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Hourly Firewood Consumption Patterns and CO_2 Emission Patterns in Rural Households of Nepal

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Received: 3 October 2020; Accepted: 31 October 2020; Published: 4 November 2020

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Abstract: Nepal has low per-capita energy use and a majority of its rural residents use firewood as their primary energy source. Excessive use of firewood in improperly ventilated buildings degrades the indoor environment and health condition of the inhabitants. This study aims to assess the influence of hourly firewood consumption patterns on CO_2 emissions and resulting concentrations in rural households in Nepal. A field survey was conducted for 24 h in 16 households during winter. The results suggest that most of the households tend to use more firewood during the morning and evening hours. Family size and number of animals reared by the households were positively correlated with firewood consumption, whereas family size was negatively correlated with per-capita firewood consumption. Per-capita firewood consumption was found to be 1.8 kg/(capita·day). Household firewood consumption and CO_2 emissions were 12 kg/(family·day) and 14.26 kg CO_2 e/(household·day), respectively. The larger households spent more time for cooking, while their consumption rate was similar (1.3 kg/h) to that of smaller households. High indoor CO_2 emissions in the morning and evening hours due to high firewood consumption may pose severe health risks to the inhabitants. Therefore, intensive awareness programs and pollution control programs are suggested for improving indoor air quality and health condition of the rural population.

Keywords: Nepal; energy use; hourly firewood use; CO_2 emission; CO_2 concentration

1. Introduction

Firewood is an important source of household energy for the rural population of many developing countries. Approximately 2.6 billion people from developing countries fulfil a majority of their basic energy demand for cooking and space heating from fuelwood, and the practice is considered to be inefficient, unhealthy, and unsustainable [1]. This trend is expected to continue in the future, especially in rural areas of developing countries [1]. Nepal is one of the least developed countries that has one of the lowest per-capita energy consumption globally [2]. The energy use and energy access levels in Nepal are significantly below the level of basic human needs, and firewood is expected to remain the dominant cooking fuel for the foreseeable future [3]. As of 2010, over 30% households lacked in access to electricity, and 78% households relied on traditional biomass for cooking and space heating [4]. According to the household survey 2015/16 of Nepal, firewood is a major source of cooking fuel for more than half of the households in the country and is used by 76.5% rural households and 38.0% urban households to meet their everyday cooking energy demands [5]. Low financial income has compelled the rural population to use inefficient sources of solid biomass energy which can trigger hazardous events when it is mishandled [6].

The World Health Organization (WHO) estimates that about 2.8 billion people in developing countries depend on solid fuels and traditional cook stoves for cooking and heating [7]. Burning of solid fuel in inefficient traditional stoves is responsible for the emission of various indoor air pollutants, which have direct and indirect impacts on the health of the inhabitants. Small and improperly ventilated buildings reduce the dilution of indoor pollutants and increase the concentration of harmful gases, which creates unfavorable indoor environments.

In developing countries like Nepal, particularly in rural areas, direct firewood consumption in inefficient traditional cook stoves without chimneys in improperly ventilated buildings is considered the major cause of indoor air pollution. Exposure to indoor air pollution is one of the important risk factor of infant and child mortality. Exposure to pollutants resulting from the burning of solid fuels has been responsible for the death of at least 4.3 million people per annum worldwide [7]. Improvements in the indoor air quality of residential buildings is important for minimizing the health burden on rural population. CO_2 emissions and the concentrations resulting from firewood consumption inside buildings are the simplest indicators of indoor air quality of residential buildings in rural areas and this information can be used to monitor the indoor air quality of residential buildings.

1.1. Literature Review

Previous studies have showed that firewood consumption varies due to socio-economic circumstances, cultural backgrounds, and availability and accessibility of fuels [8–13]. Fox [8] conducted a study on firewood consumption in a Nepali village highlighting on farm size, cast and family size. That study found a mean firewood consumption of 0.95 m^3/(person·year). Bhatta and Sachan [10] found that higher firewood consumption was mainly caused by a lack of conventional energy sources. They also concluded that firewood consumption differs according to family size: smaller families have more per capita firewood consumption than medium and large families. Bhatta and Sachan [10] also found that firewood consumption increased with altitude.

Some studies have highlighted related health concerns, focusing on the use of traditional cooking fuels and indoor environmental conditions of houses in Nepal. Pandey et al. [14] conducted research on domestic smoke pollution and acute respiratory infections in Nepal and found that episodes of moderate and severe acute respiratory infections increased with an increase in the level of exposure to domestic smoke pollution. Fuller et al. [15] used measured firewood and temperature data to validate a simple and cost-effective model of rural houses. Some other studies have highlighted the firewood use patterns associated with socio-economic factors and CO_2 emissions [16,17]. However, there has been a lack of focus on hourly variation of firewood consumption patterns and associated CO_2 emissions and concentrations in rural households of Nepal. These patterns offer important information for assessing indoor environmental conditions, and this information can be used to simulate the thermal environmental conditions and indoor air quality of such houses.

