on fossil fuel. A wide variety of biomass used as energy source including forest residues, agriculture wastes, dung cake, herbaceous and woody materials (Vamvuka and Sfakiotakis, 2011). Among this different biomass fuel wood have been considered as sustainable and traditional source of energy for remotely located poor rural households. It has been estimated that out of total need of domestic fuel, fuel wood contributes 70% in rural area and 30 % in urban areas (Deka *et al*., 2007; Dhanai *et al*., 2014). Wood biomass can be used for different purposes but most extensive use is yet as fuel wood in rural community as basic energy source for cooking purposes and heating of rooms in cold climatic conditions (Cardoso *et al*., 2015).

Due to rapid industrialization, growing human population and changing in life style has been increased the demand of energy during the recent decades. This demand is increasing about 50% up to 2030 which is mostly expected in developing countries like India, China and Brazil (Kumar and Chandrashekar, 2014). This increasing demand of energy may cause depletion in reserves of fossil fuel, enhance emission and reduce the green cover. To avoid the consumption of fossil fuel, use of biomass as energy source is considered better in reduction of CO_2 emission into the atmosphere (Fernandes and Costa, 2010).

During recent years, the energy requirement in India increased tremendously due to increased human population and majority of the population live in rural areas and use of biomass in the form of fuel wood to cater their energy requirement. It has been estimated that about 70% of energy requirement in India will be met by fuel wood and approximately 50 million tone of wood will be removed from the forest every year (Ministry of Environment and Forest, 2015). Fuel wood consumption in India especially in rural areas of India is increasing at alarming rate due to poor socioeconomic conditions. Increase in consumption of fuel wood in rural areas of India causes deforestation and rapid degradation of environment as the cutting of large number of trees without proper knowledge might be result in ecological imbalance in a particular area (Sedai *et al*., 2016). So, it is an important to segregate or screen tree species for fuel wood quality of different tree species with reference to people's preference and their constituent properties and establishment energy plantation to reduce the fuel wood crisis for rural people in the specified geographical region.

In India, several workers have studied fuel wood properties of different tree species on the basis of FVI and other properties and consumption patterns of fuel wood and other biomass in the eastern Himalayan region of India (Deka *et al*., 2007; Sedai *et al*., 2016); Bhatt *et al*., 2016 and Bhatt *et al*., 2017). However, the reports associated with local preferences using fuel wood on the basis of fuel wood properties are rarely to find by research community. Therefore, it is important to understand the characterization of species for fuel wood preference. Fuel wood value index (FVI) which is an important parameter depends on calorific value, moisture content, density and ash content for screening tree species which are desirable for fuel wood ranking (Deka *et al*., 2007).

In this present study, conceptual framework is designed to evaluate the scenario of fuel wood in this particular area of India, very specific to collection and consumption also in protected forest region. How the seasonal variation affects the consumption and collection pattern of fuel wood, also assessed and their impact on above and below ground biomass carbon stock also studied. Very limited number of case studies is available on this region of India. All the literature available on this concept mainly belongs to Himalayan region only. This particular area is untouched on study part. To fill these gaps the study concentrates on the following objectives: (1) examines the state of fuel wood, the pattern of fuelwood collection and consumption, and the role of plantation forest in supplying fuel wood to rural households; (2) Evaluation of suitable tree species for fuel wood among the different tree species of the selected plantation forest by using fuel wood value index (FVI) and calculation of emitted CO_2 and deforestation due to fuel wood burning.

5.2. Materials and methods

To Carrey out the above said objectives for this study, sampling, physical properties and energy analysis as proximate and ultimate analysis of a tree species for fuel wood and calculation of emitted CO_2 and deforestation due to burning of fair wood analysed. Further, we have estimated the fuel wood value index (FVI) of a suitable tree species for fuel wood. Detail protocol already discussed in chapter 3.

5.3. Results and discussion

5.3.1. Socio-economic condition of households

Studied village occupied 490 households with a population of 3,065 individuals, whereas the family size of studied village ranged from 4 to 22 persons per family. Out of 490 households in the selected study area, total 180 respondents between the ages of 22 and 75 years with an average age of 30–50 years were interviewed for the study. The 90% of the respondents were head of the households and responsible for collection of the fuel wood and other sources of energy for cooking daily meal and warming during the winter seasons. According to the respondents, agriculture is the main source of livelihood. The forest resources are important for their daily energy need. Demography and socio-economic conditions of the village near the selected study site is presented in (Figure. 5.1a–d). Most of the population of study area were farmers (46.83%) and labourers (26.36%) by occupation (Figure 5.1a). Caste group wise, other backward caste category (64%) was dominated in study area (b). The status of house and population structure of different religions has been presented in Figure 5.1c and d.

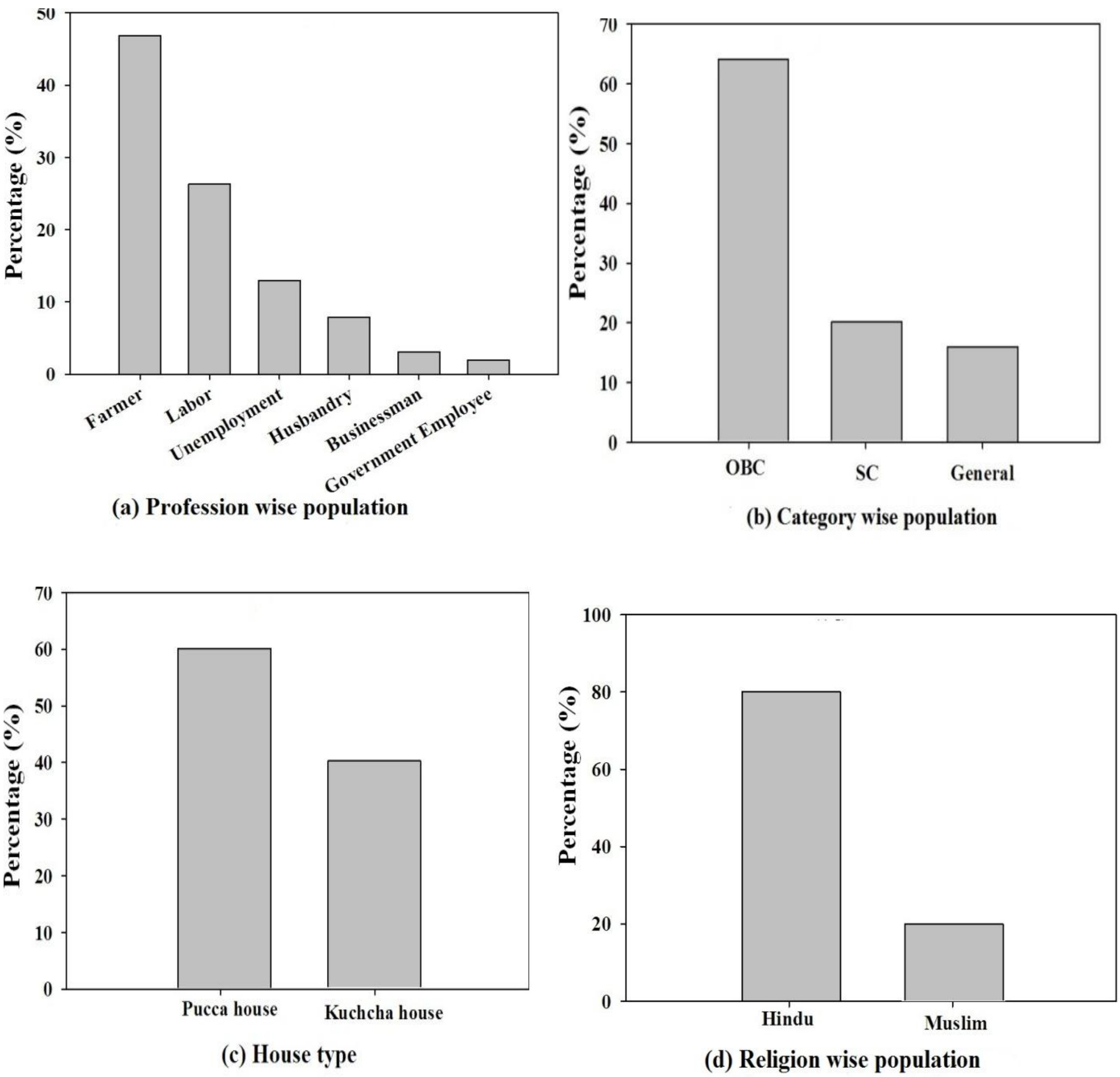

Figure 5.1. Demography and Socioeconomic status of the study site: (a): Profession wise population, (b): Category wise population, (c): House type, (d): Religion wise population.

5.3.2. Energy consumption pattern of households

In the selected study area, majority of households used fuel wood for fulfilment of daily energy need. Majority of the households collected fuel wood from plantation forest in vicinity to selected study site. Collection of fuel wood from the plantation forest was considered a sustainable fuel wood production. Composition of energy consumption, their sources and using mode at study area are given in (Figure 5.2). The study resulted that as 65% of households uses fuel wood as primary energy source, followed by cow dung 22%, agriculture residue 12% and 1.3% Kerosene (Figure 5.2a). Fuel wood using household in study area was higher in per cent value (65%) which was higher than the average value of Uttar Pradesh state, which was reported as 40% (Census of India, 2011). It is may be due to lacking of energy-saving awareness thoughts and poverty among the population. On the other hand, 71% of all households are using fuel wood in Uttar Pradesh which was higher than our estimated value65% reported in recent study of (Jain *et al.*, 2015). It is already a proven fact that traditional cooking stoves in the rural areas are less efficient due to the incomplete combustion of the fuel wood (Miah *et al*., 2009). This low efficiency is resulting in high consumption of fuel wood which is leading to the more collection of fuel wood from the forests and some health problems also. Approximately 28% households depend on plantation forest for fuel, followed by surrounding (27%) and agriculture (26%), whereas only 1% used government store for their energy needs (Figure 2b). Results show that 74% households used traditional chulha, whereas only 4% households used LPG (Figure. 5.2 c). Kitchen types used by households are given in (Figure. 5.2 d).

In this study, observations support that the energy use pattern in rural India is changing with the uptake of clean energy, but traditional fuels including fuel wood

(65%), cow dung (22%) and crop residue (12%) still constitute the major source of household cooking energy because of inadequate and unreliable supply of clean energy options at particular study area, which are almost similar to study which have been done by some previous rural area-based studies (Das and Srinivasan, 2012). However, due to increasing population and pressure, it is going to become unsustainable due to excessive collection of fuel wood. In addition to this, excessive destruction of natural forests which cause excessive pressure on plantation forest and semi-natural forest make it unsustainable and thereby leading to deforestation (Miah *et al*., 2003).

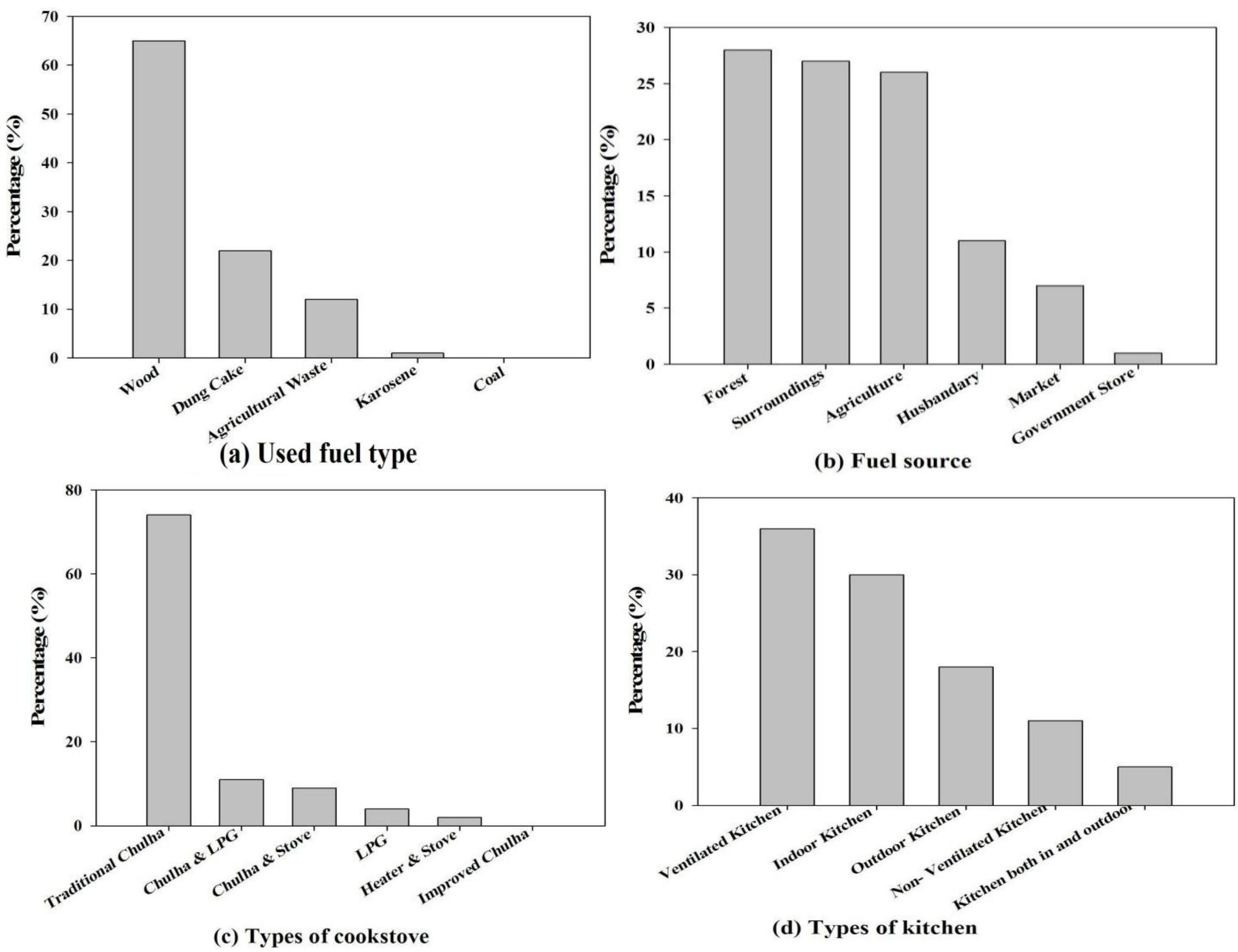

Figure 5.2. Composition of energy consumption categorized into: (a) Used fuel type, (b) fuel source, (c) Types of cook stove, (d) Type of kitchen.

Fuel wood collection and consumption from the plantation forest at study site is represented in (Table 5.1). Due to increase in population, the energy demand is increasing tremendously and majority of population living in rural area totally depend on wood biomass as main source of energy. Consumption of fuel wood from the forest ranged between 460 and 470 kg/day. Approximately 45 to 48 head load (average 46.5) were extracted from forest per day, whereas average weight of each head load was 14.5 kg. In study area, the total fuel wood extracted from the plantation forest per day basis was 485 kg/day in summer season and 520 kg/day in winter season. The reason of high value of per day forest wood extracted was that majority of households collected fuel wood from the surrounding forests. As per census of 2011, about 49% of households in India use fuel wood for cooking purposes. Fuel wood constitutes the major source of energy for cooking purposes, and about more than 853 million people use fuel wood for daily cooking in India (FSI, 1987, 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2009, 2011). The energy use pattern in rural India is changing with selection of clean energy options, but traditional fuels including fuel wood, crop residue and cow dung are still contributing the main source of household cooking energy due to inadequate and unreliable supply of clean energy.

Excessive usage of fuel wood is associated with rapid degradation of environment and insecurity of energy for rural low-income households (Sedai *et al*., 2016). The average fuel wood collection and fuel wood consumption in two different seasons that is winter season and summer season were studied. There was significant difference in fuel wood collection and fuel wood consumption in different seasons. Fuel wood is a renewable energy resource, and its consumption can only be sustained if the rate of harvesting does not exceed the growth rate (Dhanai *et al*., 2015). Average values of fuel wood collection and consumption were proportionally related to each other and could be clearly differentiated in both seasons as collection range (480–490) was highest in winter with high consuming demand in same season ranges (15–25) compared with summer season (Table 5.1).

Table 5.1. Fuel wood collection and consumption from the plantation forest

Parameters	Minimum	Maximum	Average
Consumption of fuel wood from the forest (Kg/day)	460	470	465
Number of head load produced from the forest per day	45	48	46.5
Average weight of each head loads (Kg)	12	17	14.5
Average fuel wood collected during winter seasons (Kg/day)	480	490	485
Average fuel wood collected during summer seasons (Kg/day)	250	270	260
Fuel wood consumed by individual households during winter (in percent Kg/day)	15	20	17.5
Fuel wood consumed by individual households during summer (in percent Kg/day)	7	10	8.5

5.3.4. Households income, cooking time, consumption of fuel wood and their market value

After the collection of data, the households were classified into five family size, that is very small, small, medium, large and very large. Average family income was calculated as maximum income in large family (13,000– 25,000 per month) and minimum in very small family (2,000–5,000 per month) (Table. 5.2). Average cooking time of household was 4.46 h/day/family which ranged between lowest (3.2 h/day/family) in very small family to highest

(5.9 h/day/family) in very large family. The study showed that average fuel wood consumption from the plantation forest was 4.5 t/family/day with maximum 7.1 family/day and minimum 2.5 family/day. Fuel wood constitutes the major source of energy for cooking purposes and about more than 853 million people use fuel wood for daily cooking in India (FSI, 1987, 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2009, 2011). It has been cleared from the present study that large family households consume more fuel wood than small families. It was clear that large families consumed more wood fuel and spent more money than smaller families. Consumption of fuel wood with inefficient chulha consumes higher quantities with maximum time consuming and reduce efficiency. A number of studies reported that fuel wood consumption in traditional chulha is much higher as compared with improved chulha (Alam and Chowdhury, 2010). Most of the chulha user experiences that improved chulha option is time saving during the process of cooking and explained that improved chulha cooks faster than that of traditional mud chulha for the same family members (Kuhnhenn, 2003). High values of fuel wood consumption with high cooking time in study area represent the total lacking of improved chulha and as well as poverty. Improved in cooking technology and energy plantation for fuel wood and managed in a sustainable manner will contribute to the improvement of the social and environmental situation of the local community.

The use of fuel wood as a primary source of energy for domestic and commercial use is a cause of severe deforestation in India. Similarly, the present study focuses on forest as one of the important sources of fuel wood and has been meeting the requirement of energy for rural poor households. Due to continue depletion and degradation due to excessive consumption of fuel wood, the sustainability of forest is questioned. This study discusses the production of fuel wood from the Indian forest and visualised technological intervention so that the forest can be sustainably managed. The rural environment is suffering from slow but consistent deforestation and soil erosion, which threatens the entire region’s biodiversity. One of the severe impacts of repeated fuel wood harvesting on the structure of the forest is the rapid decline of large, old trees that ultimately results in their complete disappearance. Once these trees are lost, the number of the gaps created by natural tree falls and logging increases (Ruger *et al*., 2007), which results in forest fragmentation and susceptibility to invasion by ephemerals, that inhibit the regeneration of seedlings of native tree species.

Table 5.2. Average income of the households, consumption of fuel wood, cooking time and market value of fuel wood in selected study area.

Size of Family	Number of family members	Monthly income level (₹ in thousands)	Average monthly income (₹ in thousands	Fuel wood consumption estimates (tone family^{-1}year^{-1})	Cooking time (h day^{-1} family^{-1})	Market value of annual consumption of fuel wood (in ₹)
Very small	28	2-5	2±0.81	2.5	3.2	4500
Small	40	4-7	5 ± 0.71	3.1	3.9	6,100
Medium	56	8-12	10 ± 1.07	4.2	4.1	8,200
Large	36	6-18	13 ± 3.23	5.6	5.2	10,600
Very large	20	13-25	20 ± 3.35	7.1	5.9	14,100
Average	-	-	-	4.5	4.46	8,700

4.3.5. Seasonal variations in fuel wood consumption

Fuel wood consumption in winter was significantly higher than fuel wood consumption during the summer seasons shown in (Figure 5.3). The rate of consumption from the PF was minimum 180 kg/day and maximum 250 kg/day in summer. In winter season, minimum collection was 380 kg per day and maximum was 450 kg per day. However, occasional collection was also found round the year except during rainy seasons. Fuel wood consumption by individual households was also varies in different seasons. In winter, fuel wood consumption account from the forest per day per households was minimum 10 kg/day/h and maximum 17 kg/day/ h. The value was minimum 6 kg/day /h and maximum 12 /day/ h in summer. Therefore, daily basis fuel wood consumption in winter season was found greater than in summer seasons. The additional consumption of firewood in winter was the use of firewood to boil and heating during the cold season. It has been reported that fuelwood consumption intensifies in the winter months and is heavily influenced by the seasons (Mahapatra and Mitchell, 1999). Similarly, other studies conclude that fuelwood consumption in India is heavily influenced by seasons (Bhatt and Sachan, 2004; Kandel *et al*., 2016). The amount of fuelwood collection was calculated over a 24-hour period using a weight survey method (Bhatt *et al*., 1994). Traditionally, fuel wood collected and carried on their head (Head load) and quantity was weighed to estimate the fuel wood consumption from the plantation forest on daily basis.

Photo 5.1: (a) Collection of fuel wood from the plantation forest by children and (b) collection of fuel wood by local woman on their heads.

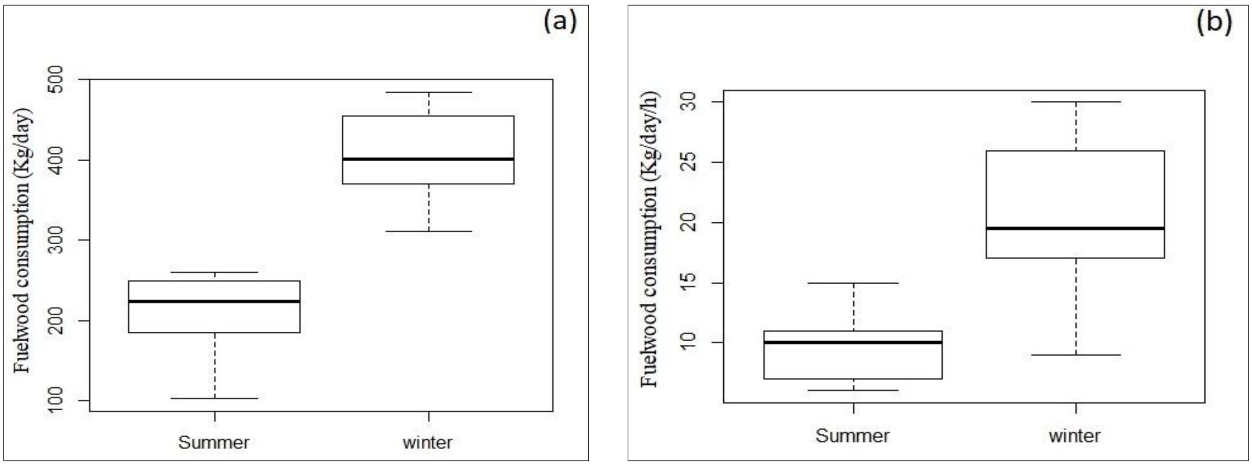

Figure 5.3. Box whisker plot for the amount of fuel wood consumption in the summer and winter season: (a) average fuel wood collected from the plantation forest per day; (b) fuel wood consumed from plantation forest per day per households.

4.3.6. Environmental impacts due to fuel wood burning

This part of the study focuses on the annual rate of deforestation and CO_2 emissions as a result of the burning of fuelwood (Bhatt *et al*., 2016; Bhatt *et al*., 2017). Burning fuel wood releases less greenhouse gases (GHGs) into the atmosphere in comparison to fossil fuel. However, its cumulative effect on total greenhouse gases and climate change is a concern for the future. With the help of the field study, it has been estimated that rural households consume approximately 470 kg of fire wood per day from selected plantation forest. Due to continuous consumption, the area will face acute shortage of its basic energy source if the current rate of deforestation continues. It is therefore important to have comprehensive forestry policies so that there is a net addition to perpetual stocks even after meeting people's essential fuel needs. To achieve this mass scale afforestation or forest plantation on degraded or waste land is required to meet the growing demand for fuel wood. Further, technologies regarding development of improved cook stove over the available traditional cook stove in the study region, which is not very energy efficient, may reduce the emission of GHGs and deforestation. (Table 5.3) shows emission of CO_2 and rate of deforestation due to fuel wood consumption.

