Assessment of Carbon Emission by Fuel Wood Burning at Different Altitudes in Five Districts of Uttarakhand in Western Himalaya

Vivek Joshi, C.K. Dhyani, Kusum Arunachalam[*], Ujjwal Kumar

School of Environment and Natural Resources Doon University, Dehradun, India
*Corresponding author: kusumdoon@gmail.com

Abstract   Fuel-wood burning is a major part of fulfilling energy requirement in rural Uttarakhand India. To analyze CO_2 emission from fuel wood burning /consumption rate at the household level at different altitude villages we surveyed seventy-two (N=72) villages in five (N=5) districts in Uttarakhand. The villages were categorized into three categories based on their altitudes (I) 1000-2000mts., (II) 2001-2300 Mtr., (III) 2301- 3200 Mtr. Fuel-wood consumption was estimated by closely calculating the daily actual wood consumed at the household level in villages categorized according to altitude. In the study 351 households were surveyed, of this 28 %, were between 1000-2000mts., 55.8%, of households were sampled in villages between 2001-2300 Mtr., and 16% of households were sampled between 2301 - 3200 Mtr. respectively. The average fuel-wood consumption at households' level in categories (I) was 11 kg/ day, in category (II) was 14.6 kg/day and in category (III) it was 17.2 kg/day. The overall average value of fuel-wood consumption in all three categories was 14.26 kg/day/ household at the state level. Twenty-nine (N=29) species are primarily being used as fuel-wood in which *Litcea monopetela, Bahunia varigata, Grewia, optiva, Pirus pashia, Pinus roxburghii, Quercus leucotricophora and Myrica sapadia, Betula Utilis* has a major share. Annual carbon emission from fuel-wood burning in rural areas was also estimated using the formula provided by the Intergovernmental Panel on Climate Change (IPCC 1996). The annual carbon emission values for sampled villages in five districts of Uttarakhand (rural) are (I) Almora 1081.4 $MtCO_2$, (II) Bageshwer 479.1 Mt CO_2, (III) Champawat 405.6M t CO_2(IV) Pithoragarh 829.8 Mt CO_2(V) Tehri Garhwal 1025.7 $MtCO_2$. The total CO_2 emission value for all five districts was 3821.6 $MtCO_2$ annually through fuel-wood burning.

***Keywords:** carbon emission, fuel-wood, IPCC (Intergovernmental Panel on Climate Change), consumption rates, t CO_2*

Cite This Article: Vivek Joshi, C.K. Dhyani, Kusum Arunachalam, and Ujjwal Kumar, "Assessment of Carbon Emission by Fuel Wood Burning at Different Altitudes in Five Districts of Uttarakhand in Western Himalaya." *Applied Ecology and Environmental Sciences*, vol. 8, no. 6 (2020): 451-458. doi: 10.12691/aees-8-6-17.

1. Introduction

Uttarakhand state has 34661.52 sq km of area under forests cover which is about 64.81 percent of its total geographical area of this roughly around 15 percent of the forest areas are either community forests or Van Panchayat forest. Another 15 percent are somewhat semi-degraded and degraded forests which are usually managed as Civil and Soyam forests areas which are managed by the revenue department of the government of Uttarakhand. Still, the majority of the population lives in Uttarakhand lives in rural areas where the demand for energy for cooking and heating are fulfilled by wood collection from nearly by Van Panchayat forest, community forests. A large part of the rural population in developing countries like India meets more than one-third of their total energy demand, principally in the domestic sector [1,2,3]. The demand for fuel-wood for cooking and

energy is particularly high in high altitude villages of Uttarakhand as compared to low and mid-altitude villages. In almost all villages of Uttarakhand fuel-wood is the essential and main source of energy, fulfilling almost entire cooking energy requirement. Fuel-wood collection from nearby forest areas is the principal component of rural domestic energy in Uttarakhand. Fuel-wood collection and consumption are intricately linked with degradation of forest areas in Uttarakhand, and surprisingly high carbon emission values through the use of traditional Chula in which are presently being used in all the villages. Fuel-wood collection from the forest areas is the only source of energy for the majority of village dwellers in living in the mountains villages in Uttarakhand [4] because it is freely and easily accessible and simple to use [5]. Due to an ever-increasing demand for fuel-wood majority of forest area out-side national parks, biosphere reserve and reserve forest areas have degraded severely, due to chronic disturbances to the trees. As the density of gas connection in villages are not evenly distributed and

the supply is also not regular, additionally due to low income of households village people tend to collect the wood which is freely available instead of any other source of energy for cooking purposes. This position has lead gradually in an acute shortage of fuel-wood in many low and mid-altitude villages in Uttarakhand. It has been reported that commercial energy (kerosene and electricity) consumption consists of only 1.41% of the total [6]. with increasing altitude, forests of different compositions are found, and so different plant species are used at three different altitudes as fuel for cooking, lighting, boiling of water, and space heating [7]. Fuel-wood collection quantities from Van Panchayat forests and community forest has resulted into resource degradation to the extent that in the majority of rural Uttarakhand the collection patterns have already exceeded the sustainable resource utilization limits impending "fuel-wood availability crisis". The present research focuses on the utilization patterns of fuel-wood tree species at different altitudes in, the quantity harvested on a seasonal and annual basis at the household level, information on the preference of woody species at different altitudes and also the carbon emission at household level from five hilly districts in the state. The fuel-wood consumption at large scale is related to the severe environmental problems including deforestation, land degradation, loss of biodiversity, climate change and adverse health effects due to the indoor air pollution. Firewood accounts for over 54 % of all global harvests per annum which results in the huge amount of forest loss [8].

