Comparative study on indoor air quality variation while burning different firewood species in Gatlang, Rasuwa, Nepal

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Research

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Abstract

Indoor Air Pollution (IAP) from smoky cooking fires causes deaths over 22,800 per year being the fourth leading cause of death in Nepal. The study aims to compare the pollution level particularly Carbon Monoxide (CO) and Particulate Matter (PM 2.5) in different firewood species. Two households one with ICS and TCS is selected purposively to monitor the concentration of pollutants in Ward no. 3 of Gatlang, Rasuwa, Nepal. IAP Meter based on Laser Sensor principle is used to monitor real time concentration of PM 2.5 and CO. 24 hours mean concentration of PM 2.5 and 8 hours mean average concentrations of CO are found to be above the WHO and National Indoor Air Quality Guidelines i.e. For ICS using household the concentration is found to be 155.26 µg/m 3 and 9 ppm respectively and household using TCS is found to be 385.12 µg/m 3 and 12.2 ppm). Both pollutants' concentration is found less in Abies Spectabilis than other species. Positive correlation is found in both households along with moisture content, amount of firewood used, etc. This result suggests the use of Abies Spectabilis as it emits less emission as compared to other species as it has less moisture content that reduces the concentration of air pollution. Keywords : Carbon Monoxide 1 , Particulate Matter (PM 2.5) 2 , Indoor Air Pollution 3

Introduction

Exposure into IAP while burning solid fuel such as wood, dung, crop residues for cooking and heating causes the premature deaths of 4 million people each year [1]. Inefficient combustion of biomass fuel and poorly regulated energy production are the major cause of air pollution, is considered as single most man-made effect [2]. Due to inefficient combustion of fuel several health damaging chemicals and pollutants such as particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide, benzene, and formaldehyde and nitrogen oxides are formed.

Around 42.2 % of the population is exposed to household air pollution in most of the middle and low-income countries and it ranks as the eighth greatest risk factor causing morbidity and mortality [3]. In developing countries, IAP is the top-fourth risk factor driving overall morbidity and mortality. Household air pollution causes non-communicable diseases including stroke, ischemic heart disease, chronic obstructive pulmonary disease (COPD) and lung cancer [4]. Apart from that, various respiratory symptoms including dry cough, phlegm production and breathing difficulties along with back pain, cardiovascular disease, cancer, blindness and low birth rates have also been linked to IAP [5].

Various factors affect the concentration of pollutants which includes: condition of household and biomass burning cook stove. Along with that several other factors such as: type of fuel, time spent in cooking, structural characteristics of houses, and ventilation practices of household (opening of windows, doors, etc.), cooking and heating methods, changes in season also causes changes in pollutant concentration [6]. However, the extent of pollution varies upon the cooking activities within the day and between the days [7].

Similarly, cooking with solid fuels such as wood over an inefficient stove leads to the exposure of incomplete combustion of various particles inside the domestic environment [8]. Factors which affects the affecting combustion of woods are moisture content, ash content, size of log, firebox size, shape and materials, flue gas outlet dimensions, air supply, stack height, natural draft, air supply and mixing, combustion rate, fuel loading and operation habits [9].

Household pollution from smoky cooking fires causes over 22,800 deaths per year [10]. It contributed to 1.6 million of premature deaths/year occurred in developing countries, being the 4th leading cause of death with 8700 deaths occurring in Nepal alone [11].

Burning of biomass fuel in traditional cook stoves (TCS) is one of the major means of cooking in rural areas in most of the developing countries [12]. Typical wood-fired cook stoves and open fires emits various particles such as: carbon monoxide, particulate matters and other noxious fumes which are up to 100 times higher than the recommended limits set by WHO [13]. It has low efficiency and is prevalent in rural areas; hence more fuel is consumed along with higher incomplete combustion of particles [14]. A study carried out in rural areas of South India showed that if an improved cooking stove replaced the traditional mud-built cooking stove, each family could reduce its annual fuel wood consumption by about two-thirds [15]. According to a report ICS saved over 88 kg of fuel wood per month on average. The report quotes the use of ICS has also reduced the cooking time, time of firewood collection, and emission of greenhouse gas, lowers the pressure on forest for firewood extraction and reduces the health hazard [16].

Approximately 80 % of energy consumption in Nepal is from the fuel wood including animal dung and the agricultural residue [17] and mountain areas being isolated, fragile and inaccessible, inhabitants are more dependent on the traditional cooking fuels. As a result, indoor air pollutants have poses great threat to human health (especially women and children who spend more time in kitchen) [18]. Also because of the comparatively cold weather in the mountain region throughout the year (mainly in the winter season), the need for firewood and other alternatives fuels becomes highest during winter season resulting more pollutants due to restricted ventilation.

The major aim of this study is to compare pollution concentration while burning locally available five different firewood species in locally used stoves types i.e. ICS and TCS. This research will help to examine the variation in air quality while burning individual types of firewood species. In order to know about the impact of burning different firewood species, the concentration of pollutants such as CO and $PM_{2.5}$ are determined. This research will help to identify the concentration of pollution while burning different firewood species that will be helpful to decision makers and local people for choosing less polluting firewood species to save health of public in some extent. There is lack of research related to variation in pollution concentration while burning different species of firewood in Himalayan household basically found in Himalayan region. . Therefore, Rasuwa district is selected as a study site to represent the condition of cold climatic situation households.