Table 5.3. Annual average fuel wood consumption, deforestation and Carbon dioxide (CO_2) emission from the selected plantation forest.

Parameter	Minimum	Maximum	Average
Fuel wood consumed from the plantation forest tonne dry biomass per year (t dm / yr)	167.90	171.55	169.73
Potential deforested wood in cubic meter (m^3)	88.36	90.28	89.32
Emission of carbon dioxide from burning of fuel wood in tonne (t CO_2)	280.29	283.01	281.60

5.3.7. Selection of tree species for energy analysis

About 25 tree species were reported in the selected plantation forest. Out of these, 12 species were chosen for the present study, which were dominant in the plantation forest and order of preference of local people as fuel wood are given in (Table.5.4). Women and children are carrying a heavy bundle of fuel wood on their head collected from the selected plantation forest (Photo.5.1 a and b).

Table. 5.4. List of selected tree species its vernacular name, maximum height and order of preference by local peoples for fuel wood.

Tree Species (Scientific name)	Vernacular or local name	Family	Species height grows up to in meter (m)	Order of use of fuel wood in selected area by local inhabitants*
Prosopis juliflora (Sw.) DC.	Vilayati Babul	Fabaceae	15	1
Alangium salvifolium (L. f.) W.	Ankol	Cornaceae	10	2
Terminalia arjuna (Roxb. ex DC)	Arjun	Combretaceae	25	3
Tectona grandis (L. f.)	Teak	Lamiaceae	30	4
Alstonia Scholaris (L.) R. Br.	Chitvan	Apocynaceae	40	5
Eucalyptus sp. (L'Hér.)	Safeda	Myrtaceae	65	6
Streblus asper (Lour.)	Sihora	Moraceae	10	7
Mangifera indica (L.)	Mango	Anacardiaceae	40	8
Eugenia jambolana (Lam.)	Jamun	Myrtaceae	38	9
Holoptelea integreifolia (Planch.)	Chilbil	Ulmaceae	18	10
Ficus benghalensis (L.)	Bargad	Moraceae	30	11
Pithecellobium dulce (Roxb.)B.	Jangal jalebi	Fabaceae	18	12

*****Collection of species in head loads on the basis of local preference, 1 for maximum collection and 12 for least collection. Here, head loads mean collection of fuel wood in local basket by local inhabitants for daily needs especially as a fuel.

5.3.8. Physical properties

Characterization of Fuel wood on the basis of physical properties plays an important role in biomass energy. Moisture content is an important property defining the easiness of fuel wood combustion. An ideal fuel wood should have higher bulk density coupled with lower moisture content. Here, bulk density and moisture content were evaluated for all the selected species and results provide a new insight for its use for societical needs.

a) Bulk density (BD) and Moisture content (MC)

As in general, an ideal species for fuel wood are those which have higher BD, higher CV and lower in ash and MC. The BD, CV, ash content, MC and fuel wood value index (FVI) of 12 subtropical tree species were investigated for screening the tree species depending upon fuel wood properties. In the present study, BD of different tree species was shown in (Table 5.5). The value ranged from 0.32 to 0.80 g/cm^3. Higher BD was found in species *P. juliflora* (0.80 g/cm^3) and lower value was found in species *S. asper* (0.32 g/cm^3). The BD of wood sample represents its compactness of wood as being genetic trait. It varies from species to species depend upon anatomical structure and chemical composition (Singh at al., 2014). Species with higher wood density are preferred as fuel wood, the reason behind this is higher energy content per unit volume and slow burning properties (Kumar et al., 2013). The MC in variety of species ranged from 38.70 to 58.67 %. Higher value was found in species *T. arjuna* (58.67 %) and lower value in *P. juliflora* (38.70 %). Generally, wood species with higher MC decrease its calorific value and species which are denser with less MC are preferred for fuel wood because per unit volume of energy content is higher and rate of burning is slow (Kataki and Konwer, 2002). Many studies reported that tropical tree species exhibited comparatively higher MC than temperate species (Bhatt *et al*., 2007). Species with higher BD contain higher carbon per unit area. Species *P. juliflora, T. grandis, A. scholaris* and *F. benghalensis* showed higher BD with less MC in comparison to other selected species. So, these species should be given preference in future energy plantation for rural community in the selected study area.

5.3.9. Energy analysis

Biomass is one of the major source of energy and is expected to plays a major role in substitution for conventional energy sources. Among biomass fuel, fuel wood consumption is an important source of energy for rural households in India. The major reasons that are responsible for fuel wood being preferred by rural households is due to their ready availability from nearby forest, free commodities, low socioeconomic status and lack of alternative energy source. Analysis of fuel wood as energy source consists of energy stored in two forms as fixed carbon and volatile matter. An ideal solid biomass should be higher calorific value and lower ash content. Calorific value indicates the amount of energy obtained from complete combustion of biomass. In any biomass higher the value of ash content there will be lower value of calorific value.

a) Ash content and calorific value (CV)

Higher amount of ash content in fuel wood cause negative impact on combustion process and ash content is very important parameter for identifying both the fuel wood quality and environmental impact. Ash content in the present study varied in different species as shown in (Table.5.5). The value ranged from 0.82 to 2.81 %, maximum value was found in species *P. dulice* (2.81%) and minimum value was found in *S. asper* (0.82%). The higher value of ash content in fuel makes it less desirable fuel, because maximum part of fuel volume could not be converted into energy (Kumar et al., 2009). The properties of fuel wood depend on quantity and qualitative properties, which includes CV, MC, BD, ash content and chemical composition. Although, many studies emphasized that dry wood shows higher CV than non-dried wood, further CV of different tree species depend on moisture content, higher the moisture content lesser will be the efficiency of fuel wood (Senelwa and Sims, 1999). The CV in the present study showed variations in different species. The value ranged from 17.32 to 22.56 MJ/kg and species like *P. juliflura* (22.56 MJ/kg) showed higher CV and *S. asper* (17.32MJ/kg) showed lower value of CV. However, in the present investigation there is no statistical difference between average CV values of studied tree species. Properties or qualities of fuel wood are known better through the estimation of CV which depends on chemical composition in different tree species (Sofer and Zaborsky, 1981). It has been reported that fuel wood species which have higher amount of lignin and extractives have higher CV and fuel wood which have predominance of cellulose and hemicelluloses as a sugar units leads to lower CV (Kumar et al., 1992). Moreover, CV of fuel depends effectively on moisture content. Higher amount of moisture content has lower efficiency in fuel wood due to reduced net calorific value of heating (Ojelel *et al*., 2015). In general, an ideal fuel wood contains high heating value or calorific value with lower ash content is more desirable.

b) Fuel wood value index (FVI)

The FVI depends on CV, BD and ash content of fuel wood. On the basis of these three parameters of fuel wood, FVI of 12 tree species were reported in (Table.5.5). The value ranges from 3.74 to 18.80. The maximum value was reported in species *P. julifulora* (18.80), *T. grandis* (14.32), *F. benghalensis* (9.85), and minimum value was found in species *A. salvifolium* (3.74), *E. jambolana* (3.66), *M. indica* (3.41). Some species shows medium or intermediate value which are considered as good quality fuel and should be concentrated in future energy plantation. For screening fuel wood efficient species, FVI is an important and insightful parameter (Deka *et al*., 2007).

Table 5.5. Calorific Value (CV), Moisture Content (MC), Bulk Density (BD), Ash Content (AC), Fuel wood Value Index (FVI) and ranking of tree species on the bases of FVI.

Species name	CV MJ /kg	MC %	BD g/cm^3	AC %	FVI	Ranking on the bases of (FVI)
Prosopis juliflora	22.56^a ± 1.27	38.70^a ± 0.83	0.80^c ± 0.71	0.96^{ab} ± 0.67	18.80	1
Tectona grandis	19.92^a ± 0.56	40.12^{ab} ± 0.72	0.64^{abc} ± 0.42	0.89^a ± 0.43	14.32	2
Ficus benghalensis	18.26^a ± 1.14	51.48^{abc} ± 0.94	0.68^{bc} ± 0.65	1.26^{ab} ± 0.15	9.85	3
Alstonia scholaris	19.33^a ± 0.63	41.85^{ab} ± 0.86	0.56^{abc} ± 0.61	1.17^{ab} ± 0.34	9.25	4
Holoptelea integrifolia	19.35^a ± 0.62	53.02^{bcd} ± 0.63	0.50^{abc} ± 0.53	1.10^{ab} ± 0.16	8.79	5
Streblus asper	17.32^a ± 0.53	57.01^d ± 1.41	0.32^a ± 0.92	0.82^a ± 0.76	6.75	6
Eucalyptus sp	20.09^a ± 1.17	58.67^d ± 1.81	0.58^{abc} ± 0.81	2.00^{ab} ± 0.27	5.82	7
Terminalia arjuna	21.63^a ± 0.83	58.51^d ± 1.11	0.57^{abc} ± 0.61	2.41^{ab} ± 0.32	5.11	8
Alangium salvifolium	18.89^a ± 1.13	53.57^{cd} ± 0.93	0.40^{ab} ± 0.31	2.02^{ab} ± 0.27	3.74	9
Eugenia jamboalana	18.12^a ± 0.31	56.79^d ± 1.36	0.37^{ab} ± 0.44	1.83^{ab} ± 0.37	3.66	10
Mangifera indica	18.35^a ± 0.43	57.99^d ± 1.12	0.45^{abc} ± 0.53	2.42^{ab} ± 0.51	3.41	11
Pithecellobium dulce	20.67^a ± 0.91	51.52^{abc} ± 1.71	0.43^{ab} ± 0.57	2.81^b ± 0.23	3.16	12

Note: # Estimation of all the average value in triplicate form: ± means SD: Standard deviation. One way ANOVA was performed to compare the mean using Tukey test ($P<0.05$). Different letters shows significant differences among different fuel wood parameters of the selected tree species.

Three factor combination CV and BD as positive character and ash content as negative character are more appropriate for determining the efficiency of wood as fuel (Saravanan *et al*., 2013). Higher value ash content causes lower value of FVI and thus has lower energy potential. Therefore, species with higher value of FVI were therefore considered as good for fuel (Ramos *et al*., 2008). On the basis of FVI, it has been conclude that species *P. juliflora, T. grandis, F. benghalensis* and *A. scholaris* possess better quality fuel wood and considered for future energy plantation in the selected study area. Further, it is important to determine the growth rate and productivity of these species under different ecological conditions, their optimum planting density and the rotation period before including them in the energy plantation program.

Ultimate analysis is very important to determine the theoretical ratio of air and fuel in thermo chemical conversion. Ultimate analyzes C, H, S and N is determined by chemical analysis and is expressed in a moisture free base. In the present investigation, results of chemical composition were presented in (Table.5.6). The value of ultimate carbon, hydrogen, nitrogen and sulfur were ranged from 40.80 to 46.06 % C, 4.72 to 6.73 % H, 0.02 to 1.39 % N and 0.012 to 0.001 % S respectively. Higher amount of elemental composition was found in species *P. juliflora* (46.80 %) C and minimum value was found in species *S. asper* (40.80 %) C. Hydrogen was found maximum in species *F. benghalensis* (6.73 %) H and minimum value was found in species *T. arjuna* (4.72%) H. Ultimate nitrogen value was found maximum in species *S. asper* (1.39 %) N and minimum value was found in species *E.* sp (0.02%) N. The minimum percent of sulfur and nitrogen in fuel wood is important from environmental point of view. Oxygen content was obtained from subtracting the value obtained from sum of C, H, N and S value from 100 %. In any fuel, carbon hydrogen and carbon oxygen bond contain lesser energy then carbon–carbon bond, maximum proportion of hydrogen and oxygen in any biomass reduce the value of energy in any fuel (Kumar *et al*., 2011).

Table 5.6. Elemental composition (Ultimate analysis), Ash content, VMC, FCC (Proximate analysis) of different tree species.

Scientific name	Ultimate analysis (%)					Proximate analysis (%)		
	C	H	N	S	O$^{\#}$	Ash	VMC	FCC$^{\#}$
A. salvifolium	43.2^{ab} ±0.61	6.35^{a} ±0.32	0.135^{a} ±0.24	0.001	51.70^{bc} ±0.67	2.02^{ab} ±0.27	78.12^{ab} ±0.14	19.98^{bc} ±0.71
A. scholaris	44.40^{bc} ±0.21	5.67^{a} ±0.43	1.34^{f} ±0.54	*	52.58^{bc} ±1.2	1.17^{ab} ±0.34	80.24^{ab} ±0.21	18.83^{bc} ±0.12
E. jambolana	43.87^{ab} ±0.21	6.24^{a} ±0.54	0.59^{cd} ±0.43	*	42.53^{a} ±0.68	1.83^{ab} ±0.37	81.07^{ab} ±0.42	17.17^{bc} ±0.21
E. sp	44.50^{ab} ±0.54	5.96^{a} ±0.54	0.02^{ab} ±0.29	*	52.48^{bc} ±0.91	2.00^{ab} ±0.27	76 $.89^{a}$ ±0.31	22.00^{d} ±0.76
F. benghalensis	45.60^{bc} ±0.64	6.73^{a} ±0.64	0.31^{ab} ±0.41	0.012	53.91^{bc} ±0.87	1.26^{ab} ±0.15	77.21^{ab} ±0.41	21.74^{d} ±0.23
H. integroifolia	45.60^{c} ±0.78	5.25^{a} ±0.37	0.123^{a} ±0.76	0.001	52.07^{bc} ±0.47	1.10^{ab} ±0.16	82.43^{cd} ±0.21	16.09^{ab} ±0.21
M. indica	42.24^{ab} ±0.43	6.12^{a} ±0.86	1.07^{g} ±0.67	*	51.85^{bc} ±0.89	2.42^{ab} ±0.51	83 $.56^{cd}$ ±0.32	14.58^{ab} ±0.23
P. juliflora	46.06^{c} ±0.44	5.69^{a} ±0.61	0.46^{bc} ±0.34	*	53.71^{bc} ±0.76	0.96^{ab} ±0.67	77.01^{a} ±0.61	22.04^{d} ±0.65
P. dulce	45.21^{bc} ±0.79	6.61^{a} ±0.29	1.135^{f} ±0.63	0.010	55.76^{c} ±0.71	2.81^{b} ±0.23	85.64^{d} ±0.31	12.19^{a} ±0.13
S. asper	40.80^{a} ±0.53	5.91^{a} ±0.64	1.399^{f} ±0.43	*	48.92^{b} ±0.83	0.82^{a} ±0.76	79.42^{ab} ±0.43	20.18^{cd} ±0.32
T. arjuna	45.30^{bc} ±0.34	4.72^{a} ±0.32	1.02^{f} ±0.67	0.012	53.45^{bc} ±0.85	2.41^{ab} ±0.32	83.91^{cd} ±0.41	14.59^{ab} ±0.41
T. grandis	45.60_{a} ±0.32	5.95_{a} ±0.78	0.86_{ef} ±0.76	0.012	53.30_{bc} ±0.96	0.89_{a} ±0.43	81.14_{bc} ±0.63	18.11_{bc} ±0.42

Note: C Carbon; H Hydrogen; N Nitrogen; S Sulfur; O Oxygen; VMC Volatile matter content; FCC Fixed carbon content; # calculated by difference method, * No value was found. One way ANOVA was performed to compare the mean using Tukey test ($P<0.05$).

Fuel wood containing higher proportion of carbon, is more desirable and lower percentage of sulfur and nitrogen is important as environmental point of view. Results of this study suggests that constituent properties of tree species should be the bases for institute conservation and cultivation of higher energy value fuel wood species to meet the present and future demand of the rural households. Different letters shows significant differences among different fuel wood parameters of the selected tree species. Rating of 12 tree species on the basis on fuel wood properties of sub-tropical tree species of north India are presented in (Table 5.7). Rating of species in term of energy output and composition of elements, the species were assigned the value 1 – 12, value 1 is for best and value 12 is for worst. Based on final rating the preferred species for fuel wood should be *P. juliflora* > *T. grandis* > *F. benghalensis* > *H. integrifolia* > *A. scholaris* > *P. dulce* > *A. salvifolium* > *S. asper* > *E. spp* > *M. indica* > *T. arjuna* > *E. jambolana.* The species *P. juliflora* with its higher calorific value and bulk density with lower moisture content was ranked the best one. And the worst rank species *E. jambolana* has the lower value of calorific value and lower bulk density with lesser moisture content. However, this study predicted that not only a single parameter is enough to choose or identifying the suitable tree species for fuel wood.

Table 5.7. Ranking of tree species on the basis of fuel wood properties and elemental composition.

Properties→ Species↓	CV	MC	BD	Ash	C	H	N	O	VMC	FCC	Over all Rank*
P. juliflora	1	1	1	3	1	9	7	6	10	1	3.34 (01)
T. grandis	5	2	3	2	4	7	6	7	8	7	4.25 (02)
F. benghalensis	10	4	2	6	2	1	9	10	11	3	4.84 (03)
H. integroifolia	6	6	7	4	3	11	11	1	4	9	5.17 (04)
A. scholaris	7	3	6	5	8	10	2	9	7	6	5.25 (05)
P. dulce	3	5	9	12	6	2	3	11	1	12	5.34 (06)
A. salvifolium	8	7	10	9	10	3	10	2	6	5	5.84 (07)
S. asper	12	9	12	1	12	8	1	3	9	4	5.92 (08)
E. sp.	4	12	4	8	7	6	12	5	12	2	6.00 (09)
M. indica	9	10	8	11	11	5	4	4	2	11	6.25 (10)
T. arjuna	2	11	5	10	5	12	5	12	3	10	6.25 (11)
E. jambolana	11	8	11	7	9	4	8	8	5	8	6.59 (12)

For quality criterion of each species the value ranges from 1- 12 and the value 1 is (best) and 12 is (worst). *(Values in brackets represents over all ranks, 1 represents best and 12 represent worst) *d) Fuel wood parametric correlation studies*

(Table. 5.8) shows Pearson Correlation coefficient between different fuel wood parameters like carbon (C), Nitrogen (N), Hydrogen (H), Oxygen (O), Moisture content (MC), Bulk density (BD), Calorific value (CV), Ash content, Volatile matter content (VMC), Fixed carbon content (FCC). The CV shows significantly positive correlation with BD and C ($P<0.05$). MC shows negative correlation with BD ($P<0.05$). BD shows significantly positive correlation with C ($P<0.01$). AC shows negative correlation with FCC ($P<0.01$) and VMC shows negative correlation with FCC ($P<0.01$) in the present study.

Table 5.8. Pearson Correlation Coefficient between Moisture content (MC), Bulk density (BD), Calorific value (CV), proximate and ultimate analysis of selected tree species.

	CV	MC	BD	AC	C	H	N	O	VMC	FCC
CV	1									
MC	-.419	1								
BD	.652*	-.638*	1							
AC	.160	.561	-.338	1						
C	.697*	-.508	.754**	-.062	1					
H	-.445	-.007	-.185	.139	-.180	1				
N	-.107	-.092	-.289	.052	-.391	-.114	1			
O	.554	-.359	.544	.118	.474	-.061	.005	1		
VMC	-.067	.543	-.119	.535	.119	-.140	.086	.146	1	
FCC	-.086	-.270	.416	-.625*	-.012	.163	-.446	-.075	-.581*	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Combustion of biomass releases fewer amounts of greenhouse gases in comparison to another conventional energy source. However, burning of fuel wood is common in rural communities, and emission of smoke due to combustion can be responsible for about 25% of particulate matter, volatile organic compound 15% and carbon monoxide contribute 13% into the atmosphere (Naeher *et al*., 2007; Singh *et al*., 2014). Fuel wood consumption has a complex interrelationship with forest degradation (Rudal, 2005). Deforestation makes life difficult to rural people as they depend on forest for their basic energy requirement and also significantly contribute in climate change. Therefore, screening of suitable tree species on the basis of fuel wood characteristics is essential to identify the tree species on the basis of reduced emission and superior for fuel wood. Production of biomass energy and comparing with other options transformation of woody biomass into bioenergy production purposes cause number of beneficial impact as energy security, creation of job, and other positive implication at regional scale (Gruenewald *et al*., 2007). However, it is important to assert that rural people are less concerning about requirement of fuel wood, therefore, acceptable feature socially is also important to be considered and to generate checklist to generate fuel wood species in the selected region (Ojelel *et al*., 2015). Comparison of different tree species on the bases of chemical composition and other parameters shows that some species as *P. juliflora, T. grandis, F. benghalensis* and *H. integreifolia* are better choice in term of energy outputs and future energy plantation in this region. However, further studies are needed to determine the growth rate of these species under different ecological conditions and productivity before energy plantation in this region.

5.4. Conclusion

The study reveals that fuel wood was largely utilised as non-commercial and cheap source of energy, followed by dung cake and agriculture residue. However, consumption rates are an important variable in defining the potential contribution of a fuel wood source and in assessing the risk of forest over-exploitation. Higher fuel wood consumption in the study area was mainly due to lack of alternative energy sources and poverty. Extensive farming for fuel wood could be one alternative to bridge the gap between supply and demand; consequently, efforts are needed to encourage afforestation of suitable fuel wood species in the barren areas around the study site, which will help immensely in reducing the degradation of surrounding forests. Due to poor socio-economic situations in the village, a significant amount of fixed carbon of plantation forest was used for cooking of food which could be saved by providing them renewable source of energy for cooking or cooking gas cylinders. Information collected in the present study will be helpful in alignment of available resources with future challenges of biomass energy demand and their utilisation in sustainable way and development in rural areas. The present results emphasize that only the single basic parameter is not enough for identifying the suitable tree species as a fuel wood. On the basis of overall ranking of different tree species in the present investigation, using FVI and other fuel wood properties, were taken into account, it is recommended that species *P. juliflora, T. grandis, F. benghalensis, , A. scholaris* and *H. integrifolia* are found as energy efficient fuel wood and attention should be given on such tree species for large scale energy plantation in future, especially in this region of Uttar Pradesh, India to fulfil the future demand of rural communities, in view of sustainable and green growth. Further, a traditional mud chulha commonly used for cooking that is thermally inefficient and a greater consumption of firewood with large emission rate of air pollutants. Therefore, an effort should be made to reduce fuelwood consumption in such areas, although the use of fuelwood is not necessarily the main cause of deforestation. This can be achieved by replacing the traditional cooking method with alternative energy-efficient cooking techniques. Hence, to assess the potential of improved cook stove technology in comparison to traditional ones also designed in this research study with particular parameters in chapter 7. In addition, the study elaborates the GHG emission rate and deforestation due to the burning of firewood by the rural households. The rate of CO_2 emission is directly proportional to consumption of fuel wood. However, efficient way of fuel wood combustion may reduce the rate of CO_2 emission and strongly recommended that mass scale afforestation program of suitable tree species for future energy plantation in the study region bridge the gap between demand and supply.

Chapter 6

Development of an energy efficient metal chulha for solid biomass fuel and evaluation of its performance

Chapter 6. Development of an energy efficient metal chulha for solid biomass fuel and evaluation of its performance

6.1. Introduction

Biomass is one of the largest and important source of fuel in domestic cooking of rural area of developing countries and used frequently for heating purposes in the extreme cold. The traditional biomass resources e.g. Cow dung cake, dried agro waste and dried wood pieces still meet a major proportion of the rural energy demand. In India majority of the households living in a rural area depends on fuel wood, dung cake and crops residue to meet their domestic energy needs and these solid fuels accounts more than 80% of total fuel used for cooking purposes (Census of India, 2011). Among these solid fuels, fuel wood is mostly used for cooking purpose in comparison to another form of solid biomass (Jana and Bhattacharya, 2011). Due to high cost and low accessibility of commercial fuels such as kerosene and LPG, people of the rural people use such easily available traditional fuel (Balakrishnan *et al*., 2004). Cooking and heating using dried biomass release hazardous pollutants in the indoor environment (Herbert and Krishnan, 2016).