The forest ecosystem is the primary aid to the sustainable livelihood of Himalayan mountain populations which provides valuable livelihood goods and services in regulating, provisioning, supporting and cultural aspects [9]. The energy consumption pattern varies according to climatic conditions, geographical features and socio-economic status of the area. Himalayan mountain communities face a severe shortage of energy resources due to poor socio-economic status [10]. Himalayan forests are among the most diminished forests around the globe. Wood contributes 90 % of the total energy consumption in the Himalayan Mountains. Pakistan is a forest-poor country with only 4.72 million hectares (5.36 %) of its landmass covered with forest. Fuel-wood is the main source of energy in > 80 % of Pakistani households [11]. Satellite imagery analyses have revealed 27 % (821 x 10³ ha) loss of forest cover in Jammu and Kashmir [12]. About 93.7 % of housing units in the state of Azad Jammu and Kashmir use wood in order to fulfill their cooking and heating demands. The population of this state consumes huge amounts of fuel-wood due to high population density, severe climatic conditions and lack of alternate fuel resources including electricity or natural gas. On the other hand, the forest cover is on the rapid decline due to immense fuel-wood extraction [13]. It is critical to determine and analyze the impacts of unplanned and unsustainable fuel-wood extraction on forest structure, composition and regeneration [14]. Fuel-wood is an important component of household economies in Pakistan: it covers about 53% of total annual domestic energy needs (Government of Pakistan 1997). It has also been estimated that 70-79% of Pakistani households use fuel-wood as the main source of energy [15,16]. The broad-leaved trees are repeatedly lopped for leaves and firewood,

leading to a gradual loss in the density of such species. The climax forest of the Western Himalaya is characterized by the dominance of oak (Quercus) species. The oak (particularly Quercus leucotrichophora and Quercus floribunda) supplies leaf fodder for cattle, wood for fuel and farm implements. With increasing demands for fodder and firewood, oak forest trees are repeatedly lopped, seed output is reduced, pressures from seed predators such as the flying squirrel (Patriots petusista var. albiventer) and langur (Presbytis entellus) have increased on an already diminished seed crop and livestock grazes the scanty young regeneration. As a result, this forest is fast disappearing [17]. Fuel-wood consumption in different parts of Asia, Africa, and Central America has been estimated by Bensel and Remedio [18]; Kituyi et al. [19]; Tabuti et al. [20]; Brouwer and Falca͂o [21]; Chen et al. [22] and Ramos et al. [23]. Estimation of fuel-wood consumption and anthropogenic pressure in forests of the Himalaya have been analyzed by Moench and Bandhopadhyay [24]; Schmidt-Vogt [25]; Sundriyal and Sharma [4]; Samant et al. [26] and Awasthi et al. [27].

2. Methodology

2.1. Study Area and Strategy

Data was collected through Survey in seventy-two (N=72) villages in five (N=5) districts of Uttarakhand. Data of 2011 census was used to estimate total rural households in all five districts for calculation of total annual carbon dioxide emission from fuel-wood burning at district and household level.

The study areas in all five districts were chosen after a thorough study of the latest Google earth imageries. After stratification of village list in five districts according to their altitudes, the random stratified sampling method was used for choosing villages for data collection from the list created. Villages were identified for sampling keeping three basic points in focus (i) proximity to forest (ii) altitude (iii) forest cover. Special care was taken to design the survey plan in such a way that the representation of all three categories of villages must be reflected in the study proper way.

2.2. Fuel Wood Calculations

Fuel-wood consumption rate in the village was calculated at the household level by weighing the total quantity of fuel-wood used in a single day for cooking and heating requirements.

To understand the fuel-wood collection quantities required at village level entire survey was divided into three altitudinal zones viz, (I) 1000-2000mts., (II) 2000-2300 Mtr., (III) 2300- 3200 Mtr. We have collected data by-monthly from selected villages at different altitudinal ranges. We have calculated average fuel-wood calculation of total sample size using single-factor ANOVA to check the significance level in our results.

All the observations and calculations were noted down in a pre-designed questioner format. Group interviews and household surveys were done for identification of species being used for fuel-wood in different locations. Systematic

data collection was done during fuel-wood, collection trips and through my daily interactions with the villagers. The data was used to develop a detailed record of how a community is using forest resources, the extent of dependence of the community on fuel-wood for daily household energy requirements. Group interviews were conducted to assess the availability of fuel-wood from Van panchayat, community forest area in five (N=5) districts of Uttarakhand viz, Almora, Bageshwer, Champawat, Pithoragarh, and Tehri Garhwal. It was surprising to note that according to census data 2011 Almora district has negative population growth but still, Almora district has largest no. of rural households and subsequently largest carbon emission rates in all five districts.

