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

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Abstract
Fuel-wood burning is a major part of fulfilling energy requirement in rural Uttarakhand India. To analyze CO2 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 %, 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.

Keywords: carbon emission, fuel-wood, IPCC (Intergovernmental Panel on Climate Change), consumption rates, t CO2

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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 nearby 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 Uttarakhund. 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 Uttarakhund 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 10^3 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 Falca’o [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 Uttarakhund. 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) 1000-2000mtrs., (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:

\[
\text{Carbon emission from the non-renewable biomass woody biomass} = \text{Quantity of non-renewable biomass} \times \text{Net calorific value of the non-renewable biomass} \times \frac{\text{CO}2\text{emission factor for the biomass fuel}}{100}.
\]

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.

| Tree Species | Fuel-wood at Different Altitudes in Five Districts |
|--------------|--------------------------------------------------|
| Mangifera indica | Pyrus communis (1000-1400 Mtr.) |
| Shorea robusta | Diploknea butyracia (1401-1900 Mtr.) |
| Mallotus philippensis | Juglans regia (1901-2300 Mtr.) |
| Cassia fistula | Myrica esculanta (2000-2300 Mtr.) |
| Ficus bengalensis | Quercus leucotrichophora (2300-3200 Mtr.) |
| Pinus roxburghii | Quercus floribunda (3200-4000 Mtr.) |
| Grewia optiva | Morus alba (4000-5000 Mtr.) |
| Emblica officinalis | Rhododendron arboreum (5000-6000 Mtr.) |
| Prunus persica | Pinus wallichiana (6000-7000 Mtr.) |
| Alnus nepalensis | Quercus semicarpifolia (7000-8000 Mtr.) |
| Bauhinia purpurea | Betula utilis (8000-9000 Mtr.) |
| Toona ciliata | Ficus bengalensis (9000-10000 Mtr.) |
| Ficus palmate | Prunus communis (10000-11000 Mtr.) |
| Myrica esculanta | Abies spectabilis (11000-12000 Mtr.) |
| Bauhinia variegata | Quercus semicarpifolia (12000-13000 Mtr.) |
| Juglans regia | Betula utilis (13000-14000 Mtr.) |

Table 1. Trees being used for Fuel-wood at Different Altitudes in Five Districts
3.2. CO₂ 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 \( t \)CO₂, \( M = \)Average fuel-wood consumption at household level in five districts, \( Q^* = \)quantity of fuel consumed in Tonne, \( Q^* = \)Annual wood consumption value in kg, \( Q1=Q^*/1000, \) NC\( V^* \)= net calorific value of fuel (TJ/natural unit) =0.015 TJ/tonne, \( EF \) (emission factor) = 109.6 tCO₂/TJ (Constant)

And \( Cr = Q^* \times NCV^* \times EF \)

3.3. Annual CO₂ 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 MtCO₂, annually followed by Tehri Garhwal 1025.7 MtCO₂ annually, Pithoragarh 829.8 MtCO₂ annually, Bageshwer 479.1 MtCO₂ annually and Champawat 405.6MtCO₂ annually (Figure 2). The total carbon emission value in rural households of all five districts was 3821.6 MtCO₂ 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 tCO₂ 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| 7746.97316 | 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 Chamyat         | 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   |
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 MtCO2 annually followed by Tehri Garhwal 1025.7 MtCO2 annually, Pithoragarh 829.8 MtCO2 annually, Bageshwer 479.1 MtCO2 annually and Champawat 405.6 MtCO2 annually (Figure 4). The total carbon emission value in rural households of all five districts was 3821.6 MtCO2 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 tCO2 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%.

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 CO2 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.
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 philippenensis, 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 Pithoragarh districts. These two districts lie in mid to high altitude Himalayan ranges and because of the topography and geographical conditions in the districts 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 arboreum were being preferred to be used as fuel-wood. In all these species Quercus leucotricophora, Quercus semicarpifolia, and Rhododendron arboreum 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.

Our study shows that the combined annual CO₂ emission from rural households of all five hilly districts was 3821614 Mt CO₂ annually. In this annual CO₂ emission, the percentage share of Almora is 28.29% Mt CO₂ annually, Bageshwer is 12.53% Mt CO₂ annually, Champawat is 10.61% Mt CO₂ annually, Pithoragarh 21.71% Mt CO₂ annually, and Tehri Garhwal is 26.83 % Mt CO₂ annually.

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 sequester carbon from the atmosphere.

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