Exposure to indoor air pollution causes serious health risks, especially to women, who cook food and children who spend much time around the cooking chulha with their mother (Singh *et al*., 2014). Inefficient way of burning of solid biomass fuel releases large amount of air pollutants like CO, $PM_{2.5}$, PM_{10}, SO_X, and NO_X (Arora *et al*., 2013; Suresh *et al*., 2016). Among these carbon monoxide (CO) has a major share of the pollutant due to incomplete combustion in indoor and semi indoor kitchens, which is associated with several respiratory, cardiovascular, dermatological and retinal diseases (Ezzati *et al*., 2010). Fine suspended particulate matter ($PM_{2.5}$) that can travel deep into the respiratory system results in serious health problems.

Exposure of $PM_{2.5}$ alone accounted about three million deaths annually and exposure due to the burning of solid biomass in indoor environment due to inefficient cook stove causes about 1.6 million cases of death per annum (WHO, 2014). It has been estimated that more than four million people residing mostly in rural areas die annually from exposure to indoor air pollution and a quarter of these deaths occur alone in South Asia (WHO, 2014; WHO, 2016). Therefore, switching to cleaner fuel is one of the promising strategies for improving indoor air quality (Grieshop *et al*., 2011). The inefficient biomass combustion for cooking also contributes to the level of global CO_2 emission significantly (Chafe *et al.*, 2014).

Burning of biomass in the traditional cook stoves is one of the widely used biomass based appliance from incenting time till date. Traditional one pot or two pot mud chulha have low thermal efficiency and huge emission of smoke as compared to the improved cook stoves (Panwar and Rathore, 2008). The government of India has initiated several programs focusing on improved cook stove, biogas plant, kerosene and energy supply, aimed to reduce the dependence on biomass fuel and reduction in emission of smoke since the early eighties. Although the evaluation of success is not analyzed properly. Recently, different initiatives have been carried out at the grass roots levels and a wide infrastructure has been created to implement projects to overcome the problems related to indoor air pollution. National Program of Improved Cook stove (NPIC 1985-2000) aims to achieve conservation of fuel wood and reduction of emissions in the indoor kitchen by the use of chimney system, but the success has remained elusive (Khandelwal *et al*., 2017).

Currently, more than 160 improved cook stove programs are operating worldwide (Ruiz-Mercado *et al*., 2011). Some of the prominent energy efficient biomass cook stoves such as Natural and forced draft cook stove, plancha cook stove, rocket mud stove, patsari improved cook stove and other improved cook stoves have been developed to alleviate the problems associated with indoor pollution and thermal performance (Venkataraman *et al*., 2010; Caroline *et al.,* 2013; Suresh *et al*., 2016). However, these improved chulhas have certain limitation in their thermal performance, risk to fire spark, ash collection system for proper disposal. In some chulhas we cannot cook two or more items at the same time and also not much significant reduction of emissions have been reported (Arora *et al*., 2013). There is still improvement need in the energy efficiency of these chulhas to reach the LPG like emission levels. The traditional mud chulha using in the study area were not only thermally inefficient, but also produce an enormous amount of smoke resulting into elevated concentration of ambient air pollutants like PM_{10}, $PM_{2.5}$, SO_X,NO_X and CO *etc.*, which ultimately cause respiratory and other health problem among the woman and children of the household. It is therefore, necessary to reduce the indoor emission concentration by switching from traditional mud chulha (TMC) to improved mud chulha (IMC). Keeping this in consideration and feedback surveys of the selected study areas it was found that the developed IMC over TMC with similar design will be more acceptable to the rural people. Therefore, the objectives of the present study were planned as a) To develop an improved metal chulha over commonly available traditional mud chulha for rural households; b) To quantify the reduction in fuel wood use attributable to IMC at household's level compared to TMC and c) Characterization of PM_{10}, $PM_{2.5}$ in term of particle size distribution and sought to determine the acceptability of the improved metal chulha to local users as well as their effectiveness in reducing indoor concentrations and efficiency. This contribution will help to raise awareness about the need for improvement in design and provide evidence data for policy implication and to switch on improved and better designed cook stoves and better designed for health care of the rural people, their economic concerns and climate benefits.

6.2. Material and methods

To Carrey out the above said objectives for this section, testing site, fuel used, methodologies for measurement of different parameter during the experiment and thermal performance of an IMC over TMC already discussed in detail in chapter 3.

6.3. Description of Developed Improved metal Chulha (IMC)

(Figure. 6.2 a and b) are typical photographs of TMC and IMC respectively. Based on the survey results of the study area, majority of the households use TMC like U shaped with an opening in the front to feed the fuel (Figure. 6.2 b). These types of chulha were not only thermally inefficient, but also produce an enormous amount of smoke resulting into elevated concentration of ambient air pollutants, which ultimately cause respiratory and other health problem among the woman and children of the household. It is therefore, necessary to reduce the indoor emission concentration by switching from TMC to IMC. Two pot rectangular metal chulha were developed and tested in present study (Figure. 6.1). The IMC was developed with a metal foil consisting of the inlet to load solid fuel and air, the combustion chamber, two holes of the pot and an outlet connected to the chimney system. The mean size of IMC is (length × width × height: 65 cm × 35 cm × 40 cm). For cooking, diameter of the pot hole is different in size; 1st pothole (25cm) and 2nd pothole (20cm) to adjust the small and medium size container.

The distance between two potholes is 10 cm. inside the Chulha, a plane inclined between two holes was developed and this structure was intended to direct the heat flame from the combustion chamber of the 1st pothole to 2nd pot hole. The grate was developed in the floor of the combustion chamber to filter the ash to the bottom of the ashtray to facilitate removal of ash that is collected in the tray for the safe disposal after combustion. Alternatively, grate has been used for charcoal as fuels in the absence of solid biomass fuel. Just below the 2nd pot hole, there is another drawer developed for the preparation of cakes and bread during the cooking process. Chimney connected in to IMC to facilitate the elimination of smoke from the interior environment.

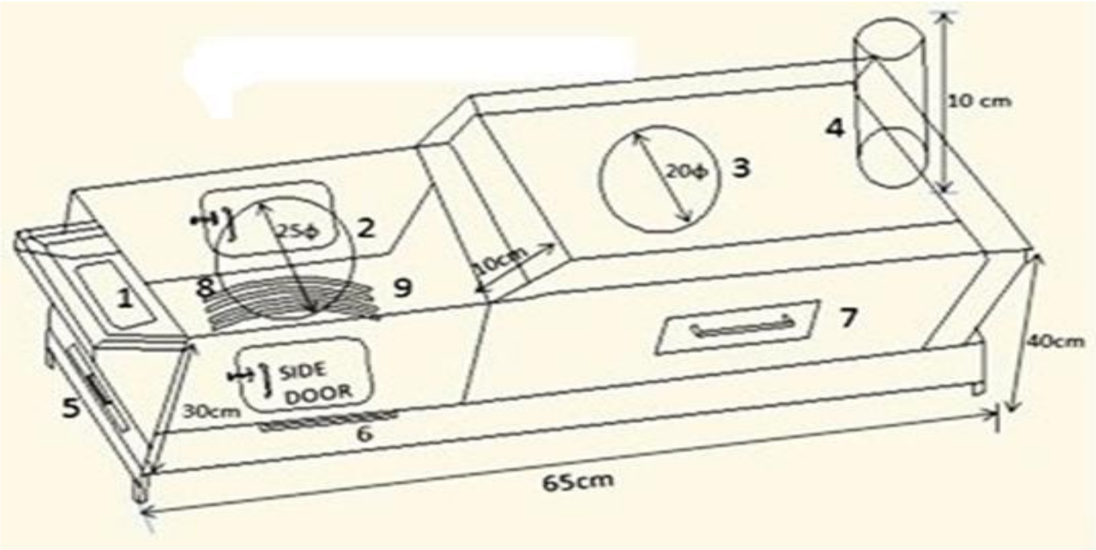

Figure 6.1. Improved metal chulha design features 1) Air/fuel inlet 2) 1st pothole 3) 2nd pothole 4) Chimney 5) Ash tray 6) Grate plate 7) Side drawer 8) Grate 9) Combustion chamber.

Figure 6.2. (a) Improved metal chulha (IMC), and (b) Traditional mud chulha (TMC) used in rural India.

The Chulha have a safety lead to minimize the risk of fire spark during cooking. The combustion chamber were designed in such a way that the minimum distance between flam and pot during the cooking processes to minimize energy wastage. The average cost for manufacturing the IMC was Rs1500 to 1800. Therefore, the initial cost would seem to be a major barrier to adoption, particularly for the poor. However, IMC requires a smaller amount of fuelwood compared to TMC and produces a relatively smaller amount of ash and smoke during the cooking process. Therefore, the costs and benefits of these IMC are most affected by relative fuel costs, efficiency, the incidence and acute respiratory disease and the cost of cooking time.

6.4. Result and discussion

6.4.1. Survey results

The energy consumption patterns its source and cook stove uses were assessed by conducting a questionnaire survey among the household members mostly women, who are responsible for daily cooking. Out of 490 households in the selected study area, 90 households were randomly selected for questioning. Results of the survey were shown in (Figure. 6.3). The pattern of energy consumption for cooking in the study area was dominated by the noncommercial source of energy. Households rely primarily on firewood, agricultural waste and cow dung cake for the daily need for energy such as cooking and heating during cold seasons. When studying the pattern of consumption of different biomass fuel, it has been reported that about 65% of households use fire wood as primary source of energy followed by cow dung 22%, Agriculture residue 12% and 1.3% Kerosene. In rural India, the main source of energy for low-income households comes from biomass fuel and about 78% comes from fuelwood and about 8% from agricultural waste as next major source of energy (Ramji *et al* 2012). Women of the households mostly spend much time in collections of fuel wood for the daily energy needs from nearby plantation forest selected for cooking. The amount of biomass fuel consumed for cooking depends on the number of factors such as type of food, number of meals per day and uses of the stove type. In addition to this, we gathered information from the respondent related to the uses of Chulha type and reported that 75% households uses TMC for cooking purposes and asked about the efficiency and health impact associated with the burning of solid biomass fuel in TMC. Approximately 90% of respondents realized that IMC would help reduce fuelwood consumption and reduce indoor smoke exposure, which was associated with reduced respiratory problems, eye irritation, and other problems of health. All data collected from the respondent were collated with a family member and physical experimentation.

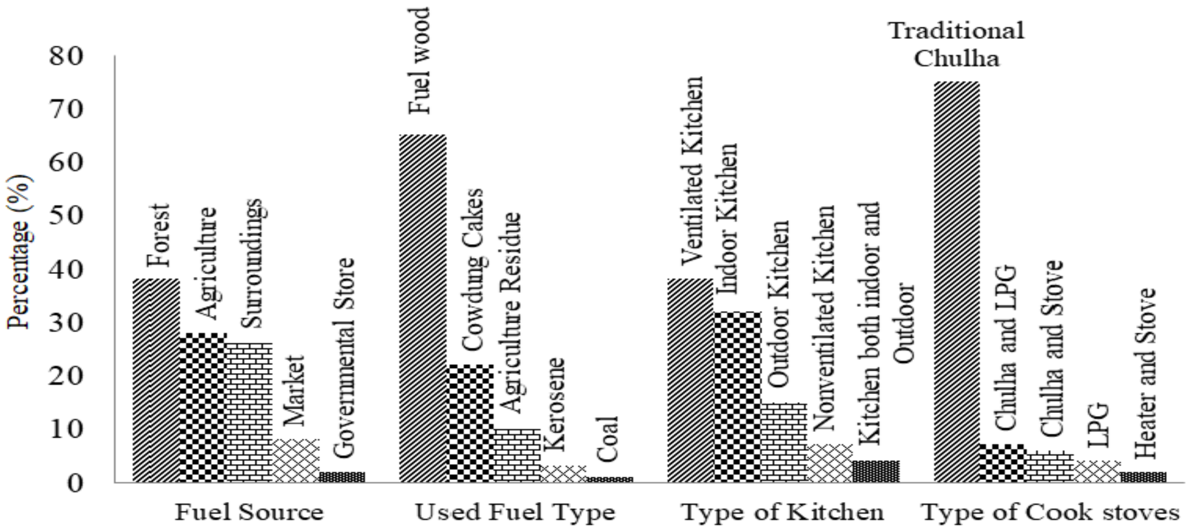

Figure.6.3. Composition of energy consumption categorised into used fuel source, fuel type, type of kitchen and cook stove.

6.4.2. Variation of different parameters Traditional Vs Improved metal chulha

6.4.2.1. Variation in PM_{10}, $PM_{2.5}$, CO, SO_X and NO_X

Exposure to indoor air pollution depends primarily on the concentration of pollutants in the indoor air and the time that individuals are exposed to the pollutants.

However, both short and long-term exposure can have a significant impact on an individual's health. The variation in the indoor air concentration of different parameters in the present investigation was shown in (Figure. 6.4). A significant reduction in the concentration of PM_{10}, $PM_{2.5}$, CO, SO_X and NO_X in the kitchen environment was observed due to the installation of IMC over TMC. The value was PM_{10} = 204.47 µgm/m^3, $PM_{2.5}$ = 73.61 µgm/m^3, CO = 13.23 µgm/m^3, SO_X = 21.99 µgm/m^3 and NO_X = 87.35 µgm/m^3 for IMC and PM_{10} = 371.14 µgm/m^3, $PM_{2.5}$ = 273.64 µgm/m^3, CO = 13.23 µgm/m^3, SO_X = 19.09 µgm/m^3 and NO_X = 89.76 µgm/m^3 for TMC. One control test was performed without any cooking activities (Fig 6.4). After the introduction of IMC there was a significant reduction in the concentration of indoor air pollutant as PM_{10} 44.90%, $PM_{2.5}$ 73.09%, CO 50.86%, SO_X 21.99% and NO_X 35.76%.The most significant difference was observed for $PM_{2.5}$ (lower by 73%). Therefore, IMC is considered to be significant pollution free compared to TMC. Newly designed MIC has properties for the complete combustion and rapid movement of gases and particulates in suspension from the combustion chamber to the chimney for the discharge of smoke at higher altitudes. The reduction of the concentration of pollutants in the indoor environment may be due to good compaction without leakage of smoke and proper handling of the ash collection system for proper disposal. Based on a comparative study, it has been reported that there was a significant reduction in indoor concentration due to the installation of an improved cook stove over traditional chulha (Singh *et al*., 2014). A significant reduction in the indoor concentration of $PM_{2.5}$ and CO was reported by using improved chulha over the use of traditional chulha for rural households in northern India (Pennise *et al*., 2009; Sota *et al*., 2014). Reduction of the concentration of indoor emissions through the installation of improved chulha, varied on the basis of technical specifications and the use of material for insulation to reduce heat loss (Raman *et al*., 2013). Other studies reported that installation of improved cook stove is considered to perform much better than the traditional stove in terms of both thermal efficiency and reduction of pollution emissions (Arora *et al*., 2013). Therefore, strategies to improve indoor air quality generally focus on improved burning of fuelwood by using an efficient cook stove that can help to reduce indoor pollution.

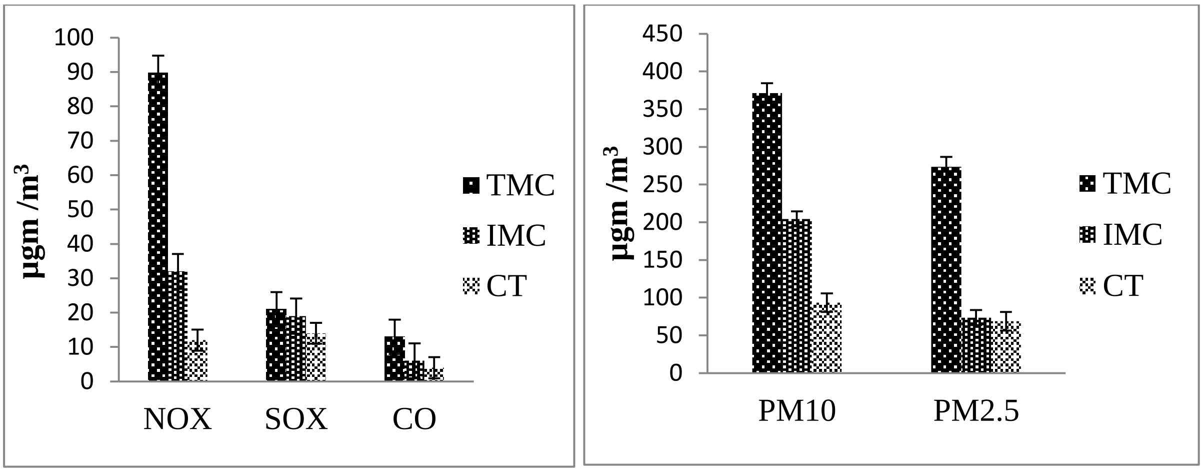

Figure 6.4. Indoor air pollution concentration measurement of Improved Metal Chulha (IMC), Tradational Mud Chulha (TMC) and Control test (CT).

6.4.2.2. Estimation of trace metal

Concentration of trace metals in the indoor environment varies according to the condition and location of the building and the activities that occur inside and outside. (Pekey *et al*., 2013). In the present results, the concentration of heavy metals (Fe, Pb, Cu, Cd, Cr, Mn, Zn and As) present in PM_{10} and $PM_{2.5}$ emitted by two type, the IMC and TMC were analyzed (Table 1).The highest concentration of trace metal in PM_{10} was Fe > Pb > Zn > Cr> Mn >Cu > Cd >As in IMC and Fe > Pb > Zn > Cr > Mn > Cu > Cd > As in TMC. In $PM_{2.5}$ highest concentration was reported as Fe > Zn > Pb > Cr >Mn > Cu > Cd > As in both IMC and TMC. The higher concentrations of iron (Fe) associated with PM10 and PM2.5 in the indoor environment was expected due to the abundance of iron as one of the main components of the earth's crust (Wang *et al*, 2006).

However, In comparison to the control test, the concentration increased in both types of chulha during the cooking processes. Installation IMC showed a significant reduction in the concentration of trace metals associated with coarser particles. A reduction of 32% Fe, 18% Pb, 23% Cu, 52% Cd, 39% Cr, 55% Mn 41% Zn and 52% As was observed in coarser fraction (PM_{10}), whereas, a reduction of 22% Fe, 14% Pb, 18% Cu, 15% Cd, 21% Cr, 5.6% Mn, 30% Zn and 45% As was observed in finer fraction of particles ($PM_{2.5}$). One control test was performed without any cooking activity was also depicted in (Table 6.1). In the present investigation, it has been found that the concentration of trace metals was found to be higher due to the burning of wood in TMC. Therefore, the present study suggested that the development of energy-efficient chulha that help in reducing the trace metal exposure that is associated with the number of health risks. Hence, health risks related to the metal composition in the indoor environment need to be evaluated further deeply in a future study.

6.4.2.3. SEM-EDS

The studied morphological features of the selected samples PM10 and PM2.5 allowed us to identify the shapes of particulate matter emitted into the indoor air. It is determined that the particulate matter have a rounded, irregular, cubic and composite shape. In order to differentiate the physicochemical characteristics of particulate matter emitted from IMC and TMC, scanning electron microscope (SEM) micrograph of both fraction of particulate matter has been investigated in this study. (Figure 6.5 a to d) shows representative images for IMC and TMC at 5000X magnification.

Table 6.1. Showing value (mean ± SD) of Metal concentration in PM_{10} and $PM_{2.5}$ measured at indoor environment during the cooking process with TMC, IMC, and CT.

	PM_{10}				$PM_{2.5}$			
µg/m^{-3}	IMC	TMC	(%) Reduction	CT	IMC	TMC	(%) Reduction	CT
Fe	1.15 ±1.23	1.69 ±1.41	32.1 ±1.2	0.50 ±1.23	0.76 ±1.32	0.986 ±1.52	22.4 ±1.32	0.406±1.21
Pb	0.57 ±1.72	0.70 ±1.23	18.6 ±1.3	0.24 ±1.21	0.35 ±1.87	0.415 ±1.43	13.9 ±1.76	0.306 ±1.43
Cu	0.10 ±1.31	0.14 ±0.76	22.6 ±2.1	0.08 ±1.62	0.07 ±0.97	0.08 ±1.87	18.1 ±2.12	0.056 ±1.47
Cd	0.02 ±2.01	0.04±0.87	52.0 ±1.6	0.01 ±1.36	0.02 ±0.87	0.03 ±1.32	15.6 ±1.92	0.011 ±1.34
Cr	0.20 ±1.32	0.33 ±0.75	38.8 ±1.1	0.10 ±1.43	0.13 ±1.23	0.16 ±2.11	21.0 ±1.43	0.129 ±0.96
Mn	0.18 ±1.65	0.40 ±1.32	55.0 ±1.2	0.17 ±1.76	0.10 ±1.32	0.10 ±1.98	05.6 ±0.98	0.046 ±0.65
Zn	0.36 ±0.95	0.62 ±1.34	41.2 ±1.7	0.13 ±1.42	0.45 ±1.53	0.64 ±1.54	29.5 ±0.67	0.40 ±0.67
As	0.01 ±0.64	0.03 ±0.64	52.2 ±0.6	0.01 ±0.14	0.015 ±0.64	0.028 ±0.64	44.9 ±0.46	0.009 ±0.64

Using secondary electron imaging, individual particle were classified into two categories viz. soot and aluminosilicates. Soot particles were found to be dominant in a coarser fraction of particulate matter followed by aluminosilicates were emitted from TMC shown in (Figure 6.5b), whereas, aluminosilicates followed by soot particles were to be dominant in a coarser fraction of particulate matter emitted from IMC. Soot exhibit chain like non fractal agglomerate of the carbonaceous particle, whereas, aluminosilicates exhibit no spherical having sharp edges like structure (Murari *et al*., 2016; Buseck *et al*., 2012). The morphology of the soot particles varied from chains to simple clusters, with a size of 1-2 μm that depends on different types of fuels, combustion conditions and atmospheric processes (Yue *et al.,* 2006). These particles are primarily emitted from burning of biomass and incomplete solid fuel combustion are mainly composed of fine particles and has attracted special attention now a days, mainly due to their contribution to changing climate, reduced visibility, and adverse effects on human health (Pipal *et al.,* 2017). The fly ash particles contain mainly aluminosilicates characterized by silicon with varying amount of magnesium, potassium, calcium and iron (Feng *et al*., 2009). These particles originate from the combustion of firewood and the size ranges of the fly ash particles are between 50 and 1 μm, with an amorphous, spherical and irregular shape (Lu et al., 2011). Aluminosilicates that have a higher content of Al, Si and K and have originated from indoor activities during the cooking processes. These particles contain predominantly silicon such as silica or quartz that originates in soil and crust (Cong *et al*., 2010). The analysis of the composition in morphological and elementary particles provides valuable information for the determination of its physicochemical properties and diverse sources. This analysis is also essential for the evaluation of the health and ecological effects of indoor air particles.