Data of fuel-wood consumption was calculated by weighing the total wood being used for cooking on a daily bases and calculating average daily consumption at household level by several measurements.

2.3. Carbon Emission Calculations

Carbon emission from burning of woody biomass in the cook-stoves was calculated using the following formula:

Carbon emission from the non-renewable biomass woody biomass = Quantity of non-renewable biomass × Net calorific value of the non-renewable biomass × CO_2emission factor for the biomass fuel.

Net calorific value of non-renewable biomass (NCVbiomass) = 0.015 TJ/tonne

(IPCC default value for fuel wood).

CO_2emission factor for the biomass fuel = 109.6 tCO 2/TJ.

(IPCC default value for biomass from IPCC report 1996).

3. Results and Discussion

Tree Species being used for fuel-wood:

In total twenty-nine (N=29) trees species were identified during the survey which was being used for fuel-wood consumption at different altitudes. Members of Rosaceae were represented by four species i.e, Pyrus malus, Pyrus communis, Prunus commianis, and Prunus which were being used as fuel-wood above persica which was being used above 2000 Mtr. Three Members of Pinaceae, family i.e, Picea smithiana, Abies spectabilis,

Pinus wallichiana, were being used above 2000 Mtr. whereas one species Pinus roxburgii was being used above 1000 mts. Fagaceae were represented by three species i.e., Quercus leucotricophora, Quercus floribunda, and Quercus semicarpifolia were being used as fuel-wood above 1800 Mtr. Moraceae was represented by three species i.e., Ficus bengalensis, Ficus palmate, and Morus alba, which were being used as fuel-wood between 1000,1300,1900 mts. respectively. Three members of legumes family i.e., Bauhinia variegate, Bauhinia purpurea, and Cassia firstula were being used between 1000, 1300 and 1400 Mtr. Betulaceae was also represented by two menbers i.e., Betula utilis and Alnus nepalensis of these two Alnus nepalensis were being used for fuel-wood between 1400 to 1900 Mtr., and Betula utilis above 3200 Mtr. Trees have been categorized according to the altitude in four different categories it was observed that some trees which are being used as fuel-wood were found in more than one category details are given in Table 1.

3.1. Calculation of Fuel-wood Consumption

It was found that in the villages situated between 1000 to 2000 mts. the average per day/household fuel-wood consumption value was 11 kg/day, in villages situated between 2000 to 2300 mts. average per day/household fuel-wood consumption value was 14.6 kg/day, and was highest in villages between 2300-3200 mts., here the average per day/household fuel-wood consumption value was 17.2 kg/ day as shown in Figure 1. There was a significant difference in consumption rates of fuel wood in the villages situated at lower altitudes i.e., 1000 to 2000 mts. and villages situated at higher altitudes 2300-3200 mts. The difference was 6.2 kg/hh / day, which makes a huge difference of 2.3 MT of fuel-wood consumption/hh/ year. The overall mean value of fuel wood consumption in all five districts was 14.26 Kg /day. The mean value obtained was used to calculate the annual fuel-wood consumption rates in the rural area of all five districts. The variation between the calculated mean at three different altitudes was 0.99, 0.9 and 1.4 Kg fuel-wood/hh/ day. The result of ANOVA shows that the P-value for calculation of average fuel-wood consumption at three different altitudes was 0.004641 which is highly significant.

Table 1. Trees being used for Fuel-wood at different Altitudes in Five Districts

Fuel-wood species (1000-1400 Mtr)	Fuel-wood species (1401-1900 Mtr)	Fuel-wood species (1901-2300 Mtr.)	Fuel-wood species (1901-2300 Mtr.)
Mangifera indica	*Pyrus communis*	*Pyrus malus*	*Pinus wallichiana*
Shorea robusta	*Diploknema butyracia*	*Cupressuss torulosa*	*Quercus semicarpifolia*
Mallotus phillipenensis	*Juglans regia*	*Picea smithiana*	*Betula utilis*
Cassia firstula	*Myrica esculanta*	*Abies spectabilis*	
Ficus bengalensis	*Quercus leucotrichophora*		
Pinus roxburghii	*Qurcus floribunda*		
Grewia optiva	*Morus alba*		
Emblica officinalis	*Rhododendron arborium*		
Prunus persica			
Alnus nepalensis			
Bauhinia purpurea			
Toona ciliata			
Ficus palmate			
Prunus commianis			
Myrica esculanta			
Bauhinia variegata			
Juglans regia			