Materials And Methods

The study is a comparative study among five types of locally using firewood species in two cook stoves i.e. ICS and TCS using random and purposive sampling during winter season inWard no. 3 of Aamachodinmo Rural Municipality, Rasuwa, Province No. 3. The study area lies at an elevation of 2313 m with longitude and latitude of 28°9’22”N and 85°15’18”E, respectively as shown in Fig. 1.

It lies in temperate zone with major vegetation type of *Alnus nepalensis, Tsugadumos, Abies spectabilis, Rhododendron sps, Quercus semicarpifolia* and many other medicinal plant species like *Alvumvisum, Swertiachirata, Juglanregia,* etc.

The populations of 1267 with 622 male and 645 females are living in 292 households [19]. The majority of people are Tamang while few belong to Biswokarma. The major sources of energy for cooking and heating is firewood whereas, the household are of mainly two types; namely typical old household (black house) and new households.

$$n = NZ2 * p(1-p)/[Nd2 + Z\hat{}2p(1-p)$$

Where,

n = Sample size

N = Total number of households

Z= value of standard variant (at 5% level of significance, Z= 1.96)

p = Estimated population proportion (10%)

d = Error limit 5%

Altogether 68 households are selected by this method from total of 292 households. Cluster sampling with total of four clusters followed by systematic sampling method is applied for questionnaire survey of total 68 households where 17 households from each cluster are surveyed.

Criteria for selection of the houses is made on the basis of the following criteria adapted from [21]

- Functional homestead (at least mother and children present),
- Cook daily in designated cooking area in home,
- Use firewood as main fuel on a daily basis,
- Firewood is either bought or collected in fixed bundles on a regular basis
- Involvement in the kitchen work

Focus group discussion is carried with women’s group focusing on types of household energy, past and presents condition of the forest, availability of firewood, consumption of firewood, challenges and opportunities regarding energy sources and health issues related to IAP.

Questionnaire survey is carried out in 68 households to collect the data regarding fuel wood consumption using random sampling.

With the help of purposive sampling technique, households are chosen based on type of cooking stove i.e. TCS and ICS to monitor 24- hours $PM_{2.5}$ and CO concentration for 5 consecutive days in each household.

Monitoring carried inside house where people burn firewood for cooking as well as their space heating. CO and $PM_{2.5}$ concentration monitored using Indoor Air Pollution Meter 4000 series. Both parameters are monitored in one minute interval throughout monitoring period. Before administrated firewood species for cooking, the moisture content of each species is measured using Moisture Meter (PMS-713) ISO 90001, CE, IEC1010. Each species of firewood species are weighted using digital weighing box. The households for the data monitoring chosen away from roads in order to exclude suspended particles generated through vehicular movements. Daily wood measurements are taken from 13th February to 9th March, 2019. IAQ is assessed by continuous monitoring for 24 hour in sampled households following the sampling protocol by National Indoor Air Quality Standard (NIAQS) and implementation guideline [22]. Households are instructed to only use wood from the weighed pile that day and store the newly collected pile for the next day. The wood is tied in one or more bundles and weighed [23].

Results

Mostly two forms of energy sources i.e. traditional and alternative sources are observed in the study area. Firewood is used in all the houses for cooking food, for space heating, preparing animal food and for making alcohol. Firewood used as energy source for cooking in winter season is 88% followed by 11% Liquefied petroleum gas (LPG) whereas during summer season the increase in use of LPG is 29.4 % whereas the use of firewood is 70.6 % as depicted in Fig.2

It is found that 22% of the households has attached kitchen with partition while 49% households has separate kitchen outside the house and 29.40 % of households has attached kitchen without partition within the house as shown in Fig. 3

Regarding the concern of cooking stoves, 87% of households has TCS whereas, 13% of the households has ICS as shown in Fig. 4.

More than 9 species of trees are used by the local people for firewood. As per the rules and regulations of the forest office the local people are allowed to collect dried, dead and fallen branches and twigs, people collected them and stored them for winter season. The major tree species that are used as firewood are presented in table below:

Table 1 Plant Species used as firewood

Local Name	Scientific Name
Pibi	*Eurya Acuminata*
Thangsing	*Alnus Nepalensis*
Chesing	*Pinus Wallichiana*
Jhangsing	*Abies Spectabilis*
Tamar	*Rhododendron Falconeri*

Among these species five species mainly *Eurya Acuminata, Pinus Wallichiana, Abies Spactabilis, Alnus Nepalensis and Rhododendron Falconeri* are most commonly used.

As the village lies near the forest villagers fetch the firewood easily from nearby forest. Out of total respondents 24% response that firewood is easily accessible and economical source of energy. Similarly, 11% response that it takes less time to cook, followed by 7% who believes that it enhances the taste, 9% response it is easy excess heating whereas 49% believed in all of the mentioned options which is shown in Fig. 5.

The average firewood consumption of a single household is found to be 7.195 kg/HH/day. Per capita firewood consumption of the households using TCS and ICS is found to be 1073.1 kg/person/year and 675.25 kg/person/year respectively.

Table 2 Per Capita Firewood Consumption of Household using TCS

Average firewood consumption (kg/HH/day)	Total number of family	Family members	Per capita firewood consumption (kg/person/day)	Per capita firewood consumption (kg/person/year)
11.168	1	3	2.94	1073.1

Table 3 Per Capita Firewood Consumption of Household using ICS

Average firewood consumption (kg/HH/day)	Total number of family	Family members	Per capita firewood consumption (kg/person/day)	Per capita firewood consumption (kg/person/year)
7.446	1	3	1.85	675.25

Species wise variation in pollution concentration

An hour average concentration of CO while burning *Alnus Nepalensis* followed by *Pinus Wallichiana, Rhododendron Falconeri, Eurya Acuminata, Abies Spactabilis* for both types of cook stove being used. Species wise average 1hour CO concentration in the household using TCS and ICS while burning with individual firewood species is found below the NIAQS value and WHO value i.e. 35 ppm as shown in Fig.