The above literature review indicates that there is a need to focus on hourly firewood consumption patterns and associated CO_2 emission patterns of rural households to understand and minimise the associated health impacts. Thus, the present study aims to assess the effects of firewood consumption patterns on CO_2 emissions and concentrations of residential buildings in rural areas of Nepal. The findings of this study can be used to understand the energy use patterns of rural households in Nepal. Furthermore, this information is important for developing effective energy policies for rural households.

1.2. Objectives

The main objective of this study was to identify the hourly firewood consumption patterns and associated CO_2 emission patterns from firewood consumption in rural houses. Furthermore, this study also intended to identify the effect of different factors, such as family size and number of animals reared, on firewood consumption patterns. The goal of this study was to provide information on hourly variations in firewood consumption and associated CO_2 emissions to concerned stockholders such as building and cook stove designers to enable cleaner indoor environments for the betterment of the living condition of the rural population.

2. Methods

2.1. Study Area and Climate

The research was conducted in Nilakantha municipality in Dhading district, situated at an altitude of approximately 1500 m. This municipality is situated 90 km west of Kathmandu. It ranges from the Himalaya in the North to the Mahabharat range in the south. Of the 199.85 km^2 of the total area under the municipality, forest occupies 99.31 km^2, which is nearly 50% of the total area [18]. The land form is sloped and terraced. This study chose this area for the investigation as the terrain, living conditions, energy use patterns, and housing conditions are representative of rural communities of the hill regions in Nepal. According to the Annual Household Survey 2015/2016, the total population of this municipality was 71,131. The major economic resources of this municipality are agriculture, trade, and tourism. However, most people in the municipality depend on subsistence and traditional agriculture [18]. Figure 1 shows the location of the study area.

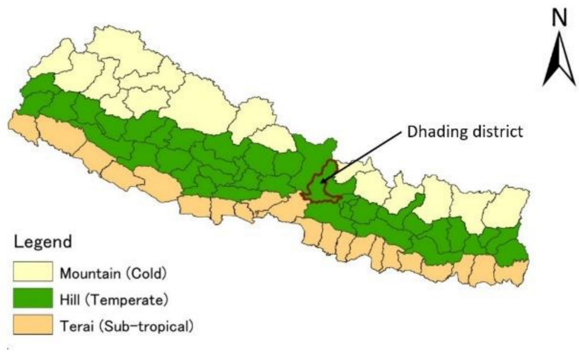


Figure 1. Map of Nepal and the study area.

Figure 2 shows the monthly mean, minimum, and maximum outdoor air temperatures obtained from the Dhading meteorological station of Dhading district. The climate of this region is temperate, and the annual average, minimum, and maximum outdoor air temperature were 22.8, 17.3, and 28.4 °C, respectively [19]. The annual average rainfall is 2329 mm, of which 80% occurs in the three months of the monsoon season [19].

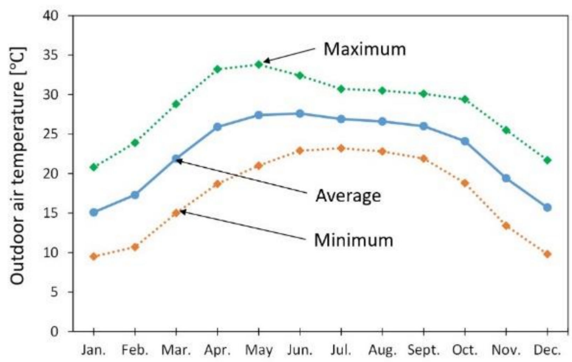
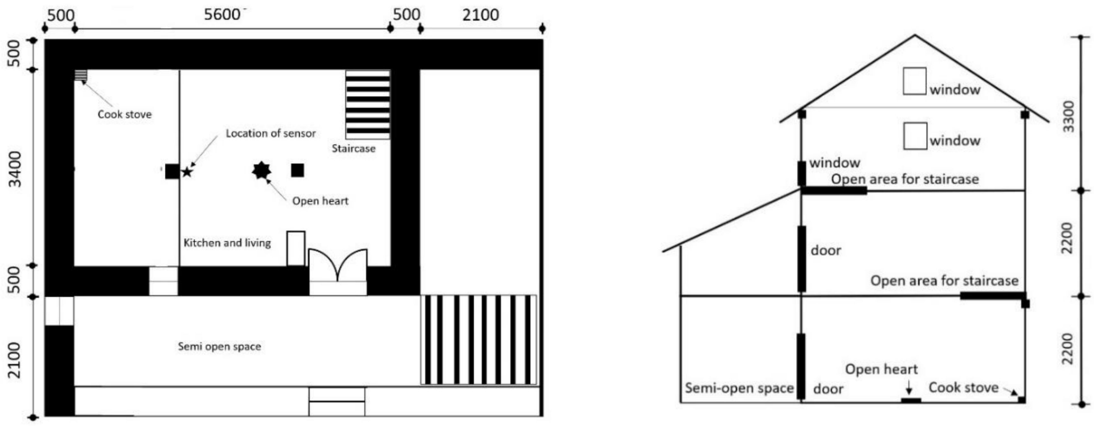