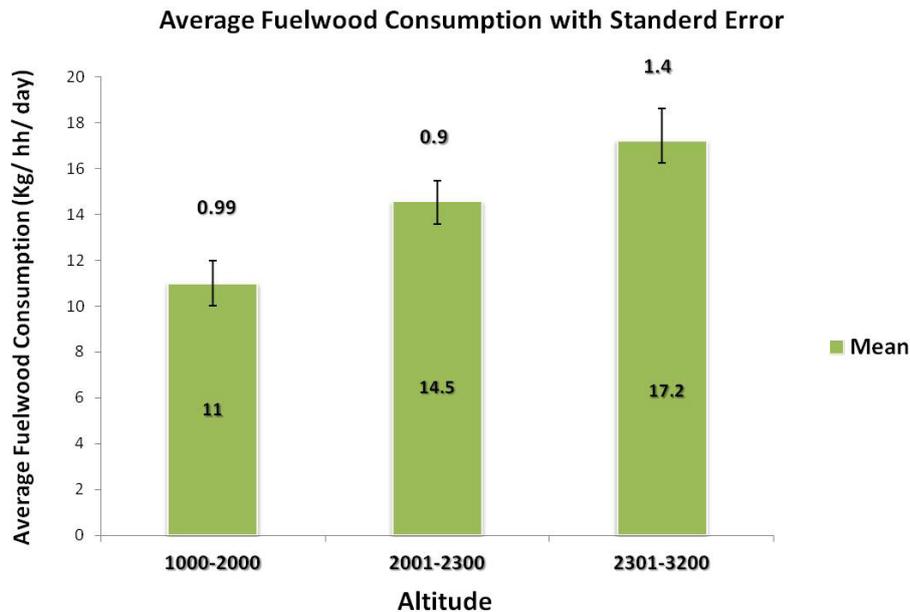**Average Fuelwood Consumption with Standerd Error**

Figure 1. Fuel-wood consumption per day / hh

3.2. CO$_2$ Emission Calculations

IPCC formula default and value were used for calculation of carbon emission from non-renewable biomass following IPCC report 1996. An example of calculation for 10 villages of Almora districts has been given in Table 2. Average fuel-wood consumption at different altitude was different for villages at lower, mid and higher altitudes. In general lower altitude was using less fuel-wood on daily bases compared to mid-altitude and high altitude villages.

Here **Cr** = quantity of carbon released tCO 2,

M=Average fuel-wood consumption at household level in five districts.

Q'= quantity of fuel consumed in Tonne,

Q*=Annual wood consumption value in kg,

Q1=Q*/1000,

NCV= net calorific value of fuel (TJ/natural unit) =0.015 TJ/tonne,

EF (emission factor) = 109.6 tCO 2/TJ (Constant)

And **Cr = Q * NCV * EF**

3.3. Annual CO$_2$ Emission

Using similar formula calculation of carbon emission was done for 2,289 villages and 1,26,382 households in Almora district, 957 villages and 55,992 households in Bageshwer, 718 villages and 47,406 households in Champawat district, 1,675 villages and 96,971 households in Pithoragarh, and 1,863 villages and 1,19,864 household in Tehri Garhwal. The source of data was from government census study (2001) done in Uttarkhand. It was observed that the carbon emission rates were highest in Almora district which was 1081.4 MtCO$_2$, annually followed by Tehri Garhwal 1025.7 MtCO$_2$ annually, Pithoragarh 829.8 MtCO$_2$ annually, Bageshwer 479.1 MtCO$_2$ annually and Champawat 405.6M tCO$_2$annually (Figure 2). The total carbon emission value in rural households of all five districts was 3821.6 MtCO$_2$ annually. It was also observed that the diversity of species being used for fuel-wood also decreases with increasing altitude, which in consequence results in more anthropogenic pressure on single species, due to which the regeneration of species is also affected. Out of 38,21,620 tCO$_2$ annual emission from five districts, the percentage share of Almora is 28.29%, Bageshwer is 12.53%, Champawat is 10.61%, Pithoraghar 21.71%, Tehri Garhwal is 26.83 %.

Table 2. Calculation of carbon emission from fuel-wood at the household level using IPCC formula

| Village Name	No of Households	M	Q'	Q*	Q1	NCV	EF	Cr
Maunidhaya	23	14.26	328	2753392.1	2753.3921	0.015	109.6	4526.6
Betandhar	24	14.26	342.2	2998022.4	2998.0224	0.015	109.6	4928.7
Bhanriakali	16	14.26	228.2	1332454.4	1332.4544	0.015	109.6	2190.6
Lal Nagari	122	14.26	1740	77469731.6	77469.7316	0.015	109.6	127360.2
Okhalyun	48	14.26	684.5	11992089.6	11992.0896	0.015	109.6	19715.0
Bhanaria Nata	21	14.26	299.5	2295360.9	2295.3609	0.015	109.6	3773.6
Bhanaria Pati	20	14.26	285.2	2081960	2081.96	0.015	109.6	3422.7
Bhanaria Seru	17	14.26	242.4	1504216.1	1504.2161	0.015	109.6	2472.9
Malli Chamyart	22	14.26	313.7	2519171.6	2519.1716	0.015	109.6	4141.5
Talli Chamari	34	14.26	484.8	6016864.4	6016.8644	0.015	109.6	9891.7
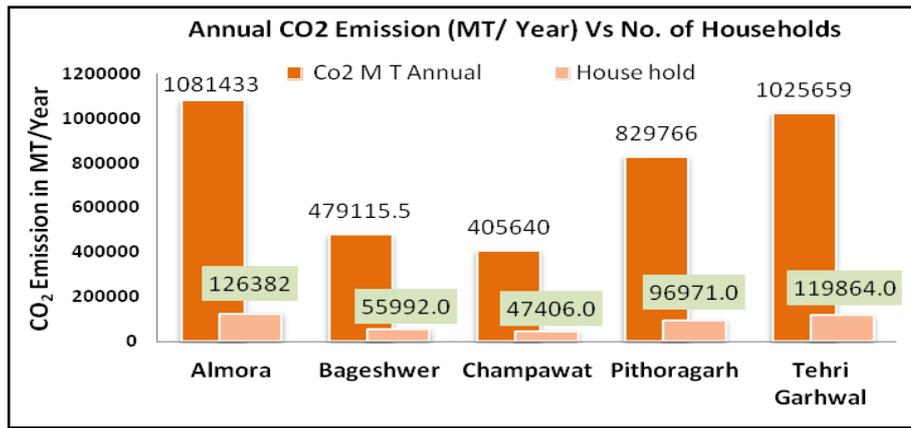
Figure 2. CO_2 Emission assessment MT/year