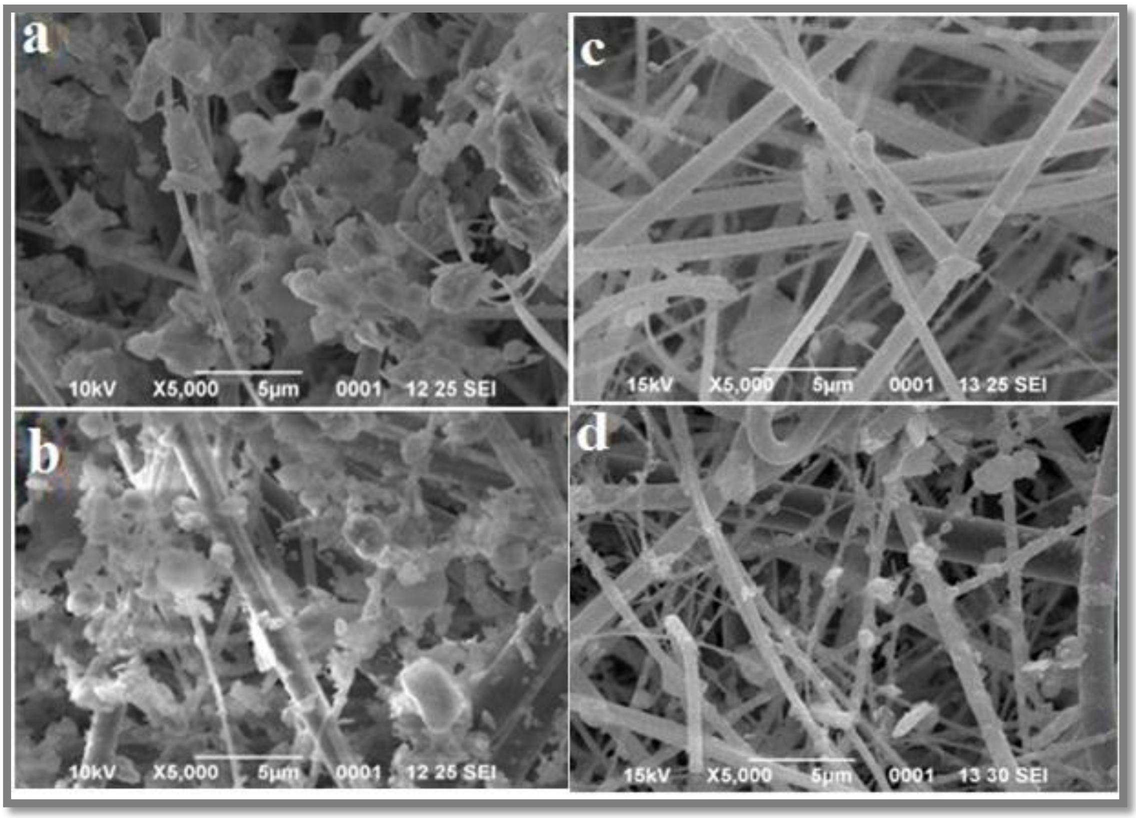

Figure 6.5. SEM micrograph of air borne particles; where, a) PM_{10} of traditional mud chulha, b) $PM_{2.5}$ of traditional mud chulha, c) PM_{10} of improved metal chulha, d) $PM_{2.5}$ of improved metal chulha.

6.4.2.4. Thermal efficiency using water boiling test (WBT)

Thermal performance of IMC over the available TMC were tested by using the three phase of WTB (cold start, hot start, and simmering test) and it was ranged from 37 - 46% for IMC and 26 - 45 for TMC. The average rate of fuelwood burn per minute, thermal efficiency and time are brought to boiling for both the cold start and hot start phases of the IMC and TMC showed that IMC showed highest thermal efficiency during all the three phases; cold start (37%), hot start (41%) and simmering (46%) at the rate of burning of fuel wood was 23, 16.6 and 14 g/min and in TMC the thermal efficiency was cold start (26%), hot start (38%) and during simmering phases (45%) at the rate of burning of fuel wood was 32.2, 25.1 and 20.6 g/min. In simmering test there was not much significant difference in the thermal efficiency of MIC over TMC (Table 6.2). However, in both types of chulha there is an increasing trend of higher thermal efficiency and lower consumption of wood during the three phases of WTB. (cold < hot < simmering). Five trail of WBT were carried out in the present investigation for both IMC and TMC and showed that the thermal performance of IMC was recorded higher than TMC. Lower efficiency of TMC may be attributed to higher consumption of fuel wood.

Table 6.2. A performance indicator of improve metal chulha (IMC) over traditional mud chulha (TMC) during different phases of water boiling test (mean ± standard error).

	IMC			TMC		
Parameters	Cold start	Hot start	Simmer test	Cold start	Hot start	Simmer test
Fuel wood consumption g /min	23.65 ±2.23	16.63 ±3.1	14.76 ±4.13	32.21 ±2.32	25.16 ±2.95	20.66 ±5.45
Thermal efficiency(η) %	37.32 ±1.02	41.24 ±2.32	46.42 ±3.64	26.42 ±3.01	38.43 ±3.43	45.52 ±3.35
Time to boil	14.67 ±1.24	12.54 ±3.79	30.15 ±4.42	20.56 ±3.81	15.67 ±4.54	30.91 ±3.64
Firepower (kW)	4.82 ±1.60	7.35 ±3.10	5.162 ±2.70	4.753 ±2.40	5.243 ±2.80	4.321 ±3.10

Other studies reported that the thermal efficiency of the improved cook stove showed 26.5 to 30.83%, which is much lower than the thermal efficiency of IMC in the current results (Panwar *et al*., 2011; Mehetre *et al*., 2016). Average time required to boil the specific amount of water in the improved cook stove showed lower as compared to the traditional chulha in both cold and hot start, which was similar value reported by another study (Jetter and Kariher, 2009; Bailis *et al*., 2007). The difference observed in the thermal efficiency of two types of chulha can also be attributed to the effective design of the combustion chamber and the air flow to the combustion chamber. The fair power indicates the ratio of wood energy consumed by cook stove per unit time. It tells the average power output of the cook stove (in watts) during the WBT.

6.5. Conclusions

The present work evaluates the thermal performance and pollution contributed by improved metal chulha over commonly available traditional mud chulha in the rural households of India. Installation of IMC enhances the thermal efficiency with the reduction of specific amount of fuelwood consumption in the present investigation. This further reduced the duration of time and the amount of fuel to prepare a particular amount of food. By encouraging the complete combustion of fuel wood in IMC reduce the concentration of indoor air emission, which reflects the lower concentration of pollutants into the indoor kitchen environment. Based on the results of the survey, almost all respondents realized that IMC would help to reduce fuelwood consumption and less exposure to smoke, especially women responsible for daily cooking in the indoor kitchen. Hence, the present study suggests that distribution of IMC among rural households in order to improve their health conditions due harmful emission during cooking processes. Further, knowledge should be imparting more about the use of IMC and its benefits for the reason that societies progress only if their people are healthy, and the government should launch programs on the basis of a different scheme for adaptation of energy efficient Chulha. Therefore, the national level program must be implemented by the government and the nongovernment organization to introduce this type of IMC. The IMC is not only beneficial to health and the environment, but also indirectly responsible for deforestation and the deterioration of ecosystem.

Chapter-7

Summery and Conclusions

Afforestation or forest plantation is one of the best strategies for the mitigation of global climate change. Role of forest ecosystem in the total balance of terrestrial carbon stock and its dynamics for mitigating climate change has highlighted the need for developing knowledge of different tree species for their carbon stocks that can act as a potential measure for mitigation of climate change. The most practical way to remove excess of CO_2 from atmosphere is storing of CO_2 into the physiological system of plants and finally to store in the soil as soil organic carbon stock. Therefore, there is no doubt that the forest act as a strong CO_2 sink and a cheaper mitigating option. Increase in afforestation or forest plantation rate may further be an incentive for sequestration of carbon and protection of natural forests from the degradation. Presently, the Plantation forests have small contribution in the total balancing of terrestrial ecosystem's carbon at both global and national level, but their contribution to store or absorb atmospheric carbon plays an important role for the future climate change mitigation.

The plantation forests are responsible for the productive and protective growth of plants. The protective plantations are predominantly intended for provision of various services such as protection of soil, rehabilitation of degraded land and carbon sequestration, whereas, the productive plantations are predominantly intended for the provisions of fuel wood, fibre, timber and non-wood products. Consumption of fuel wood is one of the most traditional activities which contribute to forest degradation in the event of people adopting an unsustainable use of forest for these activities. In fact, the demand for firewood is likely to continue to be the most important source of energy for rural areas in many countries. Wood-based energy has been viewed as a means to carbon emissions however it can be reduced, if biomass resources are consumed sustainably with efficient technology systems. Inefficiently burning of firewood creates number of adverse consequences on health, social and economics. Improved cook stoves over commonly using tradition inefficient mud chulha have been disseminated as an alternative to reduce these impacts. Numbers of studies have been conducted on the consumption of biomass energy in India, but research on the strategies to be adopted for the fuel wood needs of the rural households focused to develop mass scale afforestation of suitable tree species to meet the energy demand is still limited. On the other hand, associated impacts due to the consumption of fuel wood and emission of CO_2 due to the burning of fuel wood without precise management are still a scare.

The present study was conducted in Kahinure plantation forest of district Mau, Uttar Pradesh, India to study the characterization of mix plantation forest for soil quality and carbon sequestration, fuel wood consumption pattern of Kahinure village and emission potential from firewood burning. The developments of energy efficient metal chulha for solid biomass fuel burning to cook food and evaluation of its performance have also been investigated. Very limited number of case studies is available on southeast Uttar Pradesh in India. Most of the literature available on these aspects mainly deals to Himalayan region. The study area adopted is untouched till the study was started.

Characterization of mix plantation forest for soil quality and carbon sequestration potential

Role of forest in soil organic carbon stock and there dynamics for mitigation of GHGs has highlighted the need for more knowledge on effect of tree species on soil organic carbon stock and other soil properties. Management of forest that include afforestation or forest plantation is acceptable measure for mitigation of atmospheric CO_2 in national greenhouse gases budgets. However, quantitative estimates of the effect of tree species on the organic carbon stock of soil are still rare. In addition, the scientific basis for identifying more suitable tree species for better carbon sequestration is also limited to relatively few studies. Therefore, objective of this study was to study the impact of forest plantation on tree biomass and soil organic carbon stock and its comparison with non-forest areas (Waste land) in its surroundings, Inter relationship between different soil parameters at different soil depth and variability in carbon sequestration potential of different tree species in the plantation forest to evaluate tree species that have a better potential for carbon sequestration.

In the present study, soil in the plantation forest possessed higher soil organic carbon stock and other important soil fertility parameter than the adjacent non forest area (waste land) soil. However, with the increasing soil depth, these parameters decreased which increasing soil depth and bulk density in both plantation forest and waste land. The soil microbial biomass carbon (SMBC), soil enzyme activities like soil dehydrogenase activity, acidic and alkaline phosphates and soil respiration were higher in the plantation forest soil as compared to the waste land soil. Further, soil dehydrogenase activity was also higher in plantation forest soil. Therefore, conversion of degraded land or waste land under plantation cover is an important factor influencing the soil fertility related properties. Among the studied tree species, maximum carbon accumulation in different components (stem, branch, leaf) of certain species like *Prosopis juliflora*, *Putranjiva roxburghii*, *Pithecellobium dulce* and *Artocarpus heterophyllus* depict that these tree species can be recommended as atmospheric carbon reducers for their better potential to sequester and store carbon. The study indicated that afforestation or forest plantation enhanced SOC, nutrient stock and improved other soil properties as compared to non-forest soil i.e., waste land. Biomass studies of the plantation forest stands revealed that the stand areas still have potential for re-growth and can be developed into good plantation forest if proper protection measures are taken. The participation of local communities in the management process can yield better results than managing them without such participation. Among the studied tree species better atmospheric carbon reducer should be given priority in plantation drive in future for their role in long term climate change mitigation.

Fuel wood consumption pattern of Kahinure village and emission potential from fire wood burning

Fuel wood consumption is identified as the main source of energy in rural India for cooking purposes. Higher consumption of fuel wood is mainly due to lack of unconventional energy sources. In many developing countries fuel wood consumption is now one of the most important reasons for forest degradation. Shifting cultivation coupled with excessive deforestation for fuel wood has caused severe environmental degradation. In the present study, fuel wood consumption patterns of the plantation forest in rural area of Kahinure District Mau, Uttar Pradesh, India had been evaluated. A questionnaire survey of random sampling method was employed for 180 households to understand socio-economic conditions and energy consumption pattern for cooking purposes in the study area.

The study reveals that fuel wood was largely utilised as non-commercial and cheap source of energy, followed by dung cake and agriculture residue. About 65% of household's energy consumption was in the form of wood biomass fuel derived from the selected plantation forest. The cow dung was used by 22% households and agriculture residue by 12%. About 1.3% people used kerosene for cooking. Average cooking time was estimated at 4.46 h/day/family, and average value of fuel wood consumption was estimated at 4.5 t/family/ year, whereas average market value of annual consumption of fuel wood had been calculated as Rs 8,700.00 per households. Due to poor socio-economic situations in the village, a significant amount of fixed carbon of plantation forest was used for cooking of food which could be saved by choose of enable tree species for future energy plantation and replacing the cooking method with alternative energy efficient cooking techniques.

Further, the present study investigate fuel wood characteristics on the basis of fuel wood value index (FVI), a proximate and ultimate analysis of 12 subtropical tree species to sort out the tree species commonly used by the rural communities and examine their energy properties. The FVI was determined on the basis of calorific value (CV), bulk density (BD), and ash content (AC). The highest CV was found in *Prosopis juliflora*, and the lowest CV was found in *Streblus asper*. The AC was found maximum in *Pithecellobium dulce* and minimum in *Streblus asper*. Moisture content was ranged between 38.70 and 58.67%. Investigation of elemental composition in fuel wood revealed that carbon, nitrogen, hydrogen (CHN), and sulfur value ranged from 40 to 46% C, 4.80 to 6.80% H, 0.03 to 1.40% N, and sulfur was defected only in some species and its maximum value (0.012) was found in species of *Tectona grandis, Terminalia arjuna*, and *Ficus benghalensis.* This study revealed that only the single basic parameter is not sufficient for identifying the suitable tree species for fuel wood. On the basis of FVI and other fuel wood properties species, *Prosopis juliflora, Tectona grandis, Ficus benghalensis, Alstonia scholaris*, and *Holopetelea integrifolia* are the most preferred fuel wood species among the 12 trees studied. To enable choice of plant species for future energy plantation program may help the local people to take maximum benefit to be used as bioenergy if electricity and alternative energy sources are not available in such remote areas.

In addition, the study elaborates the GHG emission rate and deforestation due to the burning of firewood by the rural households. The rate of CO_2 emission is directly proportional to consumption of fuel wood. However, efficient way of fuel wood combustion may reduce the rate of CO_2 emission. A traditional clay chulha commonly used in the study area for cooking that is thermally inefficient and a greater higher emission of smoke. Therefore, an effort should be made to reduce the emission as a result of fuel wood burning. This can be achieved by replacing the traditional cook stove with alternative energy-efficient improved cook stove that can reduce emission and better thermal performance.

Development of Improved metal chulha for low emission and better thermal efficiency

Biomass is one of the largest and important sources of fuel in domestic cooking of developing countries. Burning of biomass in the tradition cook stove is one of the widely used biomass based appliance from incanting time to till date. In India majority of the households living in a rural area depends on fuel wood, dung cake and crops residue to meet their domestic energy needs and these solid fuels accounts more than 80% of total fuel used for cooking purposes. Inefficient way of burning of solid biomass fuel releases large amount of air pollutants like CO, $PM_{2.5}$, PM_{10}, SO_X, and NO_X. Therefore, efficient way of combustion of biomass fuel reduce indoor emission with increases the thermal efficiency. In the present study we have developed an improved metal chulha over commonly available traditional mud chulha for rural households and evaluates the performance of a newly developed improved metal chulha (IMC) over available traditional mud chulha (TMC) as energy efficient non-smoking cooking appliance for the rural households.

An extensive survey of 90 respondents revealed that majority of the households use firewood for cooking in energy inefficient TMCs. The TMC emitted considerable amount of toxic component, which can adversely affects the human health on direct exposure. To overcome this problem, we have developed an IMC, which significantly reduces energy loss and cooking time compared to TMC. In this study, we have measured the level of airborne pollutants emitted from fuelwood used for cooking purpose. In addition to this, we have also studied the thermal efficiency of IMC over TMC. A major reduction of indoor pollutants viz. PM_{10} (45%), $PM_{2.5}$ (73%), CO (51%), SO_X (22%), NO_X (36%) was recorded for IMC over the TMC. The water boiling test also indicate higher thermal efficiency during all the three phases; cold start (37%), hot start (41%) and simmering test (46%) for IMC over TMC. The fuel consumption rate (g/min) was recorded23, 16.6, 14 and 32.2, 25.1 and 20.6 for IMC and TMC respectively. Compared with TMC the IMC reduced specific fuel wood consumption, increased efficiencies and lower emissions of pollutants including PM_{10}, $PM_{2.5}$, NO_X, SO_X and CO. A social survey in the form of a questionnaire revealed that majority of households realised that IMC will be better than the traditional mud chulha in terms of handling, reduced emissions, easier cooking and efficiency. Therefore, the present study suggests that adoption of improved metal chulha reduces the indoor emission and trace metals associated with coarser fraction of the particulate matter significantly and help carbon economic by saving considerable amounts of fuel wood with lower CO_2 emission. Further, knowledge should be imparting more about the use of IMC and its benefits for the reason that societies progress only if their people are healthy, and the government should launch programs on the basis of a different scheme for adaptation of energy efficient improved chulha for poor rural households.

The overall studies presented in this thesis provide some new insights in understanding the characterization of mix plantation forest for soil quality and carbon sequestration potential, Fuel wood consumption pattern of Kahinure village and emission potential from fire wood burning and development of improved metal chulha for reduction in indoor emission and better thermal efficiency. Following are the specific conclusions from the present study.

- ❖ The current study reveal that afforestation or forest plantation even in degraded or waste land can enhance soil organic carbon (SOC) stock and improve the soil fertility in addition to provide a good sink for atmospheric carbon sequestration. Soil from plantation forest showed higher concentration of SOC, soil nutrient, soil microbial biomass carbon and soil enzyme activity as compared with non-forest area i.e. Waste land, though it reduces with increase in soil depth in both forest and non-forest areas. Increase in soil microbial biomass carbon reflects an increase in soil microbial population which is essential for long term soil productivity and fertility.
- ❖ Variability in carbon percentage in different tree species and in their components showed that certain species such as *Prosopis juliflora, Putranjiva roxburghii, Pithecellobium dulce and Artocarpus heterophyllus*have more potential in sequestration of atmospheric carbon over the other tree species studied. Priority should be given to the selected species in the region for future plantation due to their potential as atmospheric carbon sink.
- ❖ According to the results of survey, fuelwood consumption varies significantly from season to season. Daily fuel wood consumption from the forest was higher in winter as compared to summer seasons. The higher consumption of fuelwood explains possible reason for deforestation and emission of

greenhouse gases. Further, the rate of CO_2 emission is directly proportional to consumption of fuel wood. However, efficient way of fuel wood combustion may reduce the rate of CO_2 emission and strongly recommended that mass scale afforestation program of suitable tree species for future energy plantation in the study region bridge the gap between demand and supply.

- To investigate fuel wood characteristics on the basis of fuel wood value index (FVI), a proximate and ultimate analysis to sort out the tree species commonly used by the rural communities and examine their energy properties. On the basis of energy analysis only the single basic parameter is not sufficient for identifying the suitable tree species for fuel wood. On the basis of fuel wood value index (FVI) and other fuel wood properties species *Prosopis juliflora, Tectona grandis, Ficus benghalensis, Alstonia scholaris* and *Holopetelea integrifolia*are the most preferred fuel wood species and attention should be given on such tree species for large scale energy plantation in future, especially in this region of Uttar Pradesh, India to fulfil the future demand of rural communities.
- After the extensive survey, it was found that the majority of the households use traditional mud chulha for cooking in this area, which is thermally and environmentally inefficient. To overcome this drawback we have designed improved cook stoves with apparent modification in the conventional chulhas for rural people in view of their health care, economic concerns and climate benefits.
- Installation of improved metal chulha enhances the thermal efficiency with the reduction of specific amount of fuelwood consumption in the present

investigation. This further reduced the duration of time and the amount of fuel to prepare a particular amount of food.

- Therefore, the national level program must be implemented by the government and the nongovernment organization to introduce this type of improved metal chulha. The improved metal chulha is not only beneficial to health and the environment, but also indirectly responsible for deforestation and the deterioration of ecosystem.

Finally, from the present study it is concluded that plantation forest is an asset towards mitigating global climate change. Increase in carbon stock within the studied tree species and soil of the plantation forest depicts that plantation forest as an efficient carbon sequester. Since, rural India is dependent upon forest fuel wood for their energy requirements, development and management of energy efficient plantation forest like that of Kahinure plantation forest can minimize the anthropogenic pressure on natural forests. Development and inclusion of an energy efficient and eco-friendly chulha (i.e., improved metal chulha) over traditional chulhas which are commonly used in rural households can minimize indoor air pollution to a large extent. Also improved metal chulha is thermally efficient, as analysed for the use in rural areas of India.

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Publications

Publications

Baqir, Mohd., Kothari, R., Singh, R.P. (2017). Characterization and ranking of subtropical trees in a rural plantation forest of Uttar Pradesh, India, as fuel wood using fuel wood value index (FVI). *Environ Dev Sustain*, https://doi.org/10.1007/s10668-017-0057-z

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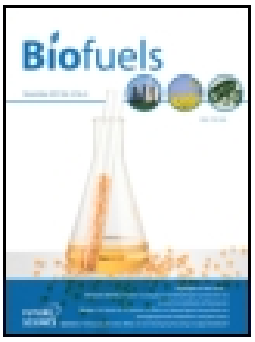

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Fuel wood consumption, and its influence on forest biomass carbon stock and emission of carbon dioxide. A case study of Kahinaur, district Mau, Uttar Pradesh, India

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ABSTRACT

This study presents a carbon budget for a plantation forest (PF) in the village of Kahinaur, district Mau, Uttar Pradesh, India. The total carbon stock in the selected PF was approximately 4500 Mg. The results showed that species such as *Prosopis juliflora* (52.0%), *Acacia nilotica* (48.5%), *Tectona grandis* (46.4%) and *Eucalyptus sp.* (45.4%) are the more carbon sequestration potential tree species comparative to 10 dominant tree species in the PF. According to the results of a survey, fuel wood consumption varies significantly from season to season. Daily fuel wood consumption from the forest ranged from a minimum 170 kg d^{-1} in summer to a maximum 450 kg/day in winter, giving an average annual consumption rate of 62.1 to 164.3 tonnes. The higher consumption of fuel wood is a possible reason for deforestation and emission of greenhouse gases. Based on calorific value, *P. juliflora*, *Terminalia arjuna*, *Eucalyptus* sp. and *T. grandis* are some of the most promising tree species in the region, that can be recommended for energy plantation. Therefore, findings of paper could be the basis for selection of suitable tree species for future energy plantation in this region and provide clues for adoption and management of such high productive ecosystem in the wake of changing climate in the future. for future energy plantation, to control the environmental damage caused by excessive use of fire wood in the region.

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Carbon sequestration; fuel wood; plantation forest; tree species

Introduction

Consumption of firewood is society's oldest source of household energy and it is still used around the globe, even in technologically advanced countries with high energy consumption [1,2]. In many countries, fuel wood consumption is now one of the most important causes of forest degradation. It has been estimated that biomass in the form of fuel wood only accounts for approximately 9% of total global energy consumption [3]. For several decades, deforestation and forest degradation have been on the development agenda worldwide in an effort to find a compromise between the lifestyle of forest dwellers and forest conservation. However, the current unsustainable methods of utilization of forest resources cause over exploitation resulting in forest degradation. Biomass accounts for approximately 14% of the total energy used globally and is the largest energy source for three quarters of the world's population, living in developing countries [4].

Collection of unsustainable fuel wood and use of inefficient conversion technology have serious implications for the environment [5,6]. Burning of fuel wood produces large amounts of carbon dioxide (CO_2), but fuel wood emissions are considered to be carbon neutral if fuel wood is harvested sustainably. Due to its incomplete and inefficient method of combustion, the use of fuel wood may not be carbon neutral because excessive carbon is released in other forms such as methane, nitrous oxide, carbon monoxide, and non-methane hydrocarbons, which have greater global warming potential (GWP) than CO_2 [7].

The Indian Forest Survey reports that about 70% of the Indian rural population depends on firewood to meet their household energy needs [8]. According to the 2011 census, approximately 49% of households in India use firewood for cooking. However, in some states this figure is higher than 80%. Poor rural households collect fuel wood from locally available resources like forests to meet their domestic energy needs. Fire wood is the most attractive of the various forms of biomass and occupies a predominant place in the rural energy budget in India [9,10]. To meet the requirement for fuel wood, a policy for a large-scale afforestation program should be developed to meet the need for fuel wood and other ecosystem services from unused land, discarded land or degraded land area, to close the gap between demand and supply. Afforestation has been recognized as a profitable and beneficial strategy for the sequestration of environmental carbon

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[11]. Measuring the short- and long-term impacts and storage capacity of forests to sequester CO_2 would allow the development of informed measures aimed at reducing net CO_2 emissions.