6 and Fig. 7. However, the emission concentration of individual species is found to be higher while burning in TCS as compared to in burning in ICS.

Particulate Matter ($PM_{2.5}$)

Hourly average $PM_{2.5}$ concentration of *Pinus Wallichiana* is found to be highest which is followed *by Rhododendron Falconeri, Eurya Acuminata, Alnus Nepalensis* and *Abies Spectabilis.*The average 1hour concentration of $PM_{2.5}$ in the household with ICS and TCS using individual firewood species is found to be exceeded the NIAQS guideline i.e. 100 μg/m^3 and WHO guideline i.e. 60 μg/m^3 as shown in Fig. 8 and Fig. 9.

Twenty four hours average concentration of $PM_{2.5}$ is found to be highest in *Pinus Wallichiana* followed *by Rhododendron Falconeri, Eurya Acuminata, Alnus Nepalensis* and *Abies Spectabilis* in both types of stove as shown in Fig. 10. Houses using ICS and TCS are found to be 155.3 μg/m^3 and 367.9 μg/m^3 respectively. It exceeds the NIAQS Value i.e. 60 μg/m^3 as well as the WHO guideline i.e. 25 μg/m^3 .

Correlation between firewood and moisture content in household using ICS (p= 0.005687, = 0.9713) which shows both firewood and moisture content are strongly correlated with each other similarly, the correlation between firewood and moisture content of household using TCS is (p= 0.0007258, r= 0.9928) which also shows the strong correlation between the parameters.

Table *4* Correlation of $PM_{2.5}$ and CO with factors contributing to IAP in household using ICS and TCS

Parameters	PM	CO
Moisture Content	0.633**	0.647**
Firewood consumption	0.571*	0.591*
Cooking phase	0.721**	0.69**

* Significant at 0.05 level (2 - tailed)

** Significant at 0.01 level (2- tailed)

The correlation carried out between the indoor air pollutants and factors contributing to them in the households with ICS and TCS reveal that there is positive correlation between $PM_{2.5}$ and moisture content and CO and moisture content (r = 0.633, r = 0.647), of amount of firewood with moisture content (r = 0.57, r = 0.581) and cooking phase (r = 0.721, r = 0.69).

Discussion

The study showed firewood as the major energy source for cooking (88%) and heating purpose (12%) which represents the high dependency on fuel wood especially in winter season because of its ease accesses as compared to other sources of cooking fuel. Various factors such as size of the family, livestock holding capacity cause fluctuation in the use of firewood. Apart from those other factors like level of education, distance and the time devoted for collection of firewood ethnicity, settlement location [24].

The use of firewood is similar to the national situation i.e., about 80 percent of energy consumption in Nepal is from the fuel wood including animal dung and the agricultural residue [17]. Such high dependency on firewood might be because of lack of other economical and accessible source for heating purpose as the area lies in Himalayan region which is similar to the study of [25] in Manaslu conservation area where 2135 kg/day firewood used in households using ICS whereas, 349 kg/day firewood used in households using TCS.

Among different firewood species used in this study the physio-chemical properties of *Abies Spectabilis* shows the moisture of 45.6 %, calorific value of 21.2 $kJkg^{-1}$, density of 0.81, ash 1.9 % and FVI 903.8 [26] Similarly, the average 8hours concentration of CO is found to be 7 ppm, average 24 hours concentration of $PM_{2.5}$ is found to be 120.0 μg/m^3. The amount of moisture content is found to be 8 % whereas, the average amount of firewood consumption is 6 kg for household using ICS while burning Abies *Spectabilis*.

Similarly, *Eurya Acuminata* has density of 0.53, moisture content 48 %, ash 1.49 % whereas, the calorific value is found to be 21.02$kJkg^{-1}$ from the physio-chemical properties, calorific value of 19.6 kJ/g, density 0.84 g/cc, ash 1.7%, biomass ash ratio 56.1%, moisture 46.2%, Nitrogen 0.22 % and FVI 2096 [27]. The average 24hours concentration of $PM_{2.5}$ is found to be 201 μg/m^3 whereas average 8hours concentration of CO is found to be 9 ppm. The amount of moisture content is found to be 10% whereas the average amount of firewood consumed is 8 kg. Though this species has densest wood but also has high ash content and makes it less desirable [28].

The fuel wood characteristics of *Alnus Nepalensis* shows moisture content of 37.41%, calorific value of 15.13 $kJkg^{-1}$, density 0.46%, ash content 1.1%, silica 0.60 fixed carbon 27%, biomass and ash ratio 90.90%, Nitrogen 0.423 %, Total carbon 66.15%, volatile matter 34.09% and FVI value of 1709 [29]. *Alnus* has energy content of 17.30, moisture content 46%, biomass/ash ratio is 17%, density of 0.32, ash 1.77%, FVI of 673.5 [28]. The average 24hour concentration of $PM_{2.5}$ is found to be 150.1 μg/m^3 whereas the 8 hours average concentration of CO is found to be 8ppm. The moisture content is found to be 9.8% whereas the average firewood consumption is 7 kg. From the study conducted by the amount of silica content in *Alnus Nepalensis* is 0.65 which is lower than the preferred value (0.70%) which shows that the species does not retain the heat for longer period of time after the fire has died off and increases cold during winter time and increase the amount of firewood consumption [29].