Using similar formula calculation of carbon emission was done for 2,289 villages and 1,26,382 households in Almora district, 957 villages and 55,992 households in Bageshwer, 718 villages and 47,406 households in Champawat district, 1,675 villages and 96,971 households in Pithoragarh, and 1,863 villages and 1,19,864 household in Tehri Garhwal. The source of data was from government census study (2001) done in Uttarkhand. It was observed that the carbon emission rates were highest in Almora district which was 1081.4 $MtCO_2$, annually followed by Tehri Garhwal 1025.7 $MtCO_2$ annually, Pithoragarh 829.8 $MtCO_2$ annually, Bageshwer 479.1 $MtCO_2$ annually and Champawat 405.6M tCO_2annually (Figure 4). The total carbon emission value in rural households of all five districts was 3821.6 $MtCO_2$annually. It was also observed that the diversity of species being used for fuel-wood also decreases with increasing altitude, which in consequence results in more anthropogenic pressure on single species, due to which the regeneration of species is also affected. Out of 38,21,620 tCO_2annual emission from five districts, the percentage share of Almora is 28.29%, Bageshwer is 12.53%, Champawat is 10.61%, Pithoraghar 21.71%, Tehri Garhwal is 26.83 %.

3.4. Monthly Variations in Fuel-wood Consumption

We have collected data bi-monthly from selected villages at different altitudinal ranges. It was observed that the monthly variations in fuel-wood consumption changed with seasons, with more fuel-wood consumption in winter months as compared to summer months. There was a difference of 7.4 kg/hh/day in summer. Whereas at mid-altitude the difference between summer and winter months, fuel-wood consumption difference was 5.2 Kg/ hh /day. At lower altitude villages the difference between summer and winter months, fuel-wood consumption was 6.6 Kg/ hh /day. The difference between maximum fuel-wood consumption from November till February at 2301-3200 mts. was of 0.1 Kg/ hh /day, whereas this difference in peak summer was 0.4 kg/hh. Figure 3. The difference between maximum fuel-wood consumption from November till February at 2001-2300 mts. was of 0.6 Kg/hh /day, whereas this difference in peak summer was 0.8 kg/hh. The difference between maximum fuel-wood consumption from November till February at 1000-2000 mts. was of 3.2 Kg/ hh /day, whereas this difference in peak summer was 0.3 kg/hh/ day. Overall the fuel-wood demand decreased in summer and increased in winters in all three altitudes. Hence the CO_2 emission rates were also higher in winter months in comparison of summer months.

3.5. Fuel-wood Consumption Pattern

The maximum fuel-wood consumption was recorded at higher altitudes 2301-3200 mts., 17.2 Kg/ hh whereas only 16% of villages were sampled between this elevation. It was followed by villages at mid altitudes between 2001-2300 mts., where the consumption was 14.6 kg/ hh but majority of village 55.8% fall in this category in our survey. The lowest fuel-wood consumption was recorded in villages situated between 1000-2000 mts. represented by 28.2 % of sampled villages.
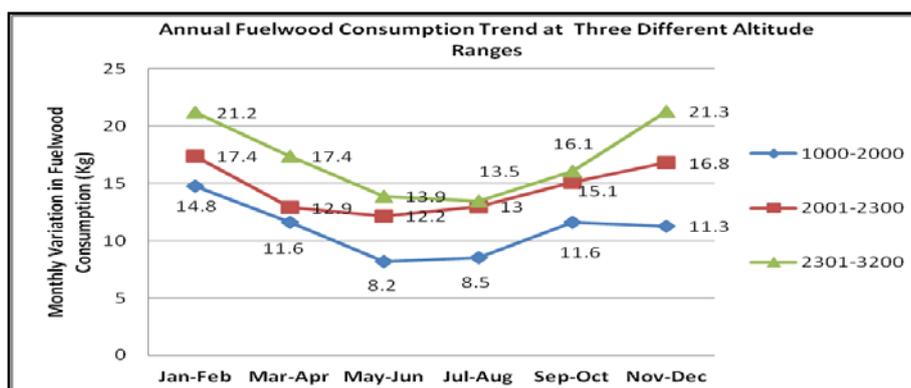