Figure 2. Monthly outdoor air temperatures of the study area, obtained from the climatological and agro-meteorological records of Nepal.

2.2. Selection of Houses

For this study, 16 households were selected from the Nilakantha municipality in Dhading district, where all inhabitants depended on subsistence agriculture for their living and used firewood in a traditional cookstove. These houses were constructed by local skillful craftsmen with locally available materials, using construction methods and designs inherited from previous generations. These houses are two- or three-story detached dwelling units. All houses had attached kitchens in the first floor of the main living house, and they burnt firewood inside the house to keep it warm during the winter. Most of the houses were south-facing, whereas only a few of them were east-facing. Figure 3 shows the ground floor plan and sectional views, and Figure 4 shows the exterior view of the investigated house.



(**a**) (**b**)

Figure 3. Design of a typical house in investigated area: (**a**) Plan view and (**b**) Sectional view (unit: mm).

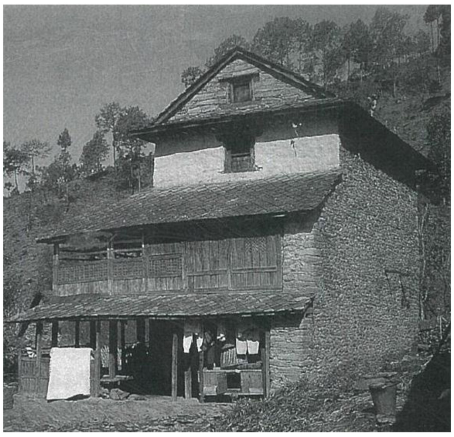


Figure 4. External view of an investigated house.

2.3. Household Characteristics

The family size of the investigated households ranged from 2 to 12 members. The average family size was 6.5, which is slightly higher than the recent average family size of 4.9 persons published in the Annual Household Survey 2014/15 of Nepal. There were equal proportions of males and females in the investigated population. All households were engaged in subsistence farming and rear animals as a part of their occupation. All households used firewood to cook meals and make tea and animal feed. No household used other fuels such as kerosene, LPG, and electricity for cooking. All investigated households had similar types of traditional cooking stoves, made using stones and mud, in the ground floor of their main house. There were no improved cook stoves in the investigated houses. Approximately 80% of the households cooked meals thrice per day, while 20% of the households cooked meals twice per day. Nearby community forests and private plantations were the main sources of firewood. Firewood chopping was mainly done by men, and firewood collection was done by all family members. Only physical energy was used for firewood collection.

2.4. Data Collection

This study was carried out in winter season of 2002 where people are still using firewood for cooking and heating. This study measured the weight of firewood used every hour over one day. All biomass used, such as firewood, twigs, and agricultural residue, was considered firewood. The measurement was conducted using a weight survey method [8,10]. Weight of the air-dried firewood bundles ready for use were measured with a spring balance and left them in the kitchen. The household members were instructed to burn firewood only from the weighted bundles. For each hour, the remaining firewood was measured and the difference in the weight between the previous hour and present hour was taken as the amount of hourly firewood consumption. A questionnaire survey was also performed simultaneously in all houses to collect necessary socio-economic and demographic information. Indoor CO_2 concentrations were measured at one-minute intervals in one of the investigated houses for two days using a digital device equipped with a sensor with an electronic data logger (Q Track, 2352, Kanomax, Osaka, Japan). The sensor had an accuracy of ±3%. The device for measuring indoor CO_2 concentrations was placed 1.1 m above the floor surface in the kitchen room. To avoid the effect of indoor CO_2 emissions, outdoor CO_2 concentrations were measured in an open area 500 m away from the houses with the instrument same as the one used for indoor measurements; the device was placed 1.5 m above the ground surface.