Pinus Wallichiana has moisture content of 55.09 ± 0.83, calorific value of 19.30± 0.34 kj/kg^{-1} density 0.49±0.01, ash 1.69±0.07%, silica 0.75±0.01%, fixed carbon 24.45±0.35%, nitrogen 0.117±0.001%, total carbon 60.40±0.78% and FVI 560±1.11 [29]. Twenty- four hours average concentration of $PM_{2.5}$ is found to be 267.1 μg/m^3 whereas 8 hours average concentration of CO is found to be 10.9 ppm. The average amount of firewood consumption is found to be 8.41 kg whereas moisture content is found to be 13.2% which is comparatively higher than other species. As comparatively higher level of nitrogen content and volatile matter is present in this species results in formation of different oxides of nitrogen while burning which leads to different health hazard and environmental pollution [30].

According to value *Rhododendron Falconeri* has moisture content of 49%, density 0.62, ash 1.28%. The average 24hours concentration of $PM_{2.5}$ is found to be 231.9 μg/m^3 and average 8 hours concentration of CO is found to be 10.1 ppm. The moisture content is found to be 12.4% whereas average firewood consumption is found to be 10.52 kg.

Higher moisture content of wood the lesser is the energy output as it is the major determinant of its combustion rate and decreases its calorific value. *Abies Spectabilis* creates less pollution in comparison to that of other species because of its low moisture content (45.6%), high calorific value (21.2 kj/kg^{-1}) [30]. As calorific value and density of *Abies Spectabilis* is higher as compare to that of other species which makes it to have more positive characteristics than that of other species. However, due to the presence of high water content and high ash content in *Pinus Wallichiana*, *Alnus Nepalensis*, *Rhododendron Falconeri* makes this species with negative characteristics i.e. higher pollution concentration than that of other species.

As FVI value plays an important role to determine the desirable wood, the FVI value of each species is taken from the studies. Study found that the FVI value of *Rhododendron Falconeri* (1922.0) is highest followed by *Eurya Acuminate* (1358.6), *Abies Spectabilis* (903.8), *Alnus Nepalensis* (673.5) and *Pinus Wallichiana* (558.89) however, the pollution level is found higher in *Rhododendron Falconeri* and *Eurya Acuminate* because of its high moisture content [30].

In poor developing countries, incomplete combustion of traditional sources often burned in poorly functioning stoves are proven to emit health hazardous $PM_{2.5}$, benzene, formaldehyde, hydrocarbons and CO have been shown to damage health of humans in household environment [31].

From this study 1hour CO concentration of both houses i.e. ICS and TCS is found below the NIAQS guideline. However 8hours average concentration of CO in both types of cooking stoves is surpassed the standard value for safe health.. It might be because of the longer cooking hours, inefficient performance of ICS. According to a study conducted by Aprovecho Research Center (ARC), which shows that the chimney stoves are less efficient as it is slower to boil and consume more fuel and had Therefore, increases the invisible $PM_{2.5}$, CO and powerful climate forcing pollutants (methane and black carbon) in rural household.

Similarly, an hour average and 24 hours average concentration of $PM_{2.5}$ for both houses with ICS and TCS has exceeded NIAQS and WHO guidelines for safe health. This is similar to the result of previous study [32]. The reason noticed during study period is the number of ventilations, dryness of the firewood, orientation and placement of chimney for ICS, opening or closing of the windows during cooking time, characteristics of the houses, methods of cooking, etc.

From the study it is found that doors and windows are closed to cope with the extreme cold condition. People usually open their doors and windows only for a short period of time. Although firewood is chopped and is placed in a dry place, due to harsh weather the wood got moisten which might be the cause of increase in concentration of pollutant.

Similarly, PM concentration is highly affected by the various activities such as sweeping, movement of the people, fuel burning duration, etc.. It also varies with the wood added, stirred, removed, pot placing while stirring food.

Cooking habits and cooking methods give rise to high emissions and high peaks of CO and $PM_{2.5}$ that occur during cooking [36] and diffuse rapidly into living spaces [33]. From the study it is found that the cooking hours (8 hours for ICS and 10 hours for TCS) also influence to increase the concentration of pollutants which is higher than the study conducted in three districts of Nepal in Illam i.e. 6-7hours, 4hours in Dang and 5hours in Dolakha. The reason for this might be due to geographical and cultural differences, in addition the differences in stove use and maintenance [34].

Although CO has been applied as surrogate measure by various researchers the findings suggests limited utility as proxy in this setting. Variation in correlation can be explained by cooking characteristics, fuel type and cooking behavior [35]. The correlation between an hour average concentration of CO and $PM_{2.5}$ is found to be strong (r = 0.9015) which is similar to that of the study of Muralidharan et al., 2015 [36] where p-value is 0.82 for household using TCS and other alternative cooking stove. Various researches also lead to conclusion that household characteristics along with condition of stove primarily influence emission and pollutant dilution which can determine $PM_{2.5}$ and CO relation as studied by Naeher et al., 2001 [37].

Conclusion

It is found that burning of *Abies Spectabilis* has low concentration of $PM_{2.5}$ and CO as compared to that of other species applied in this study. Burning of this species helps in the reduction of pollutant as it contains low moisture content and high calorific value.

$PM_{2.5}$ and CO concentrations are positively correlated (r=0.90) with the amount of firewood used (r= 0.571, r= 0.59), moisture content (r= 0.633, r=0.647) and with cooking phase (r=0.71, r=0.69) while burning individual species of firewood.