There are several studies on the consumption of biofuels in rural India, but research on the strategies adopted by rural households to grow the trees to meet demand is limited. On the other hand, the associated impact due to the consumption of fuel wood and the emission of CO_2 due to the burning of fire wood is still an issue. In this present study, a conceptual framework is designed to evaluate the scenario of fuel wood in this particular area of India, very specific to collection and consumption also in a protected forest region. How seasonal variation affects the consumption and collection pattern of fuel wood is also assessed, and the impact on above- and below-ground biomass carbon stock is also studied. A very limited number of case studies is available for this region of India. All the literature available on this concept mainly pertains to the Himalayan region only. This particular area is untouched in terms of prior study. So, the objectives of our experimental study are focused on this particular area of Uttar Pradesh, India. To fill these gaps, the designed objectives are: (1) examine the state of fuel wood, the pattern of fuel wood collection and consumption, and the role of plantation forest (PF) in supplying fuel wood to rural households; (2) determine the quantity of fuel wood harvested seasonally from the plantation forest; and (3) estimate the above- and below-ground biomass carbon stock. In addition, we evaluated the annual rate of deforestation and the rate of greenhouse gas emissions as a result of fuel wood burning.

Material and methods

Study area and climate

The selected study site is located in the village of Kahinaur, Mau district, Uttar Pradesh, in northern India (Figure 1). The study area is a PF developed by the forestry department of Uttar Pradesh under the plantation drive of mixed plant species during the year 1983 for commercial production of fuel wood, non-wood products and environmental services. The area of the PF is approximately 118 hectares and its global positioning system (GPS) location is 25°52′274′′N and 83°30′578′′E. The study area experiences a dry and wet winter type, with average rainfall of 650 to 800 mm from June to September every year. Temperature varies from a maximum of 42°C in summer to a minimum of 7°C in winter (Figure 2). The dominant tree species in the PF are *Prosopis juliflora*, *Alangium saluifolium*, *Alstonia scholaris*, *Terminalia arjuna*, *Berberis thunbergii* and *Tectona grandis*.

Data collection and analysis

During January 2016 to December 2017, an extensive field survey was conducted to study the pattern of fuel wood consumption of rural households and collection of fuel wood from the selected PF. To make the survey proceed more smoothly, permission was first

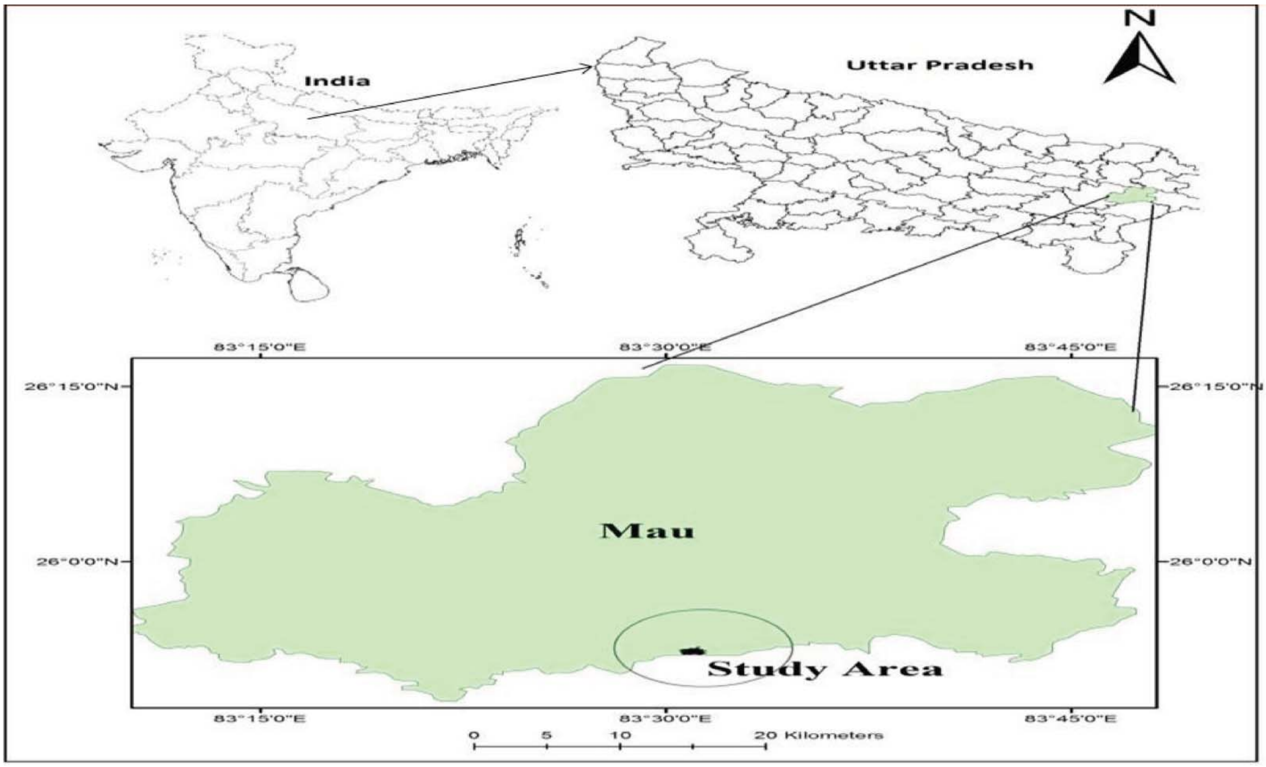

Figure 1. Map showing the location of the study site.

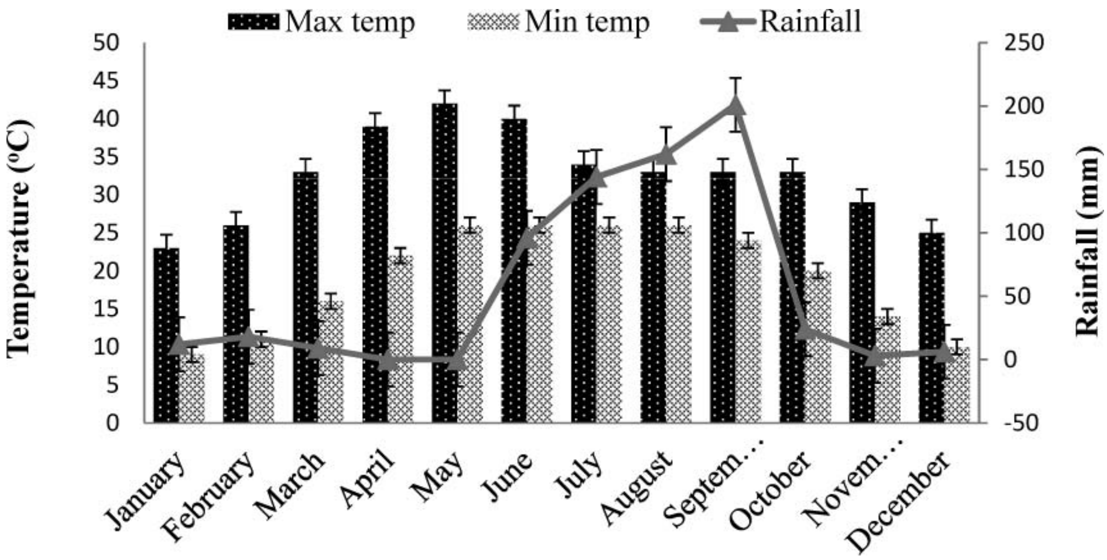

Figure 2. Climatic conditions of the selected study area during the year 2009–2014 [12].

requested from the forest department and the village leader. A preliminary survey was conducted using the questionnaire method. Out of 450 households, 90 households were randomly selected for the study of fuel wood consumption. Respondents provided information about the socioeconomic status of their household, their fuel wood consumption status and the household's preferred fuel wood species. The respondents were asked to specify their preference of fuel wood species, with other informal discussion and observation following [10]. The quantity of fuel wood collection was estimated on the basis of local people carrying bundles of fuel wood on their heads (head load). We used the head load as a standard term and asked respondents to estimate the amount of head load they collected per day. Fuel wood was collected from different sources but the majority of households collected fuel wood from the PF. The transportation of fuel wood is carried out on the head, especially by women and children to transport wood at home (Figure 3). Questions were added about the effect of season of the year on the extraction and use of firewood. The amounts of daily collection of fuel wood from the PF and the pressure on the forest were estimated. Higher pressure on the PF was reported during the winter season, with consumption of fuel wood for both cooking and heating in the cold seasons. The questionnaire used to collect the information was translated into the Hindi language.

Emission of carbon dioxide (CO_2) and deforestation due to burning of fuel wood

The annual rate of deforestation and emission of greenhouse gases (GHGs) as a result of burning of fuel wood was estimated. The volume of wood used was expressed in cubic meters (m^3), which represents deforestation (m^3) per unit of time [13]. Fuel wood biomass data was converted into tonnes of dry biomass (t dm) per cubic meter by dividing the mass unit by an expression ratio of 1.90 [13]. Total emission of carbon was estimated by multiplying the amount of biomass

Figure 3. (a) Collection of fuel wood from the plantation forest (PF) by children, and (b) collection of fuel wood by local women on their heads.

burned in t dm by the fraction of biomass oxidized and the biomass carbon content as shown in Equation (1) [14]. A default value of 0.9 was used for the fraction of oxidized biomass and wood biomass; a conversion factor of 0.5 t C/t dm was used.

$$C_t = M_t \times M_f \quad (1)$$

where C_t = total biomass burned (t dm); M_t = fraction of biomass oxidized (0.9); and M_f = woody biomass carbon content (0.5 t C/t dm).

The CO_2 emission from burning of fuel wood can be estimated by conversion of total carbon content (t C) to carbon dioxide content (t CO_2) using a conversion ratio of 44 t CO_2/12 t C, as shown in Equation (2) [14].

$$CO_2 = M_t \times M_f \times M_c \times (44\,/\,12) \quad (2)$$

where CO_2 = total CO_2 (t CO_2) released from the burning of fuel wood; M_t = total biomass burned; M_f = fraction of biomass oxidized (0.9); and M_c = Biomass carbon content (0.5 t C/t dm).

Biomass and carbon estimation

In the present study, a non-destructive approach of above-ground biomass (AGB) estimation was used. The diameter at breast height (DBH) of individual tree species was measured for the estimation of AGB using allometric equations for deciduous forest stand [15]. The DBH was used as the only independent variable to estimate the AGB. The literature revealed that DBH shows a positive correlation with AGB [16,17]. Biomass (above and below ground) and carbon were calculated by non-destructive methods, without damaging the trees. Two equations were developed to determine the biomass of dry and moist tree species independently [18,19]:

$$\text{Dry species } Y = \mathrm{Exp}\{-1.996 + 2.32\ * \ln(D)\} \quad \text{Range in DBH(cm) } 5 - 40 \quad (3)$$

$$\text{Moist species } Y = 42.69 - 12.800(D) + 1.242\left(D^2\right) \quad \text{Range in DBH (cm)} 5 - 40 \quad (4)$$

where Y is biomass per tree in kg, and D = DBH in cm.

Based on the results of different studies related to carbon estimation in wood, it has been observed that for any species of plant, 50% of its biomass can be considered carbon [20].

Calorific value (CV) and carbon concentration of individual tree species

In order to estimate the energy value and the carbon capturing potential of an individual tree species, we selected the dominant tree species in the PF. To estimate the calorific value (CV) of the wood samples on a dry weight basis, 2 g of oven-dried powdered material was burned in an oxygen bomb calorimeter [21]. There were triplicates for each sample. The carbon content in the different tree species was estimated using the loss-of-ignition method [22]. In this method, oven-dried wood samples were burned in a muffle furnace at a temperature of about 550°C. The percentage of carbon content was estimated by the weight loss [23].

Results and discussion

Socioeconomic conditions and sources of biomass energy

According to the results of the survey, the village comprised 490 households with a population of 3065, while the size of the families studied ranged from 3 to 23 persons per family. Out of 490 households in the selected study area, a total of 100 respondents were interviewed between the ages of 22 and 75, with an average age of 30–50 years for the study. Ninety percent of the respondents were heads of household and were responsible for collecting fuel wood and other energy sources for daily cooking and heating during the cold seasons. According to the respondents, agriculture is the main source of livelihood and fuel wood collected from the PF is important for their daily energy needs. As for the house of the respondents, approximately 70% have kuchha houses with grass roofs, that are not well constructed, while the remaining 30% are fully constructed with bricks and cemented (i.e. pakka homes). The main energy sources of biomass are fire wood, agricultural residues, and cow dung cake which is a traditional source of energy in rural households. Among several biomass energy sources. This may be due to easily availability from the adjoining plantation forest with out any cost. Forest conservators allow to collect fuel wood from the PF without harming the living plants. In contrast, fuel wood collected from the trees outside the PF contributes 10%. The other biomass energy sources, including agricultural residues (16%) and cow dung (13%), are shown in Table 1. The majority of the population collected wood from the selected PF, where either the wood was cut directly from the forests or dead wood of any type was collected. The collection of fuel wood is mainly carried out by women and children. The majority of

Table 1. Major source of biomass energy in households.

Biomass energy source in a household	Percentage (%)
Fuel wood from the PF	56
Fuel wood from trees outside the PF	10
Agriculture residue	16
Dung cake	13
Purchased fuel wood	5

PF: plantation forest.

Table 2. Ranking of preferred fuel wood plant species used by households near the plantation forest.

Preferred species	Common name	Family	Availability	Carbon (%)	Calorific value (MJ/kg)	Ranking (FWQ)
Prosopis juliflora	Babul	Fabaceae	Easily	52.01	22.56	1
Alangium salviifolium	Ankol	Cornaceae	Easily	43.25	18.29	8
Terminalia arjuna	Arjun	Combretaceae	Easily	45.95	21.63	3
Alstonia scholaris	Chitvan	Apocynaceae	Easily	42.25	18.89	9
Tectona grandis	Teak	Lamiaceae	Easily	46.38	19.92	6
Streblus asper	Sihora	Moraceae	Easily	41.37	17.32	10
Eucalyptus sp.	Safeda	Myrtaceae	Moderate	45.34	20.3	4
Cassia fistula	Amalatus	Fabaceae	Moderate	44.67	18.67	5
Acacia nilotica	Babool	Fabaceae	Moderate	48.45	19.68	2
Butea monosperma	Palash	Fabaceae	Moderate	43.87	17.92	7

FWQ: fuel wood quality.

households use firewood for cooking in a traditional U-shaped mud chulha. The three-stone chulha consumes a large amount of fuel wood with low thermal efficiency.

Preferred fuel wood species and their availability

Due to the low socioeconomic level in the village and the lack of alternative sources of energy, fuel wood consumption from the nearby PF is the main source of energy due to its low cost and easy availability. On completing the field work for this study, personal interviews and discussions with villagers were also completed. From all these sources a total of 10 tree species were identified as the most dominant and preferred firewood species in the study area (Table 2). The reasons for this preference were the trees' ready availability, sufficient hardness, easy burning and low smoke emission. Mostly women and children of the households travel considerable distances and spend much time in collecting fuel wood for their daily energy need for cooking and heating. The preferred tree species most commonly available for fuel wood, with details including their common name, calorific value and percentage of carbon, are shown in Table 1. In the near future, the availability of these preferred fuel wood species may become difficult, if the sustainability of the forest declines and in that case, these people would have no choice but to use whatever is available to them. Therefore, verifying the energy value of the different tree species helps us to evaluate the energy efficiency of species for future energy plantations in the selected region. The energy value of the different tree species based on ranking of fuel wood quality (FWQ) were determined and the order from highest to lowest CV was: *P. juliflora* > *T. arjuna* > *Eucalyptus* sp. > *T. grandis* > *A. nilotica* > *A. scholaris* > *Cassia fistula* > *A. Alangium folium* > *Butea monosperma* > Streblus *asper*. The carbon percentage in different tree species showed a decreasing trend in the order *P. juliflora* > *A. nilotica* > *T. arjuna* > *Eucalyptus* sp. > *C. fistula* > *B. monosperma* > *T. grandis* > *A. salviifolium* > *A. scholaris* > *S. asper*. Based on better energy value and carbon capturing potential, species should be prioritized for future plantations for energy and potential to act as an atmospheric carbon sink.

Seasonal variation in fuel wood consumption

Fuel wood consumption in winter was significantly higher than fuel wood consumption during the summer seasons, as shown in Figure 4. The rate of

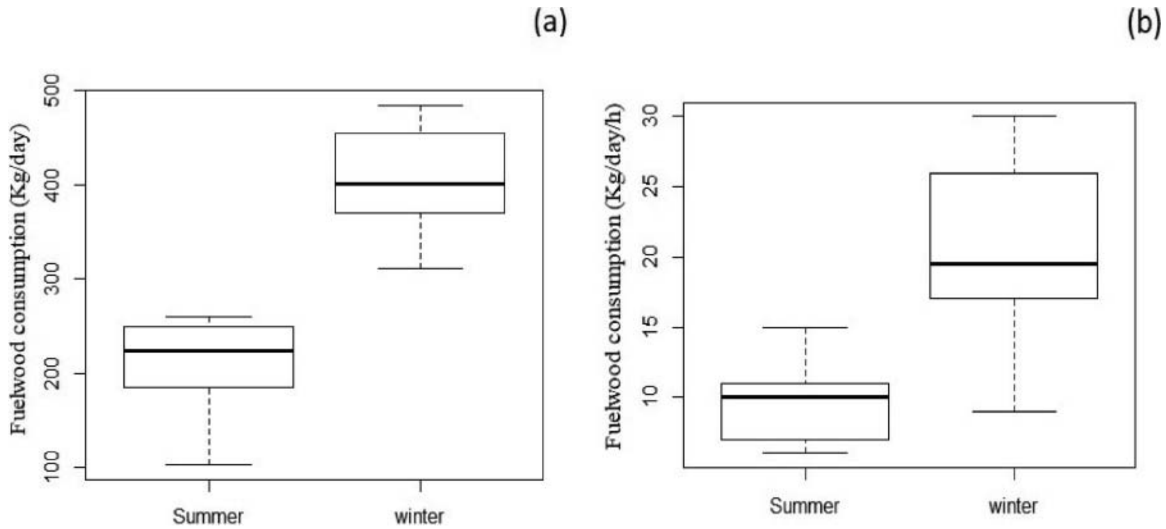

Figure 4. Box whisker plot for the amount of fuel wood consumption in the summer and winter season: (a) average fuel wood collected from the plantation forest (PF) per day; (b) fuel wood consumed from PF per day per households.

consumption from the PF was at minimum 180 kg/day and at maximum 250 kg d^{-1} in the summer. In the winter season, the minimum collection was 380 kg per day and the maximum was 450 kg per day. However, occasional collection was also found year round except during rainy seasons. Fuel wood consumption by individual households also varies in different seasons. In winter, fuel wood consumption from the forest per day per household was minimum 10 kg $d^{-1}hh^{-1}$ and maximum 17 kg $d^{-1}hh^{-1}$. This value was minimum 6 kg $d^{-1}hh^{-1}$ and maximum 12 kg $d^{-1}hh^{-1}$ in summer. Therefore, on a daily basis fuel wood consumption in the winter season was found to be greater than in the summer season. The additional consumption of firewood in winter came from the use of firewood to boil water and as heating during the cold season. It has been reported that fuel wood consumption intensifies in the winter months and is heavily influenced by the seasons [24]. Similarly, other studies conclude that fuel wood consumption in India is heavily influenced by seasons [2,25]. The amount of fuel wood collection was calculated over a 24-hour period using a weight survey method [26]. Traditionally, fuel wood collected in head loads was weighed to estimate the fuel wood consumption from the PF on a daily basis.

Environmental impact due to fuel wood burning

This part of the study focuses on the annual rate of deforestation and CO_2 emissions as a result of the burning of fuel wood [27,28]. Burning of fuel wood release less greenhouse gases into the atmosphere in comparison to fossil fuels. However, its cumulative effect on total GHGs and climate change is a concern for the future. With the help of the field study, it was estimated that rural households consume approximately 470 kg of firewood per day from the selected PF. Due to continuous consumption, the area will face an acute shortage of its basic energy source if the current rate of deforestation continues. It is therefore important to have comprehensive forestry policies so that there is a net addition to perpetual stocks even after meeting people's essential fuel needs. To achieve this, mass-scale afforestation or forest plantation on degraded or waste land is required to meet the growing demand for fuel wood. Further, the development of improved cookstoves over the available traditional cookstove in the study region, which is not very energy efficient, may reduce the deforestation and emission of GHGs. Table 3 shows the emission of CO_2 and rate of deforestation due to fuel wood consumption.

Table 3. Annual average fuel wood consumption, deforestation and carbon dioxide (CO_2) emission from the selected plantation forest.

S. no.	Parameters	Minimum	Maximum	Average
1	Fuel wood consumed from the plantation forest, in tonnes of dry biomass per year (t dm/yr)	167.90	171.55	169.73
2	Potential deforested wood, in cubic meters (m^3)	88.36	90.28	89.32
3	Emission of carbon dioxide from burning of fuel wood, in tonnes (t CO_2)	280.29	283.01	281.60

Standing tree species distribution and biomass carbon stock

A total of 62,658 trees of 36 species of the selected plantation forest (PF) were reported [12]. The dominant tree species in the PF were *P. juliflora* (26,481), *A. scholaris* (7902), *A. salviifolium* (6680), *S. asper* (5318), *T. arjuna* (6151) and *T. grandis* (4318). The DBH of the tree species ranged from 3.5 to 44 cm. Table 4 provides the average DBH and average biomass carbon stock of the standing tree species of the forest has been summarized. On the basis of the allometric equation, tree species with higher DBH increase their biomass and carbon stock due to increased accumulation of biomass with increasing tree age. The observed mean biomass and carbon stock of PF was 88.87 Mg C ha^{-1} (carbon stock of 44.43 Mg C ha^{-1}). The carbon budget of the PF covers 118 hectares of area containing approximately 5500 Mg C stock. The carbon stock of the AGB of a forest ecosystem is one of the fundamental parameters that describes its functioning [19]. Figure 5 shows the overall above-ground biomass carbon stock (AGBC) of the PF was 37.60 Mg ha^{-1} C, which is greater than that of tropical savanna forest of Australia (34 Mg C ha^{-1}), tropical dry deciduous forest of India (27 Mg C ha^{-1}) or tropical dry deciduous forest of Mexico (33 Mg C ha^{-1}) [29–32]. For other types of PF such as sal and teak, the carbon stock was reported to be 25 to 30 Mg C ha^{-1} which is also less than the present results [33]. The findings imply that PFs with mixed culture have a better potential for carbon sequestration, and tree plantation should be enhanced on unused land with management strategies. The below-ground carbon stock contributes approximately 18% of the total carbon accumulated. Therefore, the below-ground carbon stock was 765.86 Mg. However, the total carbon stored both above and below ground (AGC + BGC) of the present study was not much higher, as earlier reported from India's natural forest and some natural forest of different Asian countries such as Thailand (98.76 t ha^{-1}), Malaysia (100 t ha^{-1}) and the Philippines (86 t ha^{-1}) [34]. A number of studies have reported that the potential of a forest for carbon sequestration depends on the type of forest, the age of the forest and the size of the trees [35]. However, fast-growing tree species accumulate more carbon in their biomass than do other plantations of the same age. It has been reported that an increase in the size of the individual tree does not necessarily increase the level of biomass and carbon stock [36].

Figure 6 shows the five main species that contribute to a better carbon sequestration potential among the

Table 4. Above- and below-ground biomass carbon stock of the selected plantation forest (Mg).