2.5. Calculation for Analysis

In this study, per-capita firewood use, household firewood use, and CO_2 emissions were calculated using the following formula:

$$\text{Household firewood use } [\text{kg}/(\text{capita}\cdot\text{day})] = \frac{Total\ firewood\ used\ by\ all\ households\ in\ one\ day}{Number\ of\ total\ households} \quad (1)$$

$$\text{Per-capita firewood use } [\text{kg}/(\text{capita}\cdot\text{day})] = \frac{Total\ firewood\ used\ by\ all\ households\ in\ one\ day}{Total\ population\ of\ all\ households} \quad (2)$$

$$CO_2 \text{ emissions } [\text{kg } CO_2 \text{ e}] = \text{Amount of firewood used [kg]} \times 1.163 \text{ kg } CO_2 \text{ e /kg firewood} \quad (3)$$

CO_2 emissions from firewood consumption were calculated by multiplying the amount of firewood consumed with the emission factor used in a previous study [16].

3. Results

3.1. Firewood Consumption Rate

Firewood is a major source of cooking fuel, and nearly 60% of households in Nepal use firewood as their primary cooking fuel [17]. In this study, all households used firewood to cook meals, boil water, and make animal feed, but the quantity of firewood used varied among the investigated households depending on household size and other factors.

Daily household and per-capita firewood consumption were 12 kg/(capita·day) and 1.8 kg/(capita·day), respectively. Table 1 shows the variation in firewood consumption in the morning, day, and evening in households with different family sizes. Firewood consumption in the morning and evening was significantly higher than that during the day.

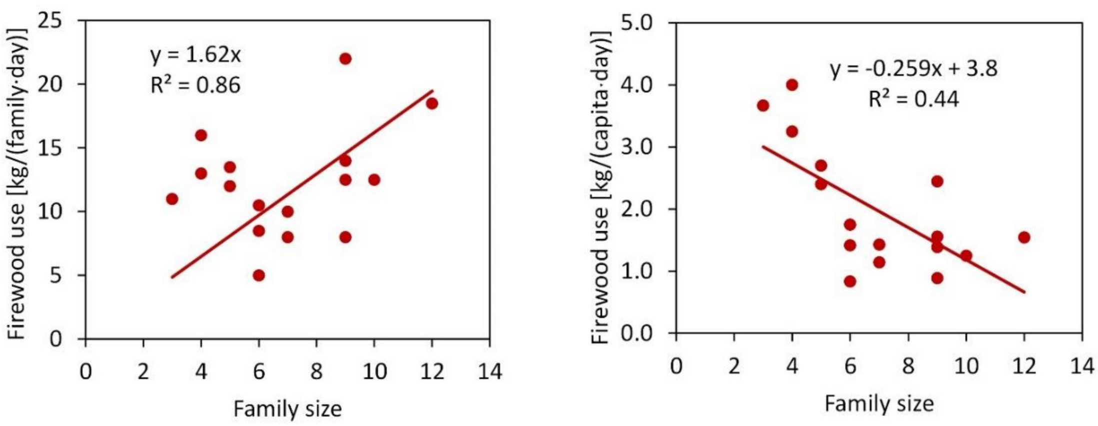
Table 1. Firewood consumption for different time of day by family size.

Family Size	Firewood Consumption [kg/(Family·Day)] Morning (5:00–10:00)	Day (10:00–15:00)	Evening (15:00–22:00)
3	6	0	5
4	6	2	7
5	6	1	6
6	5	1	3
7	5	1	3
8	0	0	0
9	6	4	4
10	7	1	4
11	0	0	0
12	7	2	11
Average	6	1	5

0: Data unavailable.

3.1.1. Relationship between Family Size and Firewood Consumption

Firewood consumption is correlated with family size [20]. In order to understand this relationship, we performed a regression analysis between family size and firewood consumption. Figure 5a shows the relationship between household firewood consumption and family size of the investigated households. The number of household members ranged from two to twelve, and household firewood consumption ranged from 5 to 22 kg/day. This result shows that the greater the family size, the larger the household firewood consumption (r = 0.93). Besides family size, factors such as number of animals reared, volume of kitchen, and indoor thermal environmental conditions of the houses might have affected household firewood consumption. As the larger households rear more livestock as a part of their income source, they require more firewood to cook animal feed [17].



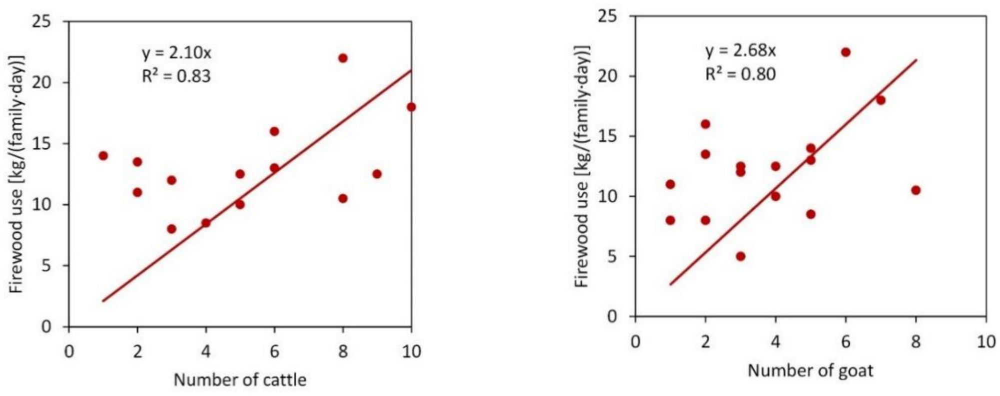
(**a**) (**b**)