Figure 3. Variation in annual fuel-wood consumption
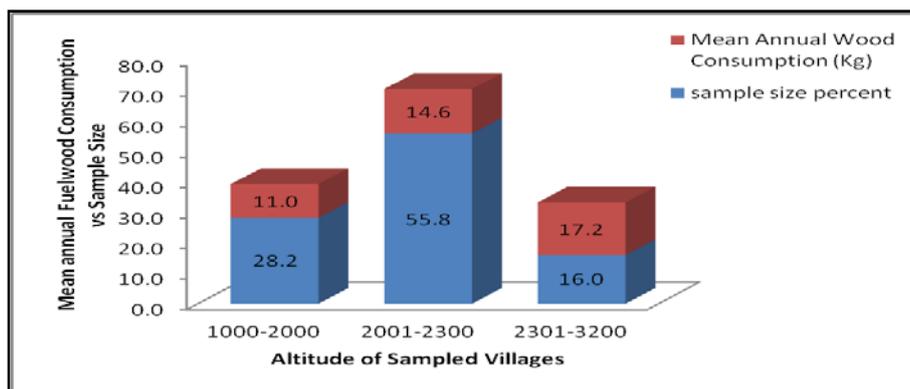
Figure 4. Sample size Vs annual fuel-wood consumption

4. Discussion and Conclusion

As the hilly districts of Almora, Champawat and Tehri Garhwal lie in mid-Himalayan ranges and because of the topography and altitudinal limitations and other geographical conditions such as availability of water sources, slope angle and deep soil availability for agricultural purposes are available at mid altitudinal zones. Therefore

all of our sampled villages were situated under 2000 mts. in these three districts. We observed that the economic status of the household does not seem to affect the fuel-wood consumption rates. Fuel-wood was being collected from *Van Panchayats* apart from trees and shrubs inside village boundary.

In Uttarakhand, every *Gram Sabha* (Village Legislation Unit) have a defined forest area under their jurisdiction named as *Van Panchayat,* which is jointly managed by Villages inside *Gram Sabha* and forest department. Between 1000 to 2000 mts. majority of forest and community forest (*Van Panchayat*) was consisting of *Pinus roxburgii* open canopy forest.

Apart from *Pinus roxburgii* open canopy forest in some places community forest also possessed trees of *Mangifera indica, Shorea robusta, Mallotus phillipenensis, Prunus persica, Bauhinia purpurea, Pyrus communis, Bauhinia variegate* and *Grewia optiva* as listed in table no.1. It was observed during this study that apart from fuel-wood collection from *Van Panchayat* people also tend to collect fuel-wood from trees growing in the village periphery and boundaries of agriculture lands. But the quantity of the wood collected from forest areas is always significantly higher as the trees growing in village periphery and boundaries of agriculture lands also serve as fodder trees for livestock, hence these trees are selectively harvested for fuel-wood.

Majority of our sampled villages 55.8% fall under the open canopy Pine dominated the forest. The difference between maximum fuel-wood consumption from November till February at 1000-2000 mts. was of 3.2 Kg/ hh /day, whereas this difference in peak summer was 0.3 kg/hh/ day. Our observation shows that the requirement of fuel-wood for cooking is significantly low in villages situated between 1000 to 2000 mts. when compared to higher altitude villages, the main reason behind this is well connected with roads and availability of gas cylinders at a time. Another reason is that the winter temperature does not drops severely hence the requirement of wood for heating purposes is lower.

Total villages sampled for fuel-wood consumption between 2001-2300 mts. were 28.2% of total sample size. All of these villages were situated in Bageshwer and Pithoraghar districts. These two districts lie in mid to high altitude Himalayan ranges and because of the topography and geographical conditions in the distracts many of the villages are situated between 2001-2300 mts. altitudinal range. The forest also tends to change naturally above 1800 mts. and the Pine forest forms an ecotone in many places with mix broadleaf forest. It was observed during our survey that above 2000 mts. the forest was either broadleaf evergreen type mix forest of coniferous evergreen forest. The choice of fuel-wood species was based on calorific values of fuel-wood as hardwood wood species generally have more calorific values than softwood species. At this altitude *Pinus roxburgii, Quercus leucotricophora, Quercus semicarpifolia, Betula utilis, Pinus wallichiana, Juglans regia*, and *Rhododendron arboretum* were being preferred to be used as fuel-wood. In all these species *Quercus leucotricophora, Quercus semicarpifolia,* and *Rhododendron arborium* were being preferred as fuel-wood species.

The average consumption of fuel-wood was way too high in high altitude villages as the weather conditions and remoteness of villages promoted more use of wood for cooking and heating purposes. It was also observed that the time period for cooking meals also increases in high altitude villages consequently resulting in more fuel-wood consumption for same meal preparation. It was observed that the monthly variations in fuel-wood consumption changed with seasons, with more fuel-wood consumption in winter months as compared to summer months. At mid-altitude, the difference between summer and winter months, fuel-wood consumption was 5.2 Kg/ hh /day. The average fuel-wood consumption values in winter months were 21.25 Kg/ hh/ day whereas in summer value was 13.45 Kg/ hh /day.

Total villages sampled for fuel-wood consumption between 2301-3200 mts. were 16 % of total sample size.