S. No.	Species name	Number of individuals	Average DBH (cm)	Average biomass carbon (kg/individual)			Total biomass and carbon (Mg/tree species)	
				TAGB	TBGB	Total	TB	TC
1	*Prosopis juliflora*	26,481	10.5	0.0452	0.0104	0.0556	1472.34	736.435
2	*Alangium salviifolium*	6680	23.7	0.4369	0.10049	0.5374	3590.03	1795.01
3	*Streblus asper*	5318	14.1	0.1091	0.0251	0.1342	713.83	356.915
4	*Butea monosperma*	115	20.3	0.2946	0.06777	0.3624	41.67	20.835
5	*Tectona grandis*	4318	18.7	0.2376	0.05465	0.2922	1262.10	631.05
6	*Shorea robusta*	32	19.3	0.2582	0.0594	0.3176	10.16	5.08
7	*Acacia nilotica*	1014	11.8	0.0645	0.01485	0.0794	80.54	40.27
8	*Pongamia pinnata*	462	11	0.0521	0.01199	0.0641	29.64	14.82
9	*Alstonia scholaris*	7902	11	0.0521	0.00894	0.0611	482.89	241.445
10	*Cassia fistula*	349	10	0.0388	0.17859	0.2174	75.90	37.95
11	*Tamarindus indica*	1	30	0.7764	0.15528	0.9317	0.93	0.465
12	*Mangifera indica*	12	28.3	0.6751	0.17859	0.8537	10.24	5.12
13	*Ficus benghalensis*	1	30	0.7764	0.17859	0.9550	0.955	0.4775
14	*Syzygium cumini*	1	30	0.7764	0.0141	0.7905	0.79	0.395
15	*Azadriachta indica*	3	11.6	0.0613	0.06777	0.1291	0.38	0.19
16	*Terminalia arjuna*	6151	20.3	0.2946	0.0652	0.3598	2213.49	1106.74
17	*Artocarpus heterophyllus*	1	20	0.2834	0.0652	0.3486	0.34	0.17
18	*Putranjiva roxburghii*	18	20	0.2834	0.0652	0.3486	6.27	3.135
19	*Buschanania lanzan*	3	20	0.2834	0.1037	0.3871	1.16	0.58
20	*Peltophar pterocarpum*	7	24	0.4508	0.0652	0.5160	3.61	1.805
21	*Neolamarckia cadamba*	4	20	0.2834	0.0652	0.3486	1.39	0.695
22	*Sapindus mukarosse*	17	20	0.2834	0.05236	0.3358	5.70	2.85
23	*Eucalyptus* sp.	28	18.4	0.2276	0.0652	0.2928	8.20	4.1
24	*Callistemon viminalis*	18	20	0.2834	0.05621	0.3397	6.11	3.055
25	*Saraca asoca*	121	18.9	0.2444	0.05621	0.3006	36.37	18.185
26	*Madhuca indica*	12	14	0.1065	0.0241	0.1306	1.56	0.46
27	*Liriodendron tulipifera*	15	19	0.2478	0.057	0.3048	4.57	2.285
28	*Berberis thunbergii*	3316	13.1	0.0881	0.02027	0.1084	359.48	179.74
29	*Ficus religiosa*	1	30	0.7764	0.17859	0.9550	0.95	0.475
30	*Phyllanthus emblica*	7	18.2	0.2211	0.05085	0.2719	1.90	0.95
31	*Aegle marmelos*	33	11.9	0.0662	0.01523	0.0814	2.68	1.34
32	*Echinops ritro*	35	21.4	0.3375	0.07763	0.4151	14.53	7.265
33	*Cordia dichotoma*	151	18.7	0.2376	0.05465	0.2922	44.13	22.065
34	*Ziziphus mauritiana*	22	8.5	0.0236	0.00543	0.0290	0.63	0.315
35	*Psidium guava*	6	7.5	0.0165	0.0038	0.0203	0.12	0.06
36	*Groot schildmos*	3	20	0.2834	0.0652	0.3486	1.04	0.52

DBH = diameter at breast height; TAGB = total above-ground biomass; TBGB = total below-ground biomass; TB = total biomass; TC = total carbon.

10 dominant tree species in the present investigation: *P. juliflora* (52.01% C), *T. arjuna* (45.95% C), *A. nilotica* (48.45% C), *T. grandis* (46.38% C) and *Eucalyptus* sp. (45.34% C). *Prosopis juliflora* is a dry species resistant to drought and can be planted in dry areas. Its roots can penetrate deep soil and can improve the organic carbon stock of the soil and play an important role in erosion control. Further, its growth rate is very fast and it can sink more atmospheric carbon per unit of biomass comparative to other tree species studied. Currently, arid zones contain the lowest level of carbon in the world per hectare [37]. Therefore, it is necessary to consider the role of the arid zone forest in capturing carbon at a regional and global level. *Terminalia arjuna*

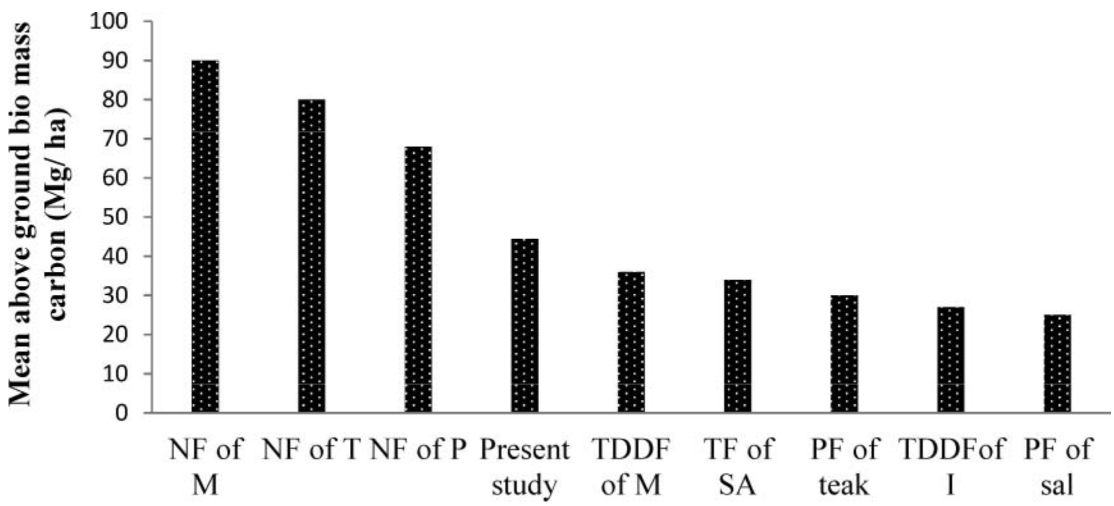

Figure 5. Comparison of above-ground biomass carbon of different types of forest, including the present study. NF of M = natural forest of Malasya; NF of T = natural forest of Thiland; NF of P = natural forest of the Philippines; TDDF of M = tropical dry deciduous forest of Mexico; TF of SA = tropical forest of savanna Australia; PF of Teak = plantation forest of teak; TDDF of I = tropical dry deciduous forest of India; PF of Sal = plantation forest of Sal.

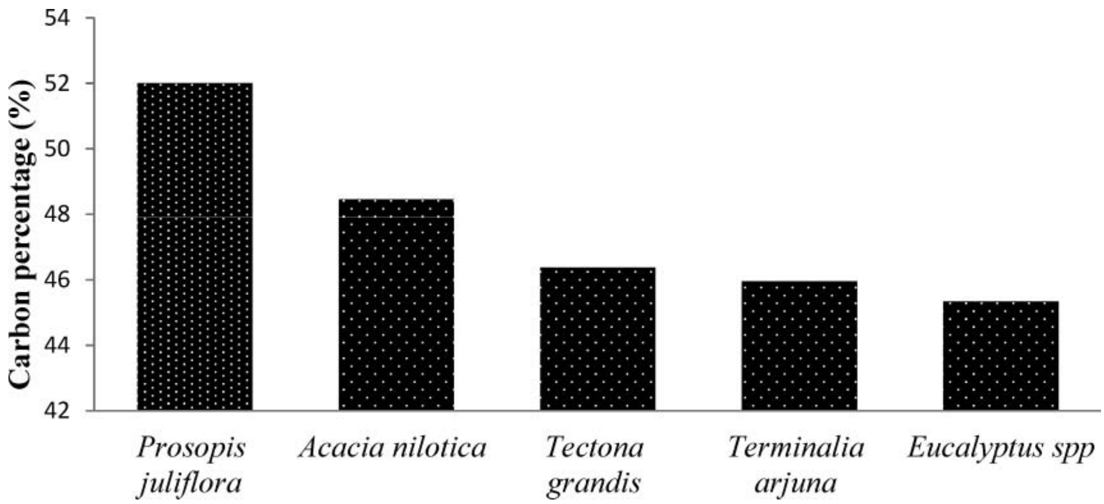

Figure 6. Top five potential carbon sequestration tree species.

is a tropical species, both dry and moist, commonly found throughout India, especially along the banks of rivers, streams and old irrigation canals, that helps reduce soil erosion. It is a large evergreen deciduous tree with very strong and long roots, and reaches a height of up to 20–30 m, with smooth gray bark, a spreading crown and drooping branchlets. The growth rate of this species is higher than that of other species and the life expectancy of the trees is 50 years or more. In India, *T. arjuna* is one of the most religious and sacred trees and also possesses versatile medicinal properties. This species is a characteristic component of tropical dry riverine forests and tropical dry and moist deciduous forests. *Tectona grandis* is a species of tropical hardwood tree and is indigenous to India; also, its growth rate is very fast. It is a valuable species that produces timber in the tropics, especially in India, Indonesia, Malaysia, Myanmar, northern Thailand and northwestern Laos [38]. This species can survive in a variety of habitats and climatic conditions, including arid areas with only 500 mm of rain per year and very humid forests with up to 5000 mm of rain per year. The area of the leaves is very large and can sink the maximum amount of CO_2. *Eucalyptus* sp. is a moist species and can grow anywhere from 33 to 300 feet tall. This species has a much faster growth rate than most other trees in cultivation, and it can live to 200 years old. *Acacia nilotica* is a dry species that can grow almost anywhere, in waterless conditions and on the marshy banks of lakes. Its growth rate varies considerably depending on location. This species is excellent for fuel wood and carbon sequestration. The government should encourage the planting of these tree species because of their better potential for sequestering and storing carbon from the atmosphere. The present study suggests that these species have good capacity to accumulate carbon and provide other ecosystem services and can be used for afforestation programs in future. The reduction of atmospheric carbon is a an important goal to reduce the current atmospheric carbon stock and allow the rapid sequestration of carbon in the future, which ultimately avoids the cost of climate change. Therefore, the creation of new plantations with these species on unused land or degraded land is a good option for high carbon accounting and credit to mitigate climate change.

Conclusion

In the study region, there is a huge dependency on biomass fuel for daily energy requirements. Fuel wood contributes approximately 66% of the total energy for cooking and heating. Fuel wood is needed to meet basic energy requirements for households in the region currently under investigation. In addition, the pattern of fuel wood consumption shows seasonal variations. Most households depend on selected PF wood to meet their energy needs. However, it has some disadvantages, such as the time required to collect, gather and transport, and also the system used to burn fuel wood. A traditional clay chulha is commonly used for cooking that is thermally inefficient and a great consumer of firewood. Therefore, an effort should be made to reduce fuel wood consumption in such areas, although the use of fuel wood is not necessarily the main cause of deforestation. This can be achieved by replacing the traditional cooking method with alternative energy-efficient cooking techniques. In addition, the study elaborates the GHG emission rate and deforestation due to the burning of firewood by the rural population. The rate of CO_2 emission is directly proportional to the consumption of fuel wood. However, an efficient method of fuel wood combustion might reduce the rate of CO_2 emission, and it is strongly recommended that mass-scale afforestation programs of suitable tree species be considered for future energy plantation in the study region, to bridge the gap between demand and supply. Further, biomass studies of the PF stands revealed that the stand areas still have potential for re-growth and can be developed into good PF if proper protection measures are taken. The participation of local communities in the management process of these forest stands has yielded better results than managing them without such participation.

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Disclosure statement

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Characterization and ranking of subtropical trees in a rural plantation forest of Uttar Pradesh, India, as fuel wood using fuel wood value index (FVI)

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Abstract The present study investigate fuel wood characteristics on the basis of fuel wood value index (FVI), a proximate and ultimate analysis of 12 subtropical tree species of rural areas of Uttar Pradesh in northern India, to sort out the tree species commonly used by the rural communities and examine their energy properties. The FVI was determined on the basis of calorific value (CV), bulk density (BD), and ash content (AC). The highest CV (22.56 MJ/kg) and BD (0.80 g/cm^3) were found in *Prosopis juliflora*, and the lowest CV (17.32 MJ/kg) and BD (0.32 g/cm^3) were found in *Streblus asper*. The AC was found maximum in *Pithecellobium dulce* (2.81%) and minimum in *S. asper* (0.83%). Moisture content was ranged between 38.70 and 58.67%. Investigation of elemental composition in fuel wood revealed that carbon, nitrogen, hydrogen (CHN), and sulfur value ranged from 40 to 46% C, 4.80 to 6.80% H, 0.03 to 1.40% N, and sulfur was defected only in some species and its maximum value (0.012) was found in species of *Tectona* grandis*,* *T. arjuna*, and *Ficus benghalensis*. This study revealed that only the single basic parameter is not sufficient for identifying the suitable tree species for fuel wood. On the basis of FVI and other fuel wood properties species, *P. juliflora, T. grandis, F. benghalensis, Alstonia scholaris*, and *Holopetelea integrifolia* are the most preferred fuel wood species among the 12 trees studied. To enable choice of plant species for future energy plantation program may help the local people to take maximum benefit to be used as bioenergy if electricity and alternative energy sources are not available in such remote areas.

Keywords Calorific value · Fuel wood · Fuel wood value index · Tree species

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1 Introduction

At present, biomass is drawing interest at global level as a renewable feed stock for energy production and reducing dependency on fossil fuel. A wide variety of biomass used as energy source including forest residues, agriculture wastes, dung cake, and herbaceous and woody materials (Vamvuka and Sfakiotakis 2011). Among these, different biomass fuel woods have been considered as sustainable and traditional source of energy for remotely located poor rural households. It has been estimated that out of total need of domestic fuel, fuel wood contributes 70% in rural area and 30% in urban areas (Deka et al. 2007; Dhanai et al. 2014). Wood biomass can be used for different purposes but most extensive use is yet as fuel wood in rural community as basic energy source for cooking purposes and heating of rooms in cold climatic conditions (Cardoso et al. 2015).

Rapid industrialization, growing human population, and changes in life style have increased the demand of energy during the recent decades. This demand is increasing about 50% up to 2030 which is mostly expected in developing countries like India, China, and Brazil (Kumar and Chandrashekar 2014). This increasing demand of energy may cause depletion in reserves of fossil fuel, enhance emission, and reduce the green cover. To avoid the consumption of fossil fuel, use of biomass as energy source is considered better in reduction of CO_2 emission into the atmosphere (Fernandes and Costa 2010).

During recent years, the energy requirement in India increased tremendously due to increased human population, and majority of the population live in rural areas and use of biomass in the form of fuel wood to cater their energy requirement. It has been estimated that about 70% of energy requirement in India will be met by fuel wood, and approximately 50 million tone of wood will be removed from the forest every year (Ministry of Environment and Forest 2015). Fuel wood consumption in India especially in rural areas of India is increasing at alarming rate due to poor socioeconomic conditions. Increase in consumption of fuel wood in rural areas of India causes deforestation and rapid degradation of environment as the cutting of large number of trees without proper knowledge might be result in ecological imbalance in a particular area (Sedai et al. 2016). So, it is an important to segregate or screen tree species for fuel wood quality of different tree species with reference to people's preference and their constituent properties and establishment energy plantation to reduce the fuel wood crisis for rural people in the specified geographical region.

In India, several workers have studied fuel wood properties of different tree species on the basis of FVI and other properties and consumption patterns of fuel wood and other biomass in the eastern Himalayan region of India (Deka et al. 2007; Kumar et al. 2010; Sedai et al. 2016; Bhatt et al. 2016; Bhatt et al. 2017). However, the reports associated with local preferences using fuel wood on the basis of fuel wood properties are rarely found by research community. Therefore, it is important to understand the characterization of species for fuel wood preference. Fuel wood value index (FVI) which is an important parameter depends on calorific value, moisture content, density, and ash content for screening tree species which are desirable for fuel wood ranking (Deka et al. 2007; Abbot et al. 1997).

One of the important factors affecting the fuel wood property is its moisture content (MC). Higher moisture content has been shown to decrease the amount of heat obtained from the wood, as maximum amount of energy from such moist wood is used to evaporate the moisture content in fuel wood, which causes to lower the efficiency of the combustion. The major elements of a wood biomass which may affect the calorific value are hydrogen, oxygen, carbon, and sulfur. Analysis of elemental composition of a wood can help to determine calorific value, desirable biomass fuel value, and their expected environmental impact (Telmo et al. 2010; Kumar et al. 2009). This study was planned to identify the tree species with more potential for fuel wood among the different trees, therefore, evaluate suitable tree species for fuel wood among the different tree species of 40-year-old plantation forest maintained by Uttar Pradesh Forest Department in vicinity of a rural area, and concentrate on evaluation of potential tree species by using FVI for energy plantation in this region for making forest biomass residue more profitable and remedy to shortage of fuel wood problem.

2 Materials and methods

The study site selected for the present study was the Kahinur plantation forest of Mau district, Uttar Pradesh, India. The plantation forest is a subtropical forest and has been developed by Uttar Pradesh Forest Department during the year 1982 for commercial production of wood and other services. The area of the plantation forest is about 120 ha and its GPS location in between 25° 52′274″N and 83° 30′578″E. The study area experiences a humid dry winter type, with average rainfall ranging from 650 to 800 mm from June to September, and the temperature varied from maximum 42 °C in summer and minimum 7 °C in winter (Fig. 1).

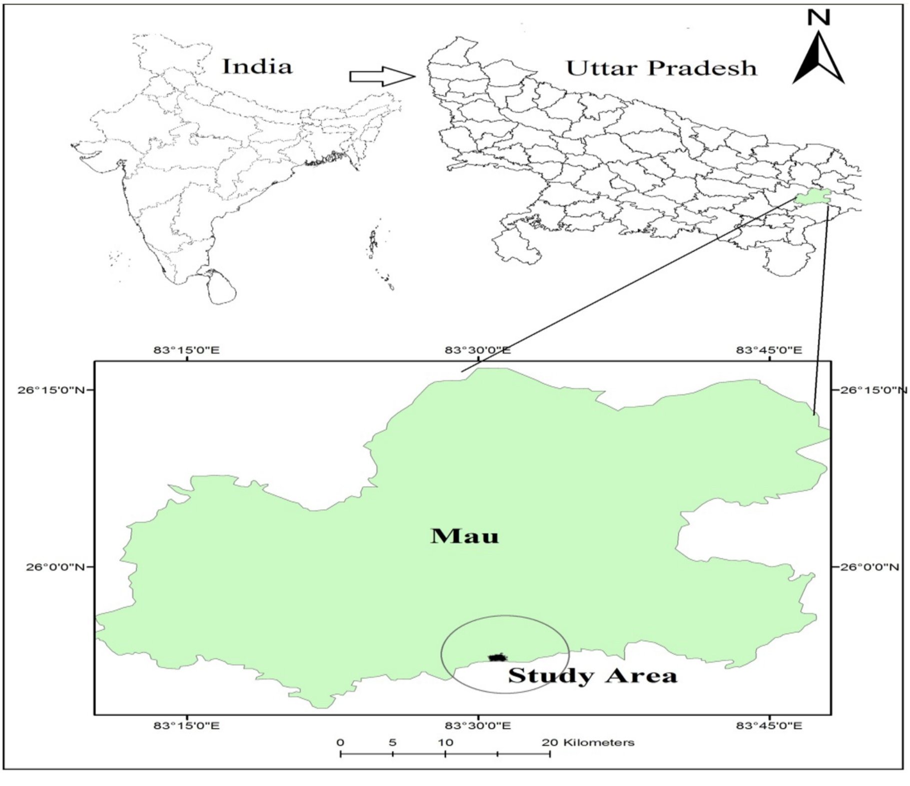

Fig. 1 Map showing location of study site

2.1 Selection of tree species for analysis

About 25 tree species were reported in the selected plantation forest. Out of these, 12 species were chosen for the present study, which were dominant in the plantation forest and order of preference of local people as fuel wood are given in (Table 1). Women and children are carrying a heavy bundle of fuel wood on their head collected from the selected plantation forest (Fig. 2a and b).

2.2 Sampling and analysis

Randomly, 12 tree species between the age group of 10–20 years were selected for sampling. Wood samples were collected from the stem of each species slightly above from the diameter at breast height (DBH). Wood samples 10 cm in length and 8 cm in width were harvested before the removal of bark from each species and were collected in polyethylene

Table 1 List of selected tree species its vernacular name, maximum height and order of preference by local peoples for fuel wood

Tree species (scientific name)	Vernacular or local name	Family	Species height grows up to in meter (m)	Order of use of fuel wood in selected area by local inhabitants[a]
P. juliflora (Sw.) DC	Vilayati babul	Fabaceae	15	1
Alangium salvifolium (L. f.) W	Ankol	Cornaceae	10	2
T. arjuna (Roxb. ex DC.)W& A	Arjun	Combretaceae	25	3
T. grandis (L. f.)	Teak	Lamiaceae	30	4
A. Scholaris (L.) R. Br	Chitvan	Apocynaceae	40	5
Eucalyptus sp. (L'Hér.)	Safeda	Myrtaceae	65	6
S. asper (Lour.)	Sihora	Moraceae	10	7
Mangifera indica (L.)	Mango	Anacardiaceae	40	8
Eugenia jambolana (Lam.)	Jamun	Myrtaceae	38	9
H. integreifolia (Planch.)	Chilbil	Ulmaceae	18	10
F. benghalensis (L.)	Bargad	Moraceae	30	11
P. dulce (Roxb.)B	Jangal jalebi	Fabaceae	18	12

[a]Collection of species in head loads on the basis of local preference, 1 for maximum collection and 12 for least collection. Here, head loads mean collection of fuel wood in local basket by local inhabitants for daily needs especially as a fuel

Fig. 2 **a** Collection of fuel wood from the plantation forest by local woman's on their heads, **b** collection of information related to how much fuel wood collected per day basis and identified which species are maximum each head loads

bag and sealed to avoid the loss of moisture content with proper labeling. All samples were taken to the laboratory of Department of Environmental Science at university campus, Lucknow, India, for determining the fuel wood properties and other elemental analysis.

2.3 Physical properties

For moisture content, freshly cut wood samples were collected in triplicate and oven-dried at 103° ± 3 °C until they attained constant weight (Valter et al. 2008).

$$\text{Moisture content (MC)} = W_F - W_O / W_O \times 100,$$

where W_F, fresh weight; W_O, oven dry weight.

Bulk density (BD) or wood density was determined by mercury displacement technique (Walker et al. 1993). The BD was determined by using equation:

$$\text{Bulk density (BD)} = W_{OD}/V_G$$

where W_{OD} is the oven dry biomass, V_G is the green volume of biomass.

2.4 Energy analysis

Energy analysis section is divided in to four subsections to obtain more conclusive data and result.

2.4.1 Determination of calorific value

To estimate the calorific value of wood samples on the basis of dry weight, 2 g of oven-dried powdered material was burnt in Rajdhani® bomb calorimeter (Bhaat and Todaria 1990). There were three replicate for each sample.

2.4.2 Proximate analysis

Ash content (at dry basis) was determined by burning of 2 g wood sample in a platinum crucible in a muffle furnace (Lenton Thermal Designs EF 11/8B) at temperature

550 ± 10 °C for 2 h. Subsequently, the ash was weighed and the ash content was determined using equation:

$$\text{Ash content (AC)} = \frac{\text{mass of ash}}{\text{mass of oven dry wood sample}} \times 100.$$

Volatile matter (at dry basis) content was determined by burning of 2 g wood sample in a fused silica crucible with lid in a muffle furnace (Lenton Thermal Designs EF 11/8B) at temperature 900 ± 10 °C for 2 h. All analyses were performed in duplicate, and the results were expressed on a dry weight basis. Fixed carbon content (FCC) was determined by using the equation below.

$$\text{FCC (\%)} = [100 - (A_C\% + V_C\%)]$$

where FCC, fixed carbon content; A_C, ash content; V_C, volatile matter content.