Figure 5. Relationship between firewood consumption and family size: (**a**) Daily household firewood consumption and family size and (**b**) Daily per-capita firewood consumption and family size.

Figure 5b shows the relationship between per-capita firewood consumption and family size. Per-capita firewood consumption ranged from 0.5 to 4 kg/day and significantly decreased as family size increased (r = −0.66). The low per-capita firewood consumption in larger households might be due to sharing of firewood used to cook animal feed and maintain the thermal environmental conditions of the houses. This shows that larger households are more efficient firewood users than smaller households, and a smaller family requires more per-capita firewood to fulfil their daily energy needs. This difference in per-capita firewood consumption between smaller and larger households is probably due to the sharing of firewood used to heat firewood burning cook stoves, cooking pots, and other indoor surroundings, which are common in all households.

3.1.2. Relationship between Livestock Rearing and Firewood Consumption

Rural population that relies on subsistence agriculture rear animals for different purposes. In the study area, people reared cow and buffalo for milk, ox for energy, particularly for ploughing cultivated land, and goat for meat. The number of animals reared influences the energy use patterns of rural households. Figure 6 presents the relationship between livestock rearing and firewood consumption. All investigated households reared cattle (here we consider cattle as cows and buffalos) and goats, but the number varied between houses. The number of cattle ranged from one to ten, and the number of goats ranged from one to eight. It can be seen from Figure 6 that there was a positive correlation between firewood use and livestock rearing, indicating that households with more livestock units use more firewood than those with fewer livestock units. This result seems reasonable because, as the number of livestock increases, the requirement of firewood for cooking animal feed also increases. Further, the correlation coefficient of cattle rearing (r = 0.91) was found to be slightly higher than that of goat rearing (r = 0.89). This might be due to the requirement of more feed for larger animals than that for smaller animals. In general, in the investigated area, people provided more feed for bigger animals, increasing firewood consumption. Households having milk-producing animals reported that they provided more animal feed to milk-producing animals for better milk production.



(**a**) (**b**)

Figure 6. Relationship between firewood consumption and livestock rearing: (**a**) Cattle rearing and (**b**) Goat rearing.

3.2. Hourly Firewood Consumption Patterns

Hourly firewood consumption patterns varied among houses depending on the work plan and cooking behavior of the residents. The investigated families normally wake up between 5:00 to 6:00 and sleeping after 21:00. The main meal was cooked twice a day, and only a few households cooked snacks during the day. Figure 7 shows the average hourly household firewood consumption patterns of the investigated households.

Generally, firewood burning started at approximately 5:00–6:00. When the residents wake up, they started a fire to make tea, followed by cooking the morning meal and animal feed between 7:00 and 9:00. Evening meal preparation started around 17:00, which took 2–3 h depending on the family size and food traditions. Only two households reported that they prepared animal feed in the evening. Out of the 16 households, 11 households used firewood thrice a day, 4 households used firewood twice a day, and 1 household with elderly residents used firewood for the whole day. Although more households used firewood thrice a day, only two distinctive consumption peaks were observed in the morning and evening. This may derive from the use of less firewood and variation of cooking time among households in day surveyed. As the elderly residents do not go for outdoor work and always stay at home, they prefer to keep the fire burning for the whole day to make tea and to keep their house warm. As shown in Figure 7, highest average hourly firewood consumption was 1.9 kg from 6:00 to 7:00, followed by 1.4 kg from 17:00 to 18:00. Higher firewood consumption in the morning is due to the common tradition of cooking meals and animal feed early in the morning.

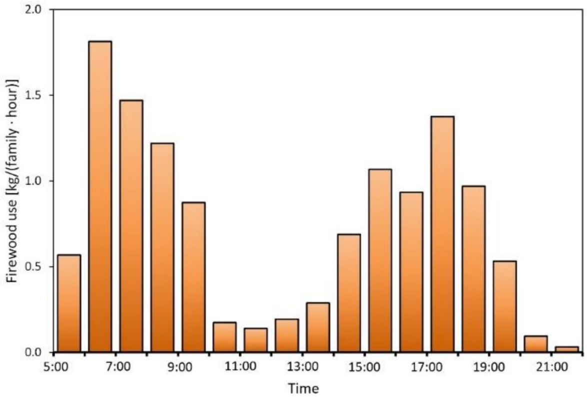


Figure 7. Average hourly firewood consumption pattern of investigated 16 households.