As expected the carbon emission rates will be highest in high altitude villages as all of the households are heavily dependent on fuel-wood supply from *Van Panchayat* forest and trees inside village boundary for their cooking and heating purposes. The main reason behind it was severe cold weather conditions from autumn till spring at these altitudes in western Himalaya. The difference in fuel-wood consumption rate in summer months at 2301-3200 mts. and 2001-2300 mts. was only 0.9 Kg of

fuel-wood/hh/day. Whereas this difference was significantly higher when compared in winter months, the difference was 3.9 Kg of fuel-wood consumption/hh/ day. This difference was about 1.4 MT of fuel-wood consumption per year at a single household level.
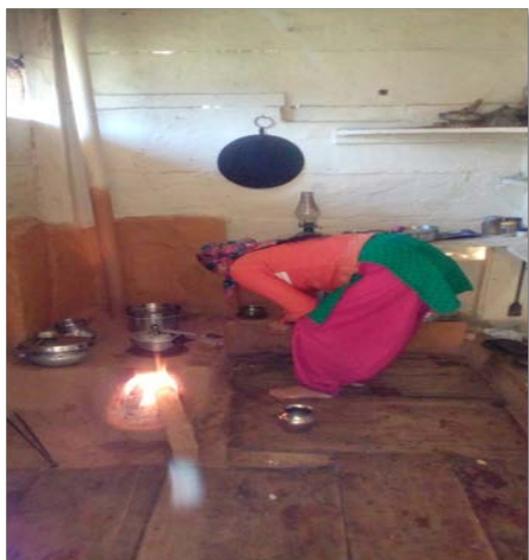

Figure 5. Wood consumption in traditional mud stove

In Uttarakhand entire rural population depends on fuel-wood collection from *Van Panchayat* forest, reserve forests, and trees, shrubs inside *Gram Sabha* (Village Legislation Unit). The main reason for fuel-wood collection is to fulfill their energy needs for cooking and heating purposes. The perpetual demand for fuel-wood collection from *Van panchayat* forest and community forest in Uttarakhand have resulted in a high degree of forest degradation due to over-exploitation of forest tree species for fuel-wood collection. The huge amount of fuel-wood burning results in significant CO_2 emissions from cooking and heating. This data shows the trend of high CO_2 emissions in rural villages of Uttarakhand in western Himalaya. Also, the method being used for wood burning is not very efficient. In Himalayan villages, the method of fuel-wood burning is very traditional using mud stoves, which are less efficient in fuel wood-burning and consequently produce more smoke in comparison of advanced wood-burning stoves. These mud stoves are not very efficient in burning the wood as a fairly large amount of energy is also lost in form of heat which is not directed for cooking, apart from smoke produced. In fact, majority of the heat produced by fuel wood-burning is lost through convection.

This reduces the cooking/heating efficiency of traditional mud stoves. Therefore, the carbon emission from /kg of wood burnet is much high through tradition cooking, heating methods in comparison of advanced wood-burning stoves.

The annual carbon emission values for five districts of Uttarakhand (rural) are (I) Almora 1081433 Mt CO_2, (II) Bageshwer 479115.5 Mt CO_2, (III) Champawat 405640 Mt CO_2 (IV) Pithoragarh 829766 Mt CO_2 (V) Tehri Garhwal 1025659 Mt CO_2. The total CO_2 emission value for all five districts was 3821614 Mt CO_2 annually through fuel-wood burning.

Our study shows that the combined annual CO_2 emission from rural households of all five hilly districts was 3821614 Mt CO_2 annually. In this annual CO_2 emission, the percentage share of Almora is 28.29% Mt CO_2 annually, Bageshwer is 12.53% Mt CO_2 annually, Champawat is 10.61% Mt CO_2 annually, Pithoraghar 21.71% Mt CO_2 annually, and Tehri Garhwal is 26.83 % Mt CO_2annually.

It was also observed that due to highly degraded *Van Panchayats* people now are facing an acute shortage of fuel-wood in the majority of low, mid-altitude villages situated in the western Himalayas. This has also led to change in the approach of the resident population as the majority of rural residents have now realized the seriousness of the situation and are interested in rejuvenating their *Van panchayat* forest and community forest, but these people require help and proper ecological education for reviving their forests. The amount of carbon emission from fuel-wood burning is quite high in all five surveyed districts of Uttarakhand, which can be either stabilized or reduced by promoting advance cooking stove and increasing purchasing power of rural villages. Use of new technology will help to stabilize the ever-increasing demand of fuel-wood for cooking in rural Uttarakhand, but serious efforts must also be done for rejuvenating the *Van panchayat* and community forest in Uttarakhand by large scale plantation of tree species being used for fuel-wood, which will also sequest carbon from the atmosphere.

Acknowledgements

References

[1]   FAO (2007). A review of the current state of bioenergy development in G8 þ5 countries (/www.fao.orgS).

[2]   Vasudevan P, Santosh. The role of women in energy related activities in the mountains. In: Kumar V, Ahuja D, editors. Rural energy planning for the Indian Himalaya. New Delhi: Wiley. (1987).

[3]   Natarajan I. Domestic fuel survey with special reference to kerosene, I. New Delhi: National Council for Applied Economic Research. (1985)

[4]   Sundriyal, R. C., & Sharma, E.. Anthropogenic pressure on tree structure and biomass in the temperate forest of mamley watershed in Sikkim. Forest Ecology and Management, 81, (1996) 113-134.