2.4.3 Ultimate analysis

Elemental analysis or ultimate analysis (carbon, hydrogen, nitrogen and sulfur) was carried out using CHN analyzer (LECO-CHN-200). Oxygen was calculated by subtracting the sum of CHN, S, and ash percentage from 100% (Kumar and Chandrashekar 2014).

2.4.4 Fuel wood value index (FVI)

For estimation of suitable tree species for fuel wood, FVI was calculated as determined by Purohit and Nautiyal (1987). The calorific value and wood density of the fuel wood were took into account as positive characters and, on the other hand, ash and moisture content as negative characters. However, moisture content of the fuel wood varies with dimension of branches and in different seasons. Therefore, moisture content cannot be considered as part of the intrinsic value of tree species for fuel wood. Therefore, the modified formula for calculation of FVI was given by Bhaat and Todaria (1990):

$$\text{Fuelwood value index (FVI)} = \frac{\text{Calorific value (MJ/Kg)} \times \text{wood density (g/cm}^3)}{\text{Ash content (\%)}}.$$

Over all rank of the fuel wood properties and elemental composition of the selected tree species were assessed on the basis of characteristic of fuel wood and elemental composition. For each attribute, rating of species was made using 1–12 number (1 is for best and 12 is for worst). Based on the total score obtained for each species, was then divided by the number species was selected for the present pool value (Simonne et al. 1999).

2.5 Statistical analysis

Study results were statistically analyzed by using SPSS 16 software. Pearson correlation coefficient was used to calculate the relationship between different fuel wood parameters. An analysis of variance (ANOVA) was performed for statistical comparison of means. The mean differences between species were evaluated using Tukey's test ($P < 0.05$).

3 Results and discussion

3.1 Physical properties

Characterization of fuel wood on the basis of physical properties plays an important role in biomass energy. Moisture content is an important property defining the easiness of fuel wood combustion. An ideal fuel wood should have higher bulk density coupled with lower moisture content. Here, bulk density and moisture content were evaluated for all the selected species and results provide a new insight for its use for societal needs.

3.1.1 Bulk density (BD) and moisture content (MC)

As in general, ideal species for fuel wood are those which have higher BD, higher CV, and lower ash and MC. The BD, CV, ash content, MC, and fuel wood value index (FVI) of 12 subtropical tree species were investigated for screening the tree species depending upon fuel wood properties. In the present study, BD of different tree species is shown in Table 3. The value ranged from 0.32 to 0.80 g/cm^3. Higher BD was found in species *P. juliflora* (0.80 g/cm^3), and lower value was found in species *S. asper* (0.32 g/cm^3). The BD of wood sample represents its compactness of wood as being genetic trait. It varies from species to species depending upon anatomical structure and chemical composition (Zobel and Talbert 1984; Singh et al. 2014). Species with higher wood density are preferred as fuel wood; the reason behind this is higher energy content per unit volume and slow burning properties (Goel and Behl 1996). The MC in variety of species ranged from 38.70 to 58.67%. Higher value was found in species *T. arjuna* (58.67%) and lower value in *P. juliflora* (38.70%). Generally, wood species with higher MC decrease its calorific value and species which are denser with less MC are preferred for fuel wood because per unit volume of energy content is higher and rate of burning is slow (Kataki and Konwer 2002). Many studies reported that tropical tree species exhibited comparatively higher MC than temperate species (Bhaat et al. 2007). Species with higher BD contain higher carbon per unit area. Species *P. juliflora, T. grandis, A. scholaris*, and *F. benghalensis* showed higher BD with less MC in comparison with other selected species. So, these species should be given preference in future energy plantation for rural community in the selected study area.

3.2 Energy analysis

Biomass is one of the major sources of energy and is expected to play a major role in substitution for conventional energy sources. Analysis of fuel wood as energy source consists of energy stored in two forms as fixed carbon and volatile matter. An ideal solid biomass should have higher calorific value and lower ash content. Calorific value indicates the amount of energy obtained from complete combustion of biomass. In any biomass, the higher the value of ash content, the lower value the calorific value.

3.2.1 Ash content and calorific value (CV)

Higher amount of ash content in fuel wood cause negative impact on combustion process, and ash content is very important parameter for identifying both the fuel wood quality and environmental impact. Ash content in the present study varied in different species as shown in (Table 2). The value ranged from 0.82 to 2.81%, maximum value was found in species

Table 2 Calorific value (CV), moisture content (MC), bulk density (BD), ash content (AC), fuel wood value index (FVI), and ranking of tree species on the bases of FVI

Species name	CV (MJ/kg)	MC (%)	BD (g/cm^3)	AC (%)	FVI	Ranking on the bases of (FVI)
P. juliflora	22.56^{a} ± 1.27	38.70^{a} ± 0.83	0.80^{c} ± 0.71	0.96^{ab} ± 0.67	18.80	1
T. grandis	19.92^{a} ± 0.56	40.12^{ab} ± 0.72	0.64^{abc} ± 0.42	0.89^{a} ± 0.43	14.32	2
F. benghalensis	18.26^{a} ± 1.14	51.48^{abc} ± 0.94	0.68^{bc} ± 0.65	1.26^{ab} ± 0.15	9.85	3
A. scholaris	19.33^{a} ± 0.63	41.85^{ab} ± 0.86	0.56^{abc} ± 0.61	1.17^{ab} ± 0.34	9.25	4
H. integrifolia	19.35^{a} ± 0.62	53.02^{bcd} ± 0.63	0.50^{abc} ± 0.53	1.10^{ab} ± 0.16	8.79	5
S. asper	17.32^{a} ± 0.53	57.01^{d} ± 1.41	0.32^{a} ± 0.92	0.82^{a} ± 0.76	6.75	6
E. sp	20.09^{a} ± 1.17	58.67^{d} ± 1.81	0.58^{abc} ± 0.81	2.00^{ab} ± 0.27	5.82	7
T. arjuna	21.63^{a} ± 0.83	58.51^{d} ± 1.11	0.57^{abc} ± 0.61	2.41^{ab} ± 0.32	5.11	8
A. salvifolium	18.89^{a} ± 1.13	53.57 ^{cd} ± 0.93	0.40^{ab} ± 0.31	2.02^{ab} ± 0.27	3.74	9
E. jambolana	18.12^{a} ± 0.31	56.79^{d} ± 1.36	0.37^{ab} ± 0.44	1.83^{ab} ± 0.37	3.66	10
M. indica	18.35^{a} ± 0.43	57.99^{d} ± 1.12	0.45^{abc} ± 0.53	2.42^{ab} ± 0.51	3.41	11
P. dulce	20.67^{a} ± 0.91	51.52^{abc} ± 1.71	0.43^{ab} ± 0.57	2.81^{b} ± 0.23	3.16	12

Estimation of all the average value in triplicate form: ± means SD: standard deviation. One-way ANOVA was performed to compare the mean using Tukey's test ($P < 0.05$). Different letters shows significant differences among different fuel wood parameters of the selected tree species

P. dulice (2.81%), and minimum value was found in *S. asper* (0.82%). The higher value of ash content in fuel makes it less desirable fuel, because maximum part of fuel volume could not be converted into energy (Kumar et al. 2009). The properties of fuel wood depend on quantity and qualitative properties, which includes CV, MC, BD, ash content, and chemical composition. Although many studies emphasized that dry wood shows higher CV than non-dried wood, further CV of different tree species depends on moisture content; higher the moisture content, lesser will be the efficiency of fuel wood (Senelwa and Sims 1999). The CV in the present study showed variations in different species. The value ranged from 17.32 to 22.56 MJ/kg, and species like *P. juliflura* (22.56 MJ/kg) showed higher CV, and *S. asper* (17.32 MJ/kg) showed lower value of CV. However, in the present investigation, there is no statistical difference between average CV values of studied tree species. Properties or qualities of fuel wood are known better through the estimation of CV which depends on chemical composition in different tree species (Sofer and Zaborsky 1981). It has been reported that fuel wood species which have higher amount of lignin and extractives have higher CV and fuel wood which has predominance of cellulose and hemicelluloses as a sugar units leads to lower CV (Kumar et al. 1992). Moreover, CV of fuel depends effectively on moisture content. Higher amount of moisture content has lower efficiency in fuel wood due to reduced net calorific value of heating (Ojelel et al. 2015). In general, an ideal fuel wood containing high heating value or calorific value with lower ash content is more desirable.

3.2.2 Fuel wood value index (FVI)

The FVI depends on CV, BD, and ash content of fuel wood. On the basis of these three parameters of fuel wood, FVI of 12 tree species is reported in Table 2. The value ranges from 3.74 to 18.80. The maximum value was reported in species *P. julifulora* (18.80), *T. grandis* (14.32)*, F. benghalensis* (9.85), and minimum value was found in species *A. salvifolium* (3.74), *E. jambolana* (3.66), and *M. indica* (3.41). Some species shows medium or intermediate value which are considered as good quality fuel and should be concentrated in future energy plantation. For screening fuel wood efficient species, FVI is an important and insightful parameter (Deka et al. 2007). Three-factor combination CV and BD as positive character and ash content as negative character is more appropriate for determining the efficiency of wood as fuel (Saravanan et al. 2013). Higher value ash content causes lower value of FVI and thus has lower energy potential. Therefore, species with higher value of FVI were therefore considered as good for fuel (Ramos et al. 2008). On the basis of FVI, it has been conclude that species *P. juliflora, T. grandis, F. benghalensis*, and *A. scholaris* possess better-quality fuel wood and is considered for future energy plantation in the selected study area.

3.2.3 Proximate and ultimate analysis (Elemental composition)

The percentage of volatile matter content (VMC) in the present results ranged from 76.89 to 85.64% as shown in (Table 3). Among all the tree species, maximum value of VMC was found in species *P. dulce* (85.64%), and minimum value was observed in species *Eucalyptus* sp (76.89%). Higher amount of VMC in wood results higher number of functional groups and lesser number of aromatic structures. It has been investigated that fuel wood with higher content of volatile matter, wax, resin, and lignin content produces higher heat during combustion process (Jain 1994; Kataki and Konwer 2002). Fixed carbon content (FCC) ranged from 12.19 to 22.04%. It was found maximum in species *P. juliflora* (22.04%) for FCC, and minimum value was found in species *P. dulice* (12.19%) for FCC. When the biomass heated during the combustion process, the volatile matter escapes first and burns in gaseous state and fixed carbon is left behind as char, which burns later in the form of solid state. Higher value of FCC adds higher value of energy in plant materials (Kumar et al 1992; Kumar et al. 2010).

Ultimate analysis is very important to determine the theoretical ratio of air and fuel in thermochemical conversion. In the present investigation, results of chemical composition are presented in Table 3. The value of ultimate carbon, hydrogen, nitrogen, and sulfur ranged from 40.80 to 46.06% C, 4.72 to 6.73% H, 0.02 to 1.39% N, and 0.012 to 0.001% S, respectively. Higher amount of elemental composition was found in species *P. juliflora* (46.80%) C, and minimum value was found in species *S. asper* (40.80%) C. Hydrogen was found maximum in species *F. benghalensis* (6.73%) H, and minimum value was found in species *T. arjuna* (4.72%) H. Ultimate nitrogen value was found maximum in species *S. asper* (1.39%) N and minimum value was found in species *E.* sp (0.02%) N. The minimum percent of sulfur and nitrogen in fuel wood is important from environmental point of view. Oxygen content was obtained from subtracting the value obtained from sum of C, H, N, and S value from 100%. In any fuel, carbon–hydrogen and carbon–oxygen bond contains lesser energy than carbon–carbon bond, and maximum proportion of hydrogen and oxygen in any biomass reduces the value of energy in any fuel (Nordin 1994; Kumar et al. 2010).

Table 3 Elemental composition (Ultimate analysis), ash content, VMC, FCC (proximate analysis) of different tree species

Scientific name	Ultimate analysis (%)					Proximate analysis (%)		
	C	H	N	S	$O^{\#}$	Ash	VMC	$FCC^{\#}$
A. salvifolium	$43.2^{ab} \pm 0.61$	$6.35^{a} \pm 0.32$	$0.135^{a} \pm 0.24$	0.001	$51.70^{bc} \pm 0.67$	$2.02^{ab} \pm 0.27$	$78.12^{ab} \pm 0.14$	$19.98^{bc} \pm 0.71$
A. scholaris	$44.40^{bc} \pm 0.21$	$5.67^{a} \pm 0.43$	$1.34^{f} \pm 0.54$	*	$52.58^{bc} \pm 1.2$	$1.17^{ab} \pm 0.34$	$80.24^{ab} \pm 0.21$	$18.83^{bc} \pm 0.12$
E. jambolana	$43.87^{ab} \pm 0.21$	$6.24^{a} \pm 0.54$	$0.59^{cd} \pm 0.43$	*	$42.53^{a} \pm 0.68$	$1.83^{ab} \pm 0.37$	$81.07^{ab} \pm 0.42$	$17.17^{bc} \pm 0.21$
E. sp	$44.50^{ab} \pm 0.54$	$5.96^{a} \pm 0.54$	$0.02^{ab} \pm 0.29$	*	$52.48^{bc} \pm 0.91$	$2.00^{ab} \pm 0.27$	$76.89^{a} \pm 0.31$	$22.00^{d} \pm 0.76$
F. benghalensis	$45.60^{bc} \pm 0.64$	$6.73^{a} \pm 0.64$	$0.31^{ab} \pm 0.41$	0.012	$53.91^{bc} \pm 0.87$	$1.26^{ab} \pm 0.15$	$77.21^{ab} \pm 0.41$	$21.74^{d} \pm 0.23$
H. integroifolia	$45.60^{c} \pm 0.78$	$5.25^{a} \pm 0.37$	$0.123^{a} \pm 0.76$	0.001	$52.07^{bc} \pm 0.47$	$1.10^{ab} \pm 0.16$	$82.43^{cd} \pm 0.21$	$16.09^{ab} \pm 0.21$
M. indica	$42.24^{ab} \pm 0.43$	$6.12^{a} \pm 0.86$	$1.07^{g} \pm 0.67$	*	$51.85^{bc} \pm 0.89$	$2.42^{ab} \pm 0.51$	$83.56^{cd} \pm 0.32$	$14.58^{ab} \pm 0.23$
P. juliflora	$46.06^{c} \pm 0.44$	$5.69^{a} \pm 0.61$	$0.46^{bc} \pm 0.34$	*	$53.71^{bc} \pm 0.76$	$0.96^{ab} \pm 0.67$	$77.01^{a} \pm 0.61$	$22.04^{d} \pm 0.65$
P. dulce	$45.21^{bc} \pm 0.79$	$6.61^{a} \pm 0.29$	$1.135^{f} \pm 0.63$	0.010	$55.76^{c} \pm 0.71$	$2.81^{b} \pm 0.23$	$85.64^{d} \pm 0.31$	$12.19^{a} \pm 0.13$
S. asper	$40.80^{a} \pm 0.53$	$5.91^{a} \pm 0.64$	$1.399^{f} \pm 0.43$	*	$48.92^{b} \pm 0.83$	$0.82^{a} \pm 0.76$	$79.42^{ab} \pm 0.43$	$20.18^{cd} \pm 0.32$
T. arjuna	$45.30^{bc} \pm 0.34$	$4.72^{a} \pm 0.32$	$1.02^{f} \pm 0.67$	0.012	$53.45^{bc} \pm 0.85$	$2.41^{ab} \pm 0.32$	$83.91^{cd} \pm 0.41$	$14.59^{ab} \pm 0.41$
T. grandis	$45.60^{a} \pm 0.32$	$5.95^{a} \pm 0.78$	$0.86^{ef} \pm 0.76$	0.012	$53.30^{bc} \pm 0.96$	$0.89^{a} \pm 0.43$	$81.14^{bc} \pm 0.63$	$18.11^{bc} \pm 0.42$

C carbon; H hydrogen; N nitrogen; S sulfur; O oxygen; VMC volatile matter content; FCC fixed carbon content; # calculated by difference method, * no value was found. One-way ANOVA was performed to compare the mean using Tukey's test ($P < 0.05$). Different letters shows significant differences among different fuel wood parameters of the selected tree species

Fuel wood containing higher proportion of carbon is more desirable and lower percentage of sulfur and nitrogen is important from an environmental point of view.

Rating of 12 tree species on the basis on fuel wood properties of subtropical tree species of north India is presented in Table 4. In rating of species in terms of energy output and composition of elements, the species were assigned the value 1–12: Value 1 is for the best and value 12 is for the worst. Based on final rating, the preferred species for fuel wood should be *P. juliflora* > *T. grandis* > *F. benghalensis* > *H. integrifolia* > *A. scholaris* > *P. dulce* > *A. salvifolium* > *S. asper* > *E. spp* > *M. indica* > *T. arjuna* > *E. jambolana*. The species *P. juliflora* with its higher calorific value and bulk density with lower moisture content was ranked the best one. And the worst rank species *E. jambolana* has the lower value of calorific value and lower bulk density with lesser moisture content. However, this study predicted that only a single parameter is not enough to choose or identify the suitable tree species for fuel wood.

3.2.4 Fuel wood parametric correlation studies

Table 5 shows Pearson correlation coefficient between different fuel wood parameters like carbon (C), nitrogen (N), hydrogen (H), oxygen (O), moisture content (MC), bulk density (BD), calorific value (CV), ash content, volatile matter content (VMC), and fixed carbon content (FCC). The CV shows significantly positive correlation with BD and C ($P < 0.05$). MC shows negative correlation with BD ($P < 0.05$). BD shows significantly positive correlation with C ($P < 0.01$). AC shows negative correlation with FCC ($P < 0.01$), and VMC shows negative correlation with FCC ($P < 0.01$) in the present study.

Combustion of biomass releases fewer amounts of green house gases in comparison with another conventional energy source. However, burning of fuel wood is common in rural communities, and emission of smoke due to combustion can be responsible for about 25% of particulate matter, volatile organic compound 15%, and carbon monoxide

Table 4 Ranking of tree species on the basis of fuel wood properties and elemental composition

Species	Properties									
	CV	MC	BD	Ash	C	H	N	O	VMC	FCC	Over all rank[a]
P. juliflora	1	1	1	3	1	9	7	6	10	1	3.34 (01)
T. grandis	5	2	3	2	4	7	6	7	8	7	4.25 (02)
F. benghalensis	10	4	2	6	2	1	9	10	11	3	4.84 (03)
H. integroifolia	6	6	7	4	3	11	11	1	4	9	5.17 (04)
A. scholaris	7	3	6	5	8	10	2	9	7	6	5.25 (05)
P. dulce	3	5	9	12	6	2	3	11	1	12	5.34 (06)
A. salvifolium	8	7	10	9	10	3	10	2	6	5	5.84 (07)
S. asper	12	9	12	1	12	8	1	3	9	4	5.92 (08)
E. sp.	4	12	4	8	7	6	12	5	12	2	6.00 (09)
M. indica	9	10	8	11	11	5	4	4	2	11	6.25 (10)
T. arjuna	2	11	5	10	5	12	5	12	3	10	6.25 (11)
E. jambolana	11	8	11	7	9	4	8	8	5	8	6.59 (12)

For quality criterion of each species the value ranges from 1 to 12 and the value 1 is (best) and 12 is (worst)

[a]Values in brackets represents over all ranks, 1 represents best and 12 represent worst

Table 5 Pearson correlation coefficient between moisture content (MC), bulk density (BD), calorific value (CV), proximate and ultimate analysis of selected tree species

	CV	MC	BD	AC	C	H	N	O	VMC	FCC
CV	1									
MC	− .419	1								
BD	.652*	− .638*	1							
AC	.160	.561	− .338	1						
C	.697*	− .508	.754**	− .062	1					
H	− .445	− .007	− .185	.139	− .180	1				
N	− .107	− .092	− .289	.052	− .391	− .114	1			
O	.554	− .359	.544	.118	.474	− .061	.005	1		
VMC	− .067	.543	− .119	.535	.119	− .140	.086	.146	1	
FCC	− .086	− .270	.416	− .625*	− .012	.163	− .446	− .075	− .581*	1

**Correlation is significant at the 0.01 level (two tailed)

*Correlation is significant at the 0.05 level (two tailed)

contribute 13% into the atmosphere (Naeher et al. 2007; Singh et al. 2014). Fuel wood consumption has a complex interrelationship with forest degradation (Rudel 2005). Deforestation makes life difficult to rural people as they depend on forest for their basic energy requirement and also significantly contribute in climate change. Therefore, screening of suitable tree species on the basis of fuel wood characteristics is essential to identify the tree species on the basis of reduced emission and superior for fuel wood. Production of biomass energy and comparing with other options for transformation of woody biomass into bioenergy production purposes have number of beneficial impact such as energy security, creation of job, and other positive implication at regional scale (Gruenewald et al. 2007). However, it is important to assert that rural people are less concerning about requirement of fuel wood, and therefore, acceptable feature socially is also important to be considered and to generate checklist to generate fuel wood species in the selected region (Ojelel et al. 2015). Comparison of different tree species on the bases of chemical composition and other parameters shows that some species as *P. juliflora, T. grandis, F. benghalensis*, and *H. integreifolia* are better choice in term of energy outputs and future energy plantation in this region. However, further studies are needed to determine the growth rate of these species under different ecological conditions and productivity before energy plantation in this region.

4 Conclusion

Planting and harvesting of suitable tree species for energy purposes are a part of world energy strategy and should be optimized regionally. The present results emphasize that only the single basic parameter is not enough for identifying the suitable tree species as a fuel wood. The present investigation accentuate that calorific value is not the only factor for evaluating the better-quality fuel wood, but there are other parameters which also have significant effect. As compared to ash content, calorific value and bulk density of some species show higher calorific value, and lesser bulk density and some species show higher calorific value and higher ash content compared to different species in the present results. On the basis of overall ranking of different tree species in the present investigation, using FVI and other fuel wood properties, which were taken into account, it is recommended that species *P. juliflora, T. grandis, F. benghalensis,, A. scholaris*, and *H. integrifolia* are found as energy efficient fuel wood and that attention should be given on such tree species for large-scale energy plantation in future, especially in this region of Uttar Pradesh, India, to fulfill the future demand of rural communities, in view of sustainable and green growth.

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RESEARCH ARTICLE

Calorific Value and Fuel Wood Consumption Patterns of a Plantation Forest at Kahinure (Distt Mau), Uttar Pradesh, India by Villagers

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Abstract In the present study, calorific value of different fuel wood biomass and its consumption patterns of the plantation forest in rural area of Kahinure (Distt Mau) Uttar Pradesh, India had been evaluated. A questionnaire survey of random sampling method was employed for 180 households to understand socio-economic conditions and energy use pattern for cooking purposes in the study area. The study reveals that fuel wood was largely utilised as non-commercial and cheap source of energy, followed by dung cake and agriculture residue. The highest calorific value was estimated by *Prosopis juliflora* (22.56 MJ/kg) followed in *Terminalia arjuna* (21.63 MJ/kg) and *Pithecellobium dulce* (20.67 MJ/kg), whereas the lowest value was found in *Streblus asper* (17.32 MJ/kg). About 65% of household energy consumption was in form of wood biomass fuel derived from the plantation forest. The cow dung was used by 22% households and agriculture residue by 12%. About 1.3% people used kerosene for cooking. Average cooking time was estimated at 4.46 h/day/family, and average value of fuel wood consumption was estimated at 4.5 t/family/year, whereas average market value of annual consumption of fuel wood had been calculated as Rs 8,700.00 per households. Due to poor socio-economic situations in the village, a significant amount of fixed carbon of plantation forest was used for cooking of food which could be saved by providing them renewable source of energy for cooking or cooking gas cylinders.

Keywords Consumption, Calorific value, Fuel wood, Households, Plantation forest, Rural area, Wood biomass

1. Introduction

Globally, wood biomass is considered one of the primary sources of energy for meeting the daily energy need, and it has been estimated that approximately 3 billion people use solid biomass fuel including wood, dung cake, agriculture waste and coal throughout the world (Bond *et al*., 2004). Wood biomass accounts for about 14% of total energy used globally and is the largest energy source for three-quarters of the world's population living in the developing countries (Sedai *et al.,* 2016). The total average annual production of wood fuel for energy in the developing countries increases nearly 17.6% over the last decade (Simon and Singh, 2015). In India, over 170 million households and almost 800 million people depends on traditional chulha using solid biofuels such as wood, agricultural waste, coal and dried cattle manure (Singh *et al*., 2014). Rural areas largely depend on locally available resources like forests and agriculture crops to meet their domestic energy needs. Among the various forms of biomass, firewood is the most attractive and occupies a predominant place in the rural energy budget of the country (Jaiswal and Bhattacharya, 2013). Fuel wood is the only source of energy for many people living in the rural areas due to the lack of other available energy sources.