3.3. Relationship between Cooking Time and Rate of Firewood Consumption

Indoor air pollution depends on the amount and type of fuel used in a household [21]. The indoor air quality of a rural households is affected by firewood consumption inside the houses, and exposure to pollution from firewood consumption has been linked to a variety of health issues [14]. Cooking time and firewood consumption rate are considered simple indicators to determine the exposure and intensity of indoor air pollution. Therefore, we compared cooking time and firewood consumption rate with respect to the household size. This study classified all households into small and large households depending on the number of family members. Family members ranging from two to six were considered small households and family members ranging from seven to twelve were considered large households. The average size of the small and large families was estimated at 5 and 9 persons/family, respectively.

Figure 8 shows the relationship between firewood consumption and cooking time for small and big households. In this figure, the slope of the regression lines corresponds to the hourly rate of firewood consumption in kg/hour. The cooking time of small households ranged from 6 to 12 h, and that of the big households ranged from 8 to 15 h per day. The average cooking time was 8.7 and 9.9 h/day for small and big households, respectively. As shown in Figure 8, there was a strong relationship between firewood use and cooking time in both small (r = 0.84) and big (r = 0.88) households. However, there was no significant difference in the rate of firewood use between small and big households. The average rate of firewood consumption was similar between small and big households (1.3 kg/h), possibly due to the use of similar types of cook stoves. This implies that both small and big households use firewood at a similar rate. However, big households have to use firewood for longer durations to fulfil their cooking energy requirements.

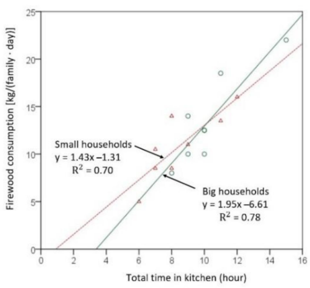
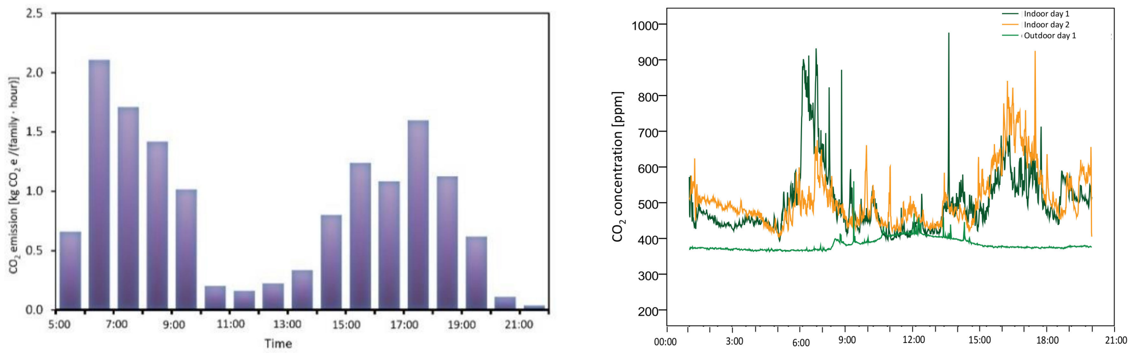


Figure 8. Relationship between firewood consumption and cooking time.

3.4. CO_2 Emission and Concentration

3.4.1. Hourly Variation of CO_2

Household firewood consumption generates indoor air pollution. The amount of firewood used, type of cookstove, and ventilation capacity of the building are the determining factors for variation in indoor CO_2 emissions and concentrations. Figure 9a shows the average variation in CO_2 emissions, and Figure 9b shows the variation in CO_2 concentrations measured in the investigated house during the survey period. Household CO_2 emissions ranged from 0.04 to 2.11 kg CO_2 e/(household·hour), and household CO_2 emissions from firewood consumption were 14.26 kg CO_2 e/(household·day). A similar hourly pattern of CO_2 emissions and concentrations can be seen in Figure 9. This figure also shows high emissions in the morning and evening hours, which reflects the firewood consumption patterns shown in Figure 7. Generally, in rural Nepal, people cook meals and animal feed before and after their outdoor agricultural work. Therefore, high CO_2 emissions were found in the morning and evening hours due to high firewood consumption. Lower emissions during the day were associated with a lower amount of firewood use.



(**a**) (**b**)

Figure 9. Diurnal variation of CO_2: (**a**) CO_2 emissions and (**b**) CO_2 concentrations.