The concentration of pollutants' is found comparably less in *Abies Spectabilis* than other species and it has less moisture content that reduces the concentration of air pollution. Hence, this study suggests using of *Abies Spectabilis* as a comparatively less polluting species than other firewood species applied in this study that saves the health of dwellers to some extent.

Ethics Declarations

Competing interests

The authors declare that they have no competing interests

Availability of data and materials

No such sources of data or materials are used for this study except own field monitoring data and agencies standard guideline values.

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Contributions

All the authors have contributed to the structure, content, and writing of the paper. All authors read and approved the final manuscript.

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Figures

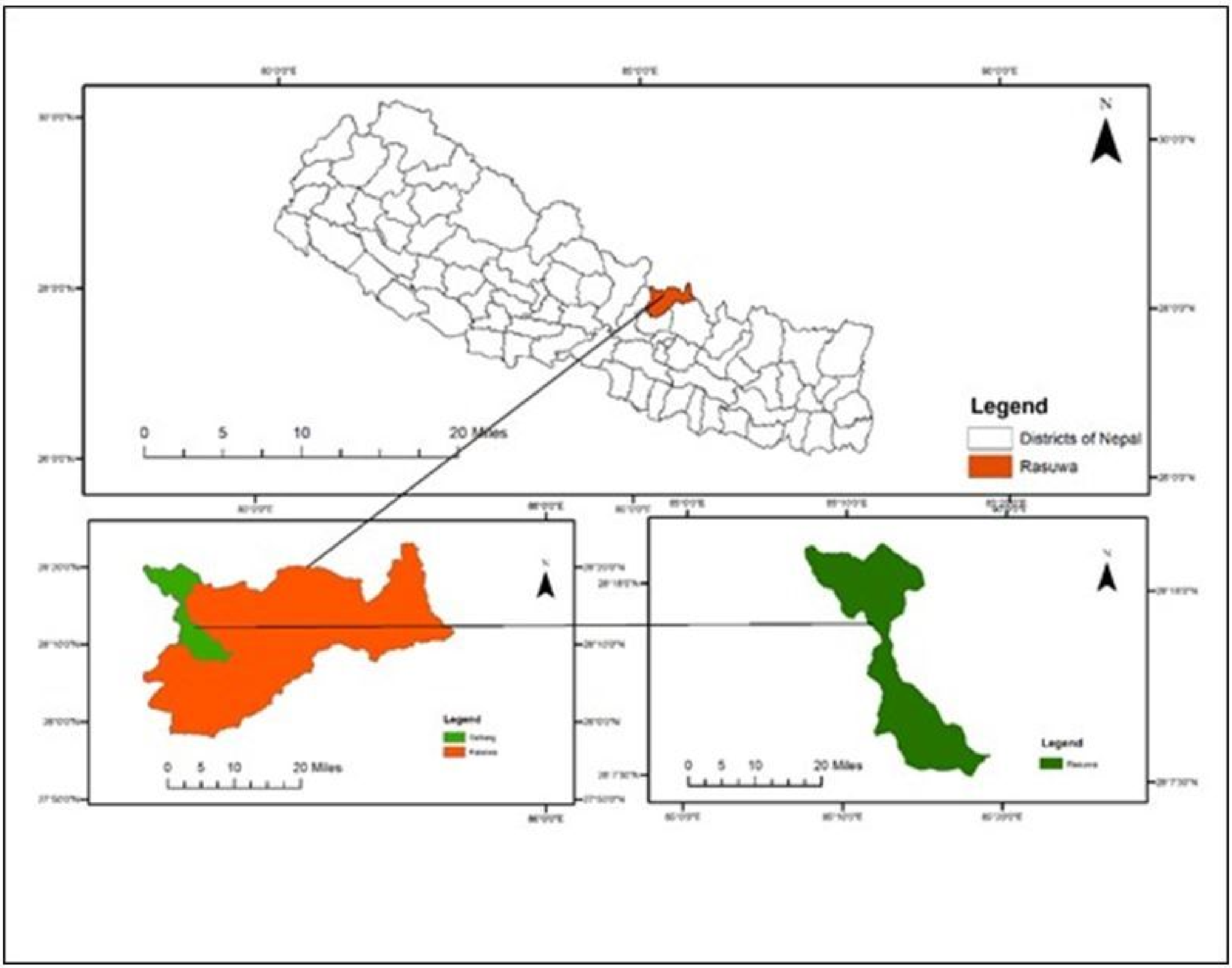

Figure 1

Map of Gatlang, Rasuwa Nepal

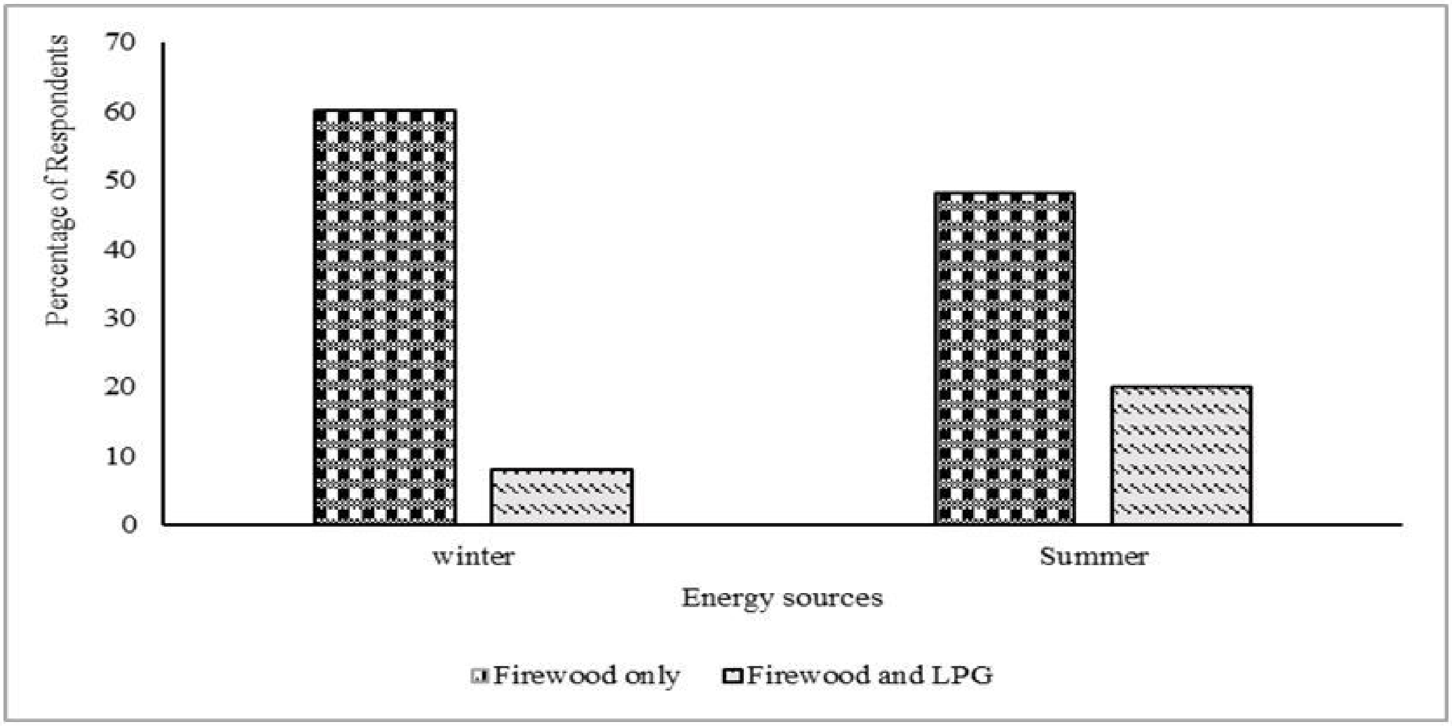

Figure 2