[5]   Blaikie P. The Political Economy of Soil Erosion in Developing Countries. New York: Longman (1985).

[6]   Kumar P. Natural Resource Policy: Some Related Issues. In: Dewan ML, Bahadur J, editors. Uttaranchal Vision and Action Programme: Concept Publishing Company; New Delhi. (2005)

[7]   Bhatt BP, Todaria NP Fuel-wood characteristics of some mountain trees and shrubs. Biomass (1990) 21: 233- 38.

[8]   Williams A, CM Shackleton. Fuel wood use in South Africa: Where to in the 21st Century? The Southern African Forestry Journal (2002) 196(1): 1-7.

[9] Bhatt B, M Sachan. Firewood consumption along an altitudinal gradient in mountain villages of India. Biomass and Bioenergy (2004) 27(1): 69-75.

[10] Démurger S, M Fournier.. Poverty and firewood consumption: A case study of rural households in northern China. China economic review (2011) 22(4): 512-523.

[11] Shaheen H, RA Qureshi, ZK Shinwari.. Structural diversity, vegetation dynamics and anthropogenic impact on lesser Himalayan sub-tropical forests of Bagh district, Kashmir. Pakistan Journal of Botany (2011a) 43(4): 1861-1866.

[12] Joshi P, S Singh, S Agarwal, P Roy. Forest cover assessment in the western Himalayas, Himachal Pradesh using IRS 1 C/1 D WiFS data. Current Science (2001) 80(8): 941-947.

[13] Shaheen H, RA Qureshi, Z Ullah, T Ahmad. 2011b. Anthropogenic pressure on the western Himalayan moist temperate forests of Bagh, Azad Jammu & Kashmir. Pakistan Journal of Botany (2011b) 43(1): 695-703.

[14] Pant S.. Response of Pinus wallichiana to climate change, a study from Manaslu conservation area, Western Nepal. Master's Thesis in Environmental Science. Kathmandu, Nepal. Central Department of Environmental Science, Tribhuvan University. (2013) 61 p.

[15] Siddiqui KM. 2000. Wood fuel in the national energy balance. In: RWEDP [Regional Wood Energy Development Program], editor. Wood Fuel Production and Marketing in Pakistan. National Workshop, Faislabad, Pakistan, 28-30 October 1997. RWEDP Report no.49. Bangkok, Thailand: FAO [Food and Agriculture Organization of United Nations], 25-30.

[16] Hafeez SM. 2000. Bio-energy for meeting growing energy needs. In: RWEDP [Regional Wood Energy Development Programme], editor. Wood Fuel Production and Marketing in Pakistan. National Workshop, Faisalabad, Pakistan, 28-30 October. RWEDP Report No 49. Bangkok, Thailand: FAO [Food and Agriculture Organization of the United Nations], (1997) 143-149.

[17] Singh, J. S.. Man and forest interaction in central Himalaya. In J. S. Singh & S. P. Singh (Eds.), Himalayan environment and development: Problems and perspectives (1992) (pp. 51-60). Nainital: Gyanodaya Prakashan, Nainital.

[18] Bensel, T. G., & Remedio, E. M.. Residential energy use patterns in Cebu City, Philippines. Energy, (1995) 20, 173-187.

[19] Kituyi, E., Marufu, L., Wandiga, S., Jumba, I. O., Andreae, M., & Helas, G.. Biofuel availability and domestic use patterns in Kenya. Biomass and Bioenergy, (2001) 20, 71-82.

[20] Tabuti, J. R. S., Dhillion, S. S., & Lye, K. A.. Firewood use in Bulamogi County, Uganda: Species selection, harvesting and consumption patterns. Biomass and Bioenergy, (2003) 25(6), 581-596.

[21] Brouwer, R., & Falca˜o, M. P.. Wood fuel consumption in Maputo, Mozambique. Biomass and Bioenergy, (2004) 27, 233-245.

[22] Chen, L., Heerink, N., & Berg, M.. Energy consumption in rural China: A household model for three villages in Jiangxi Province. Ecological Economics, (2006) 58, 407-420.

[23] Ramos, M. A., Medeiros, P. M., Almeida, A. L. S., Feliciano, A. L. P., & Albuquerque, U. P.. Use and knowledge of fuel-wood in an area of caatinga vegetation in NE Brazil. Biomass and Bioenergy, (2008a) 32, 510-517.

[24] Moench, M., & Bandhopadhyay, J. People-forest interaction: A neglected parameter in Himalayan forest management. Mountain Research and Development, (1986) 6, 3-16.

[25] Schmidt-Vogt, D. High altitude forests in the Jugal Himal, eastern-central Nepal: Forest types and human impact. Sfuttgart: Franz Steinar Verlag (1990).

[26] Samant, S. S., Dhar, U., & Rawal, R. S. (2000). Assessment of fuel resource diversity and utilization patterns in Askot wildlife sanctuary in Kumaun Himalaya, India, for conservation and management. Environmental Conservation, 27, 5-13.

[27] Awasthi, A., Uniyal, S. K., Rawat, G. S., & Rajvanshi, A. Forest resource availability and its use by the migratory villages of Uttarkashi, Garhwal Himalaya, India. Forest Ecology and Management, (2003) 174, 13-24.