Figure 9b shows high indoor CO_2 concentrations in the morning and evening hours. This is due to the higher emissions of CO_2 from higher firewood consumption during these hours. Indoor CO_2 concentration depends on many factors such as type and amount of fuel used, infiltration and ventilation rate, and the behavior of the residents. In this study, the CO_2 concentration trends were similar to the firewood consumption patterns as firewood burning is the major factor influencing indoor CO_2 concentrations in residential buildings in rural areas. The average values of indoor and outdoor CO_2 concentrations were 420 and 400 ppm, respectively. The highest indoor CO_2 concentration was 900 ppm in the morning, which is below the WHO standard for indoor air quality.

3.4.2. Relationship between CO_2 Emission and Concentration

As explained in the previous section, firewood burning is the main source of indoor CO_2 emissions, which influence the indoor CO_2 concentrations. To determine the relationship between CO_2 emissions and concentrations, we conducted a regression analysis between hourly CO_2 concentrations calculated from measured data and hourly CO_2 emissions calculated from hourly firewood consumption of the investigated house. As shown in Figure 10, a positive linear relationship ($r = 0.60$) between CO_2 emissions concentrations was obtained. This result seems reasonable as firewood consumption inside the house increases the level of indoor CO_2 concentration also increases. The number of occupancies is also one of influential factors in indoor CO_2 concentration. In this study, only a female household member responsible for cooking was exposed to the emission frequently during the daytime but no one during sleep. Other building characteristics, such as infiltration and ventilation rate, play an important role in the variation of indoor CO_2 concentration. However, due to the limited research data collected, this study cannot further discuss the quantities of CO_2 that leaves the house through chimneys and diffuse into the surrounding environment.

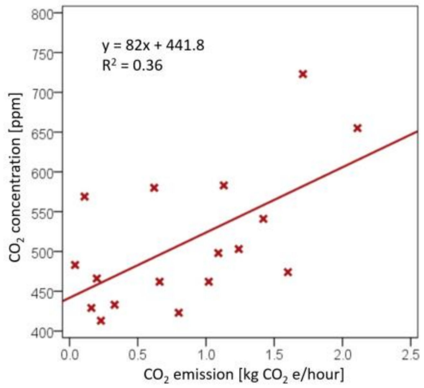


Figure 10. Relationship between CO_2 emissions and concentrations.

4. Discussion

A large number of households in Nepal still rely on firewood for cooking fuels. There have been several studies on firewood consumption patterns in Nepal, and these studies reported that the annual per capita firewood use varies widely among different parts of the country [10–12,21–25]. Table 2 shows the results of similar studies conducted in temperate regions of Nepal and India. The firewood consumption in the present study was 663 kg/(capita·year), which falls in the middle of values from previous studies. Several factors could have affected the rate of firewood consumption as there was significant variation in firewood consumption patterns within similar climatic zones [23–26]. Another cause might be the difference in the research method applied. For example, some researchers measured firewood use only for a few days, but some researchers measured firewood consumption for longer periods, which can influence the firewood consumption rate in similar climatic regions.

Table 2. Results of previous studies carried out in temperate climatic regions.

References	Periods	Country	Study Area	Climate, Altitude	Firewood Use [kg/(Capita·Year)]
This study	2002	Nepal	Dhading	Temperate	663
Fox [8]	1981	Nepal	Gorkha	Temperate	570
Shrestha [11]	2003	Nepal	Gorkha, Dhading	Temperate	464
Bhatta and Sachan [10]	2000–2001	India	Uttranchal	1500–2000 m	720
Webb & Dhakal [25]	2002–2003	Nepal	Dhading	Temperate	683
Kandel et al. [26]	none	Nepal	Dolakha	Temperate	612

The per-capita firewood consumption rate in this study was 1.8 kg/(capita·day), which is similar to the results of Fox [8] and Pokharel et al. [17], and higher than that of Rijal [9]. The difference might be associated with differences in the socio-economic conditions of the people, availability of fuels in the locality, and family size. Other methodological differences may also have influenced these results. In this study, firewood data were collected on hourly basis for one day in each house during winter, but in the study conducted by Rijal [9], firewood data were collected on daily basis for the whole year. Therefore, seasonal factors must have affected the results. As this study was conducted in winter, we found a marginally higher value of firewood consumption rate than the previous study [9]. The present study shows that firewood consumption differs according to family size; i.e., per-capita firewood consumption is negatively correlated with family size and household firewood consumption is positively correlated with family size. Bhatta and Sachan [10] also found similar results and reported that smaller families have more per capita firewood consumption than those of medium and large families. Our present study is consistent with previous studies indicating that smaller households have higher per capita firewood consumption than bigger households, and bigger households are typically efficient firewood users [9,10].