According to 2011 Indian Census, approximately 66% of households relied primarily as solid biomass fuel for energy; this includes 23% urban households and 86% rural households, which adversely affect respiratory health of the individuals. It reduces local forest cover and soil biodiversity dependent on those forests or plant rhizosphere and contributes to carbon release by burning the fuel wood (Anenberg *et al.,* 2013). National Sample Survey resulted that as of 2011–2012, around 80% of Indian households used some form of traditional fuels to satisfy their cooking and heating needs (Jain *et al*., 2015). The adverse health, livelihood, local environment and climate impacts generated by household biomass burning have gained increased attention in the past few years.

The quality of fuel wood is recognised by their calorific value, which is normally governed by the availability, time duration of burning, maximum temperature and the ash content (Lisardo *et al*., 2003). Generally, species burn for

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longer time and emit less smoke is considered more preferred. However, majority of rural people consume fuel wood as whatever fuel wood is available without considering energy value, ecological factor and sustainability. Factors responsible for performance of fuel wood are calorific value, moisture content, bulk density and ash content (Todaro *et al.,* 2015). Higher the moisture content, results decrease in the combustion efficiency of the fuel wood. Important attempts have established the negative effect of moisture content on its calorific value (Kumar *et al*., 2009). The calorific value of fuel wood indicates the amount of heat that develops from the complete combustion of wood sample with a given mass. The variance in calorific value in different species can be attributed to its chemical composition.

This paper is an attempt to document the socio-economic attributes of households in the rural area of Kahinure (District Mau), Uttar Pradesh, India and their dependency on plantation forest in terms of using fuel wood as energy alternatives based on information gathered from the field study and household survey. The study concentrates on the following objectives: (i) calorific value estimation of plantation forest species in study area, (ii) analysing the consumption and collection of fuel wood in the selected households for estimating the fuel wood requirement in the area. This information will be useful in designing and implementing appropriate conservation strategies in the area by understanding the needs of households, livelihood opportunities, forest dependency and their critical consequences in deforestation and forest degradation process under the particular set of ecological, sociological, economic and political conditions.

2. Material and Methods

2.1 Study Area

The study area, a rural area of Mau district, is located in Uttar Pradesh, India with a population of about 3,065. The study area lies between 25°52′274″N and 83°30′578″E. Maximum population of the study area used biomass as fuel wood and cow dung as primary source of energy for daily cooking purposes. Forest covered in the study area consists of plantation forest which is classified under subtropical deciduous forest. Plantation forest was distributed on 118 ha along the studied village. Such plantation forest dominantly has four types of plantation association that is (i) *Tectona grandis* plantation, (ii) *P. juliflora* plantation, (iii) *Eucalyptus* plantation and (iv) mixed plantation forest. Majority of households depend on surrounding plantation forest for their fuel wood.

2.2 Sampling Methods

The current study was conducted during the year 2015–2016. Before the collection of exact data, a reconnaissance survey has been done to understand the number of households, family size or family member, energy use pattern, biomass used for cooking purposes, chulha used for cooking and other important parameters for the study. About 180 households were randomly selected for the present study. The information was collected by questionnaire method which is related to socio-economic condition and energy use pattern of households. Interviews were conducted and recorded using structured questionnaires. The survey questionnaire was translated into local language Hindi, wherever necessary, help of a local person was taken who accompanied the authors during the survey. The questionnaires were supplemented within formal meetings and discussions. One questionnaire was filled by each household. The survey report undertook complete investigation about the selected village depending on surrounding forest for fuel wood. Villager's dependency on the forest fuel wood, fuel collection per day per household and number of head loads (local units, fuel wood carried on the head for domestic purposes) was counted per day production from the plantation forest and identified which species are maximum in each head loads. Fuel wood consumption on household level was calculated on the basis of family size. On the basis of total number of family members, we have divided the family size in five different family classes (Miah *et al*., 2003): very small (4–8 members), small (9–12 members), medium (13–16 members), large (17–20 members) and very large (21–24 members). The respondents were also asked for their involvement in tree plantation and their support on energy plantation on waste land and degraded land. All the data collected from the respondents were cross-checked with family members and physical verification.

2.3 Calorific Value Determination

Estimation of gross calorific value of wood samples on the basis of per unit biomass was determined by 2 g of oven-dried powdered wood samples in three replicates for each sample. Oxygen bomb calorimeter method was used for calorific value determination (Bhatt and Todaria, 1990).

2.4 Socio-economic Condition of Households

Studied village occupied 490 households with a population of 3,065 individuals, whereas the family size of studied village ranged from 4 to 22 persons per family. Out of 490 households in the selected study area, total 180 respondents between the ages of 22 and 75 years with an average age of 30–50 years were interviewed for the study. The 90% of the respondents were head of the households and responsible for collection of the fuel wood and other sources of energy for cooking daily meal and warming during the winter seasons. According to the respondents, agriculture

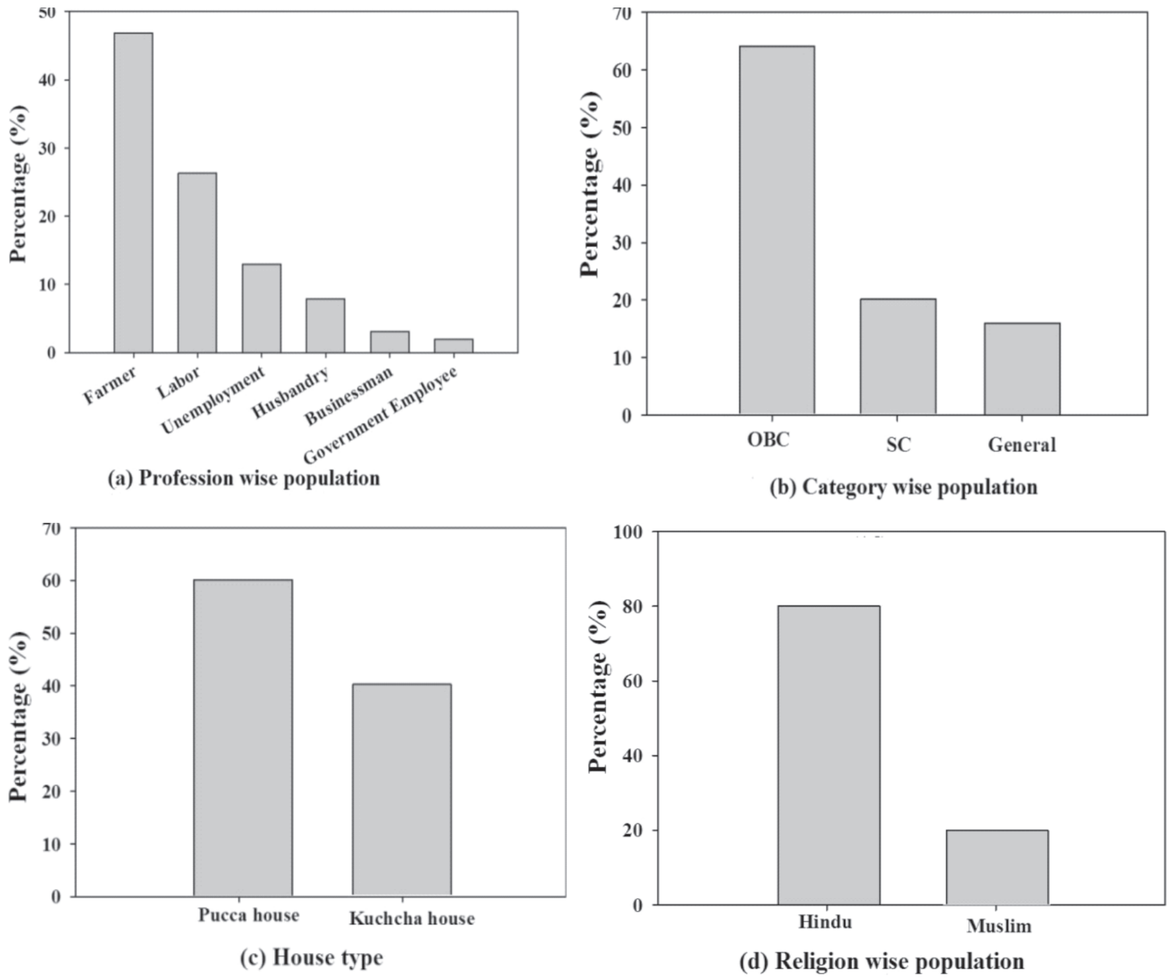

Figure 1. Demography and socio-economic status of the study site: (a) Profession-wise population, (b) category-wise population, (c) house type, (d) religion-wise population

is the main source of livelihood. The forest resources are important for their daily energy need. Demography and socio-economic conditions of the village near the selected study site is presented in Figure 1a–d. Most of the population of study area were farmers (46.83%) and labourers (26.36%) by occupation (Figure 1a). Caste group wise, other backward caste category (64%) was dominated in study area (b). The status of house and population structure of different religions has been presented in Figure 1c and d.

3. Result and Discussion

3.1 Forest Plant Community Composition and Calorific Values of Plant Species

The preferred dominant fuel wood species of study site were *P. juliflora*, *Alangium salviifolium*, *T. arjuna*, *T. grandis* and *Alstonia scholaris.* Details of all species, their vernacular name, calorific values and species ranking on the basis of fuel wood quality are shown in Table 1. Calorific value is an important parameter of tree species that reflects capacity to fix solar radiation during photosynthesis and estimates the amount of heat energy released during combustion of plant tissue. Calorific values of different studied species are given in Table 1. It is an important index for evaluating material cycles and energy conversion in forest ecosystems. Calorific value of species is not only affected by its composition and structure but also other environmental factors as illumination intensity, photoperiod, soil type and nutritional condition (Zeng *et al*., 2014). Highest calorific value occupied by *P. juliflora* (22.56 ± 1.27 MJ/kg), followed by *T. arjuna* (21.63 ± 0.83 MJ/kg) and *P. dulce* (20.67 ± 0.91 MJ/kg), whereas lowest value found in *S. asper* (17.32 ± 0.53 MJ/kg). In general, an ideal fuel wood species should contain high heating value or calorific value with lower value of moisture, and ash content is more desirable. In the present survey report, subtropical tree species were screened and found that these species had a potential as an energy-efficient crops for future energy plantation in this region. Calorific values

Table 1. Species composition of plantation forest and their calorific values and ranking on fuel wood quality

Species	Vernacular Name	Gross Calorific Value (MJ/kg)	Ranking (Fuel Wood Quality)
P. juliflora	Vilayati Babul	22.56 ± 1.27	1
A. salviifolium	Ankol	18.89 ± 1.13	2
T. arjuna	Arjun	21.63 ± 0.83	3
T. grandis	Sagwan	19.92 ± 0.56	4
A. scholaris	Chitvan	19.33 ± 0.63	5
Eucalyptus sp.	Safeda	20.09 ± 1.17	6
S. asper	Sihora	17.32 ± 0.53	7
Madhuca longifolia	Mahva	18.35 ± 0.43	8
Eugenia jambolana	Jamun	18.12 ± 0.31	9
Holoptelea integrifolia	Chilbil	19.35 ± 0.62	10
Ficus benghalensis	Bargad	18.26 ± 1.14	11
P. dulce	Jungle Jalebi	20.67 ± 0.91	12

variation among different tree species and within species has been reported and shows significantly correlative to age too (Bao *et al.,* 2006) however studied plantation forest species having similar age. It has been reported that higher concentrations of extractives and lignin result in greater calorific value (White, 1987; Kataki and Knower, 2001). However, effective calorific value also depends on the moisture content. The higher the moisture content, the less efficient is the wood as a fuel as the net calorific value for heating is reduced (Kumar *et al*., 2011).

3.2 Energy Consumption Pattern of Households

In the selected study area, majority of households used fuel wood for fulfilment of daily energy need. Majority of the households collected fuel wood from plantation forest in vicinity to selected study site. Collection of fuel wood from the plantation forest was considered a sustainable fuel wood production. Composition of energy consumption, their sources and using mode at study area are given in Figure 2. The study resulted that as 65% of households uses fuel wood as primary energy source, followed by cow dung 22%, agriculture residue 12% and 1.3% Kerosene (Figure 2a). Fuel wood using household in study area was higher in per cent value (65%) which was higher than the average value of Uttar Pradesh state, which was reported as 40% (Census of India, 2011). It is may be due to lacking of energy-saving-awareness thoughts and poverty among the population. On the other hand, 71% of all households are using fuel wood in Uttar Pradesh which was higher than our estimated value 65% reported in recent study of Jain *et al.* (2015). It is already a proven fact that traditional cooking stoves in the rural areas are less efficient due to the incomplete combustion of the fuel wood (Miah *et al.,* 2009). This low efficiency is resulting in high consumption of fuel wood which is leading to the more collection of fuel wood from the forests and some health problems also. Approximately 28% households depend on plantation forest for fuel, followed by surrounding (27%) and agriculture (26%), whereas only 1% used government store for their energy needs (Figure 2b). Results show that 74% households used traditional chulha, whereas only 4% households used LPG (Figure 1c). Kitchen types used by households are given in Figure 2d.

In this study, observations support that the energy use pattern in rural India is changing with the uptake of clean energy, but traditional fuels including fuel wood (65%), cow dung (22%) and crop residue (12%) still constitute the major source of household cooking energy because of inadequate and unreliable supply of clean energy options at particular study area, which are almost similar to study which have been done by some previous rural area-based studies (Balakrishnan *et al*., 2004; Das and Srinivasan, 2012). However, due to increasing population and pressure, it is going to become unsustainable due to excessive collection of fuel wood. In addition to this, excessive destruction of natural forests which cause excessive pressure on plantation forest and semi-natural forest make it unsustainable and thereby leading to deforestation (Jashimuddin *et al.,* 2006; Miah *et al*., 2003). Fuel wood collection and consumption from the plantation forest at study site is represented in Table 3. Due to increase in population, the energy demand is increasing tremendously and majority of population living in rural area totally depend on wood biomass as main source of energy. Consumption of fuel wood from the forest ranged between 460 and 470 kg/day. Approximately 45 to 48 head load (average 46.5) were extracted from forest per day, whereas average weight of each head load was 14.5 kg. In study area, the total fuel wood extracted from the plantation forest per day basis was 485 kg/day in summer season and

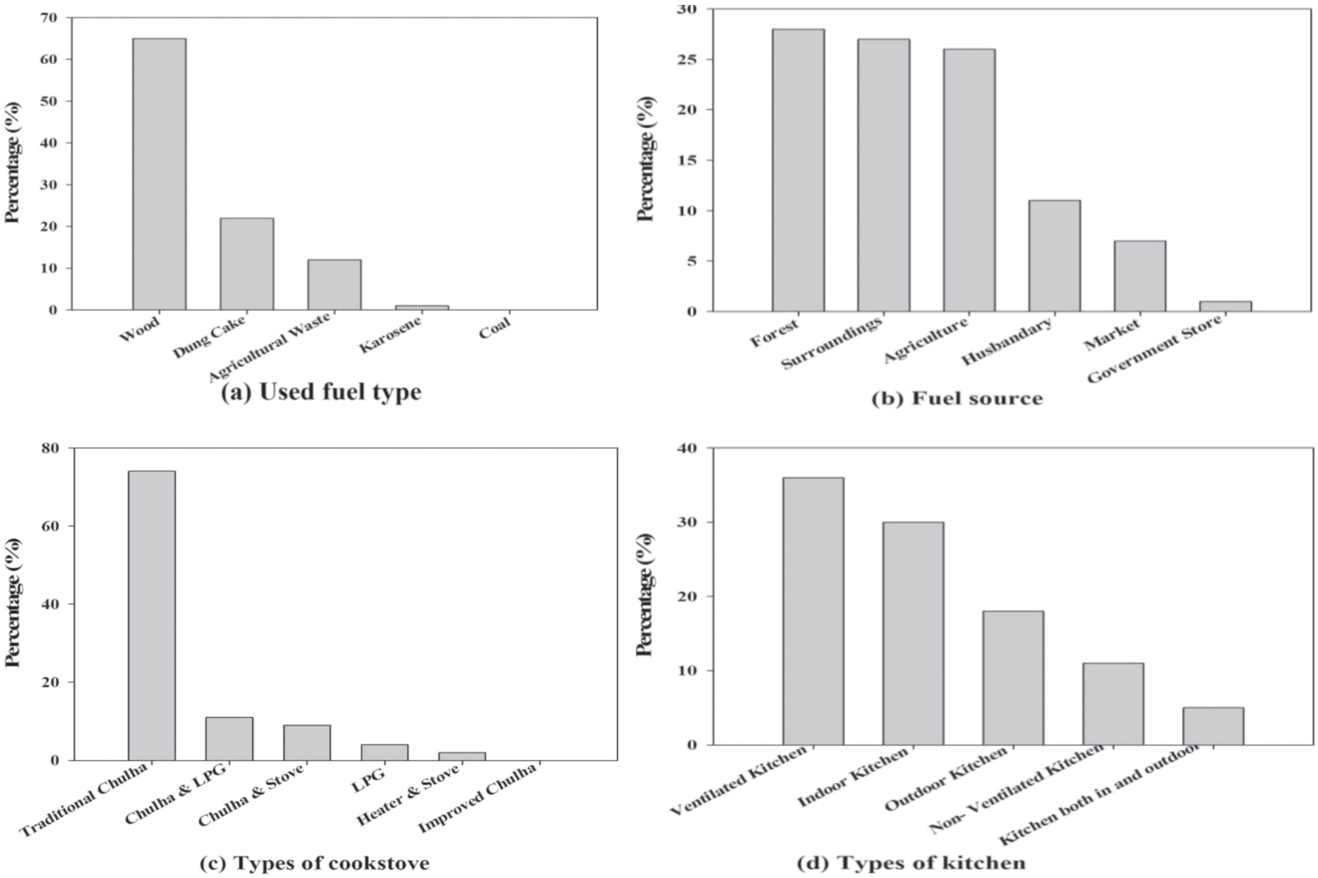

Figure 2. Composition of energy consumption categorised into: (a) used fuel type, (b) fuel source, (c) types of cook stove, (d) type of kitchen

520 kg/day in winter season. The reason of high value of per day forest wood extracted was that majority of households collected fuel wood from the surrounding forests. As per census of 2011, about 49% of households in India use fuel wood for cooking purposes. Fuel wood constitutes the major source of energy for cooking purposes, and about more than 853 million people use fuel wood for daily cooking in India (FSI, 1987, 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2009, 2011). The energy use pattern in rural India is changing with selection of clean energy options, but traditional fuels including fuel wood, crop residue and cow dung are still contributing the main source of household cooking energy due to inadequate and unreliable supply of clean energy.

Excessive usage of fuel wood is associated with rapid degradation of environment and insecurity of energy for rural low-income households (Sedai *et al*., 2016). The average fuel wood collection and fuel wood consumption in two different seasons that is winter season and summer season were studied. There was significant difference in fuel wood collection and fuel wood consumption in different seasons. Fuel wood is a renewable energy resource, and its consumption can only be sustained if the rate of harvesting does not exceed the growth rate (Dhanai *et al*., 2015). Average values of fuel wood collection and consumption were proportionally related to each other and could be clearly differentiated in both seasons as collection range (480–490) was highest in winter with high consuming demand in same season ranges (15–25) compared with summer season (Table 2).

3.3 Households Income, Cooking Time, Consumption of Fuel Wood and Their Market Value

After the collection of data, the households were classified into five family size, that is very small, small, medium, large and very large. Average family income was calculated as maximum income in large family (13,000–25,000 per month) and minimum in very small family (2,000–5,000 per month) (Table 3). Average cooking time of household was 4.46 h/day/family which ranged between lowest (3.2 h/day/family) in very small family to highest (5.9 h/day/family) in very large family. The study showed that average fuel wood consumption from the plantation forest was 4.5 t/family/day with maximum 7.1 family/day

Table 2. Fuel wood collection and consumption from the plantation forest

Parameters	Minimum	Maximum	Average
Consumption of fuel wood from the forest (kg/day)	460	470	465
Number of head load produced from the forest per day	45	48	46.5
Average weight of each head loads (kg)	12	17	14.5
Average fuel wood collected during winter seasons (kg/day)	480	490	485
Average fuel wood collected during summer seasons (kg/day)	250	270	520
Fuel wood consumed by individual households during winter (in per cent kg/day)	15	20	17.5
Fuel wood consumed by individual households during summer (in per cent kg/day)	7	10	8.5

Table 3. Average income of the households, consumption of fuel wood, cooking time and market value of fuel wood in selected study area

Size of Family	Number of Family Members	Monthly Income Level (₹ in Thousands)	Average Monthly Income (₹ in Thousands)	Fuel Wood Consumption Estimates (t/family/year)	Cooking Time (h/day/family)	Market Value of Annual Consumption of Fuel Wood (in ₹)
Very small	28	2–5	2 ± 0.81	2.5	3.2	4,500
Small	40	4–7	5 ± 0.71	3.1	3.9	6,100
Medium	56	8–12	10 ± 1.07	4.2	4.1	8,200
Large	36	6–18	13 ± 3.23	5.6	5.2	10,600
Very large	20	13–25	20 ± 3.35	7.1	5.9	14,100
Average	–	–	–	4.5	4.46	8,700

and minimum 2.5 family/day. Fuel wood constitutes the major source of energy for cooking purposes and about more than 853 million people use fuel wood for daily cooking in India (FSI, 1987, 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2009, 2011). It has been cleared from the present study that large family households consume more fuel wood than small families. It was clear that large families consumed more wood fuel and spent more money than smaller families. Consumption of fuel wood with inefficient chulha consumes higher quantities with maximum time consuming and reduce efficiency. A number of studies reported that fuel wood consumption in traditional chulha is much higher as compared with improved chulha (Alam and Chowdhury, 2010). Most of the chulha user experiences that improved chulha option is time saving during the process of cooking and explained that improved chulha cooks faster than that of traditional mud chulha for the same family members (Kuhnhenn, 2003). High values of fuel wood consumption with high cooking time in study area represent the total lacking of improved chulha and as well as poverty.

The use of fuel wood as a primary source of energy for domestic and commercial use is a cause of severe deforestation in India. Similarly, the present study focuses on forest as one of the important sources of fuel wood and has been meeting the requirement of energy for rural poor households. Due to continue depletion and degradation due to excessive consumption of fuel wood, the sustainability of forest is questioned. This study discusses the production of fuel wood from the Indian forest and visualised technological intervention so that the forest can be sustainably managed. The rural environment is suffering from slow but consistent deforestation and soil erosion, which threatens the entire region's biodiversity. One of the severe impacts of repeated fuel wood harvesting on the structure of the forest is the rapid decline of large, old trees that ultimately results in their complete disappearance. Once these trees are lost, the number of the gaps created by natural tree falls and logging increases (Ruger *et al.,* 2007), which results in forest fragmentation and susceptibility to invasion by ephemerals, that inhibit the regeneration of seedlings of native tree species.

4. Conclusion

Consumption rates are an important variable in defining the potential contribution of a fuel wood source and in assessing the risk of forest over-exploitation. In this regard, study of calorific value of different species in plantation forest of study area will be helpful to recommend their role as a fuel wood species which were investigated here. *P. juliflora* was dominant plant species of studied forest area. It was also a highly ranked species as fuel wood due to their high calorific value. Higher fuel wood consumption in the study area was mainly due to lack of alternative energy sources and poverty. Extensive farming for fuel wood could be one alternative to bridge the gap between supply and demand; consequently, efforts are needed to encourage afforestation of suitable fuel wood species as *P. juliflora, T. arjuna and P. dulce* in the barren areas around the study site, which will help immensely in reducing the degradation of surrounding forests. Information collected in the present study will be helpful in alignment of available resources with future challenges of biomass energy demand and their utilisation in sustainable way and development in rural areas.

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