The household firewood consumption in this study was 12 kg/family·day, which is higher than the results obtained in other studies [8,17]. The cause of higher household firewood consumption in this study might be associated with family size, and the number of animals reared. We found that household firewood consumption is positively correlated with household size. This result aligns with many other studies that have also found that household firewood consumption was positively correlated with family size [8,10,20,26]. Thus, we confirmed that household size was indeed an important factor of firewood consumption.

Nepal is an agriculturally dominant economy where 74% of the households rely on the subsistence-based agricultural [26,27]. People living in rural areas rear many animals for energy, meat, and other economic purposes that may affect the household firewood consumption patterns. The results of this study showed a positive relationship between firewood consumption and the number of livestock reared. This is similar to many other studies that have found that households with more livestock units consume more firewood [28–30]. This result is however opposite to the result obtained by Bewket [13] in Ethiopia, where household firewood consumption was negatively correlated with the number of livestock units. The reason for lower firewood consumption by households with more livestock units was the use of animal dung as a substitute for firewood in Ethiopia [13]. In the present study, people used animal dung only as organic fertilizer, and hence firewood consumption did not decrease with an increase in the number of livestock units. On the contrary, the amount of firewood consumption increased with the increase in the number of livestock units due to the requirement of additional firewood for preparing animal feed.

Indoor air pollution produced by the domestic combustion of solid fuels is a significant cause of morbidity and mortality across the world especially in developing countries [31]. The present study has found that all investigated households used more firewood in the morning and evening hours. It indicates that high CO_2 emissions and high indoor CO_2 concentrations in the morning and evening hours may pose a serious health risk to the rural people. The health problem due to indoor air pollution in rural households becomes more severe during winter when cooking occurs in non-ventilated conditions, and people enjoy staying near the cooking place for a longer time to keep themselves warm [32–35]. We can speculate that the installation and use of mechanical ventilation system in the rural households would result in some health gain, particularly in the morning and evening hours. Rijal et al. [33] showed that installation of an improved cook stove can minimize indoor air pollution in rural areas of Nepal. Therefore, improved cooking technology and introduction of mechanical ventilation in the rural houses with necessary preventive measures would be the ideal way of dealing with indoor air pollution. To create favorable indoor environment in the rural houses, knowledge on hourly firewood consumption helps assess the influence of firewood consumption on indoor air pollution.

Average exposure on firewood consumption was found to be 8.7 and 9.9 h/day for small and big households, respectively, which is higher than the exposure time of 3–7 h/day reported by Ranavat et al. [36]. Longer cooking time has a significant negative effect on the health condition of people who are exposed directly to firewood burning [7,14,37,38]. Pandey [39] found that significantly higher proportion of women as compared to men were exposed to household smoke pollution in Nepal which creates serious health problems especially for women and children.

Household CO_2 emission was found 14.26 kg CO_2 e/(household·day) which is more than the value of 6.4 kg CO_2 e/(household·day) obtained in Bangladesh [16]. This difference might be due to the difference in the type and rate of fuel used and the efficiency of cooking devices used between the two countries. The use of clean cooking fuel and efficient technologies can play an important role in the reduction of household CO_2 emissions. Therefore, an intensive awareness program is required to improve the indoor air quality and health condition of the rural population.

5. Conclusions

Based on the present study conducted to assess the hourly firewood consumption patterns and associated CO_2 emission patterns of rural households in Nepal, we summaries our findings below:

- People living in rural areas fulfil their daily energy need by using firewood, and the rate of per-capita and household firewood consumption was found to be 1.8 kg/(capita·day) and 12 kg/(family·day), respectively.
- Household firewood consumption was positively correlated with family size and the number of livestock reared. The per-capita firewood consumption was negatively correlated with family size.
- The average cooking time was found to be 8.7 and 9.9 h/day for small and big households, respectively. Regardless of household size, people consumed firewood at the same rate (1.3 kg/h). However, bigger households spent more time cooking to fulfil their daily energy needs.
- High emissions of indoor CO_2 in the morning and evening hours due to high firewood consumption may pose a serious health risk to the rural population. Therefore, intensive awareness programs and installation and use of mechanical ventilation devices in the morning and evening would improve the air quality and health conditions of the rural population.
- Household CO_2 concentration was positively correlated with CO_2 emissions due to firewood burning, and daily CO_2 emissions were 14.26 kg CO_2 e/(household·day). Clean cooking fuels and efficient cooking technologies would help minimize household CO_2 emissions.

Author Contributions: P.T.R.: Formal analysis, writing original draft and addressing review comments. R.H.B.: Data curation, formal analysis and eliding paper. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the Japan Society of the Promotion of Science.

Acknowledgments: We would like to thank the residents who participated in the survey.

Conflicts of Interest: The authors declare no conflict of interest.

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