Energy source for cooking

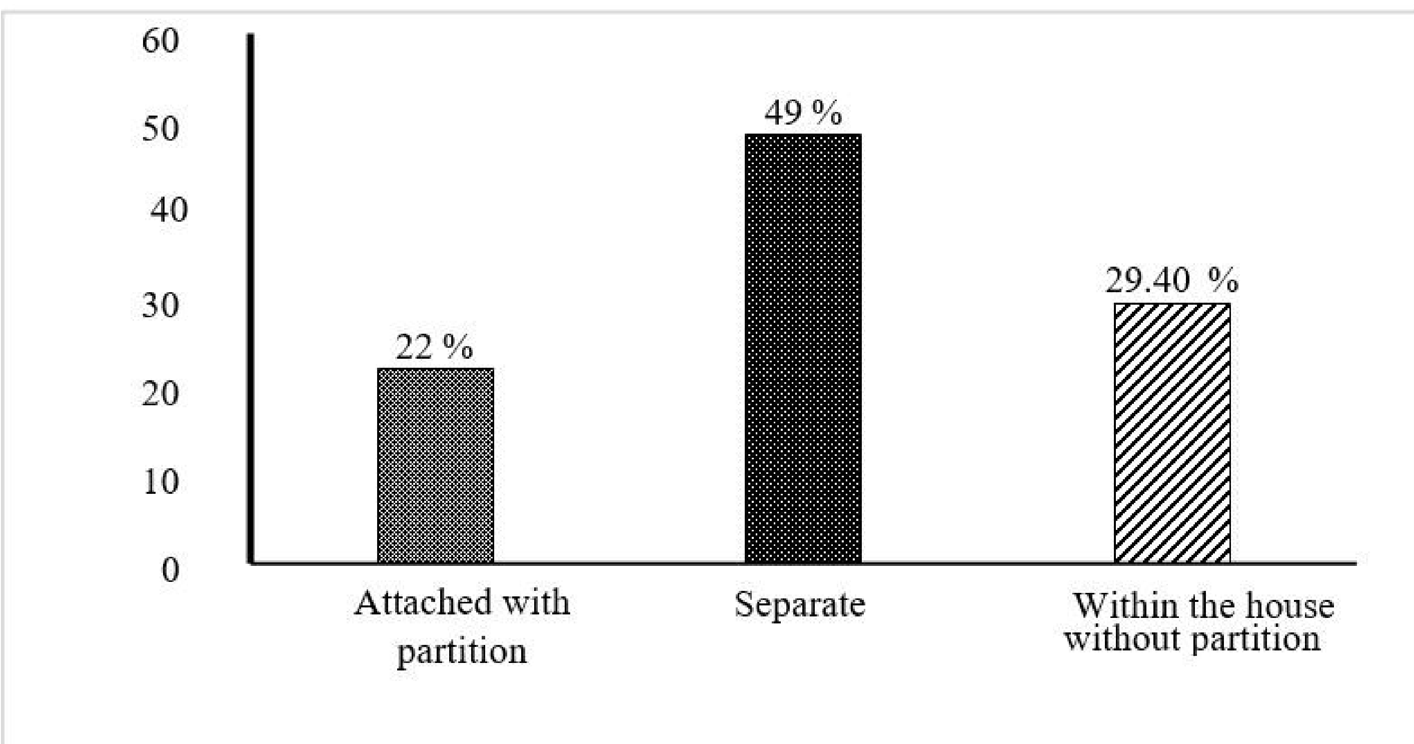

Figure 3

Kitchen Configuration

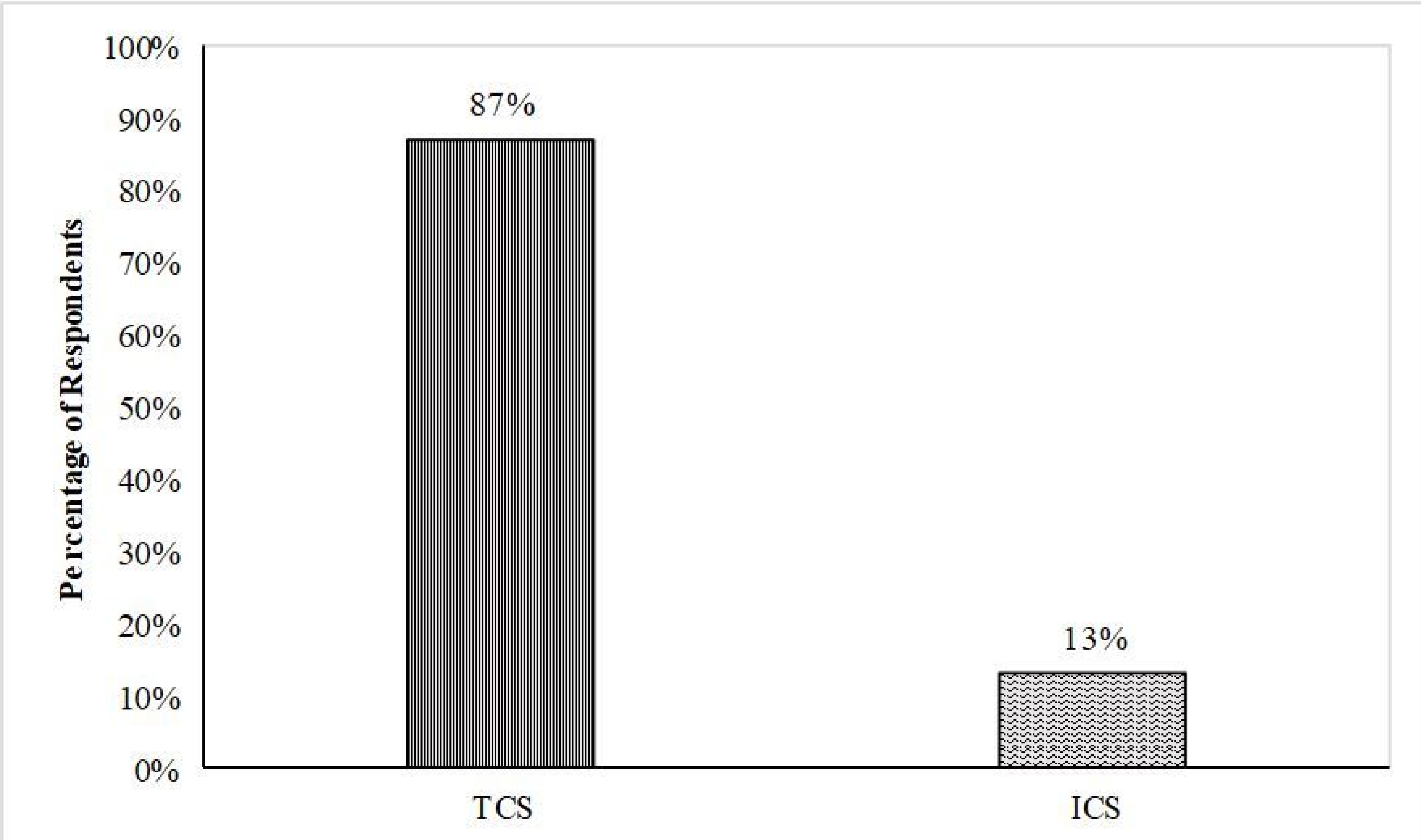

Figure 4

Types of cook stoves

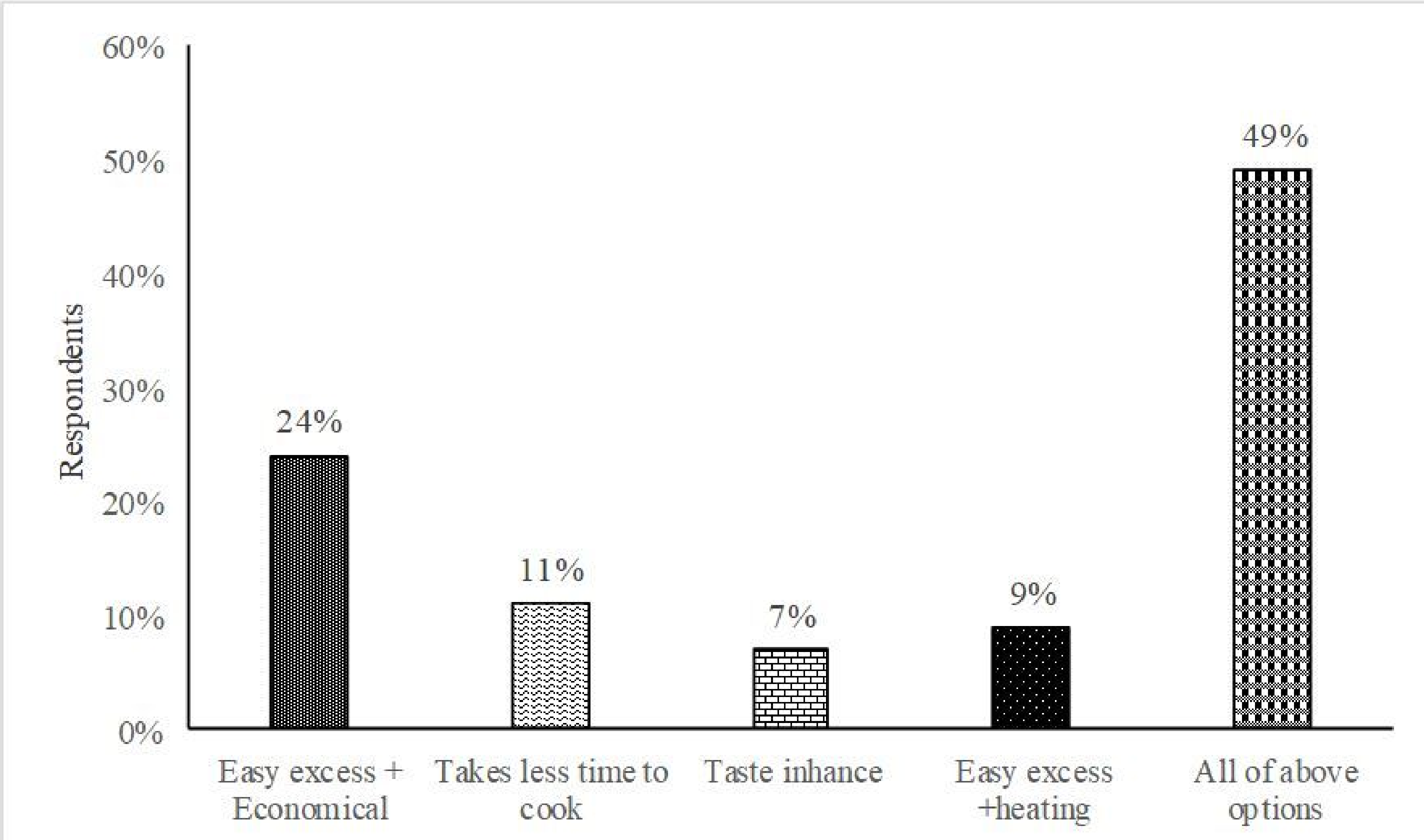

Figure 5

Preference of firewood

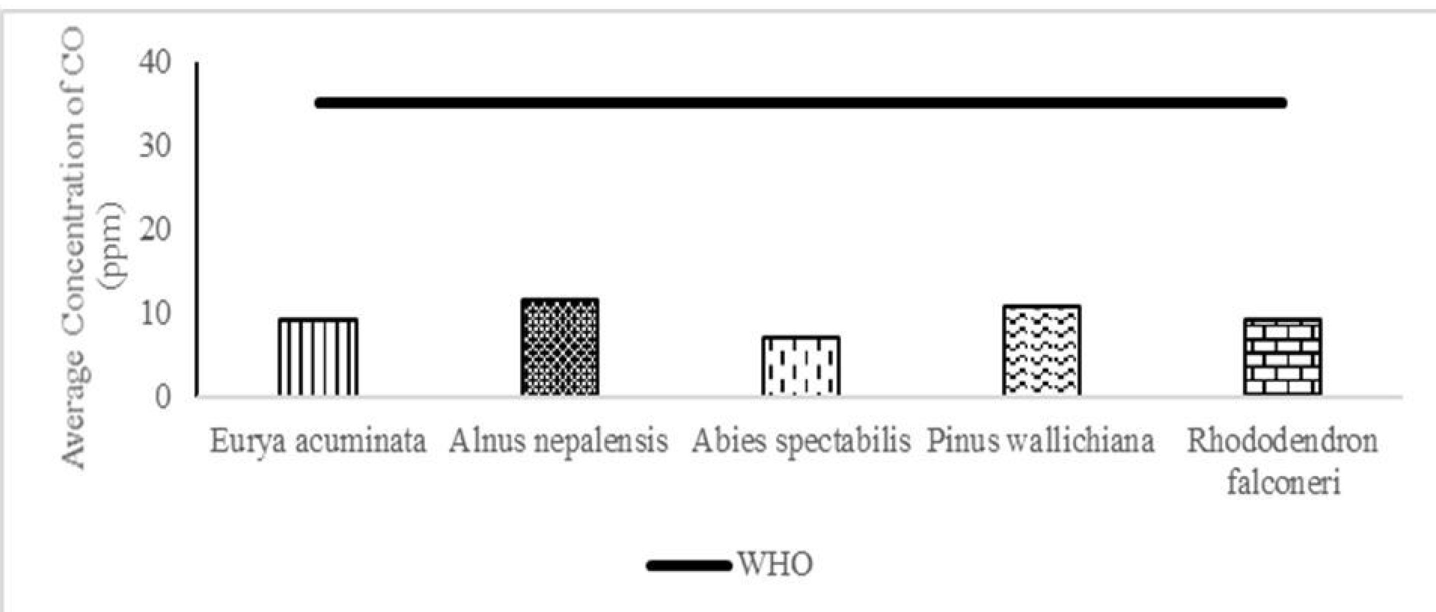

Figure 6

Average 1hour concentration of CO in households using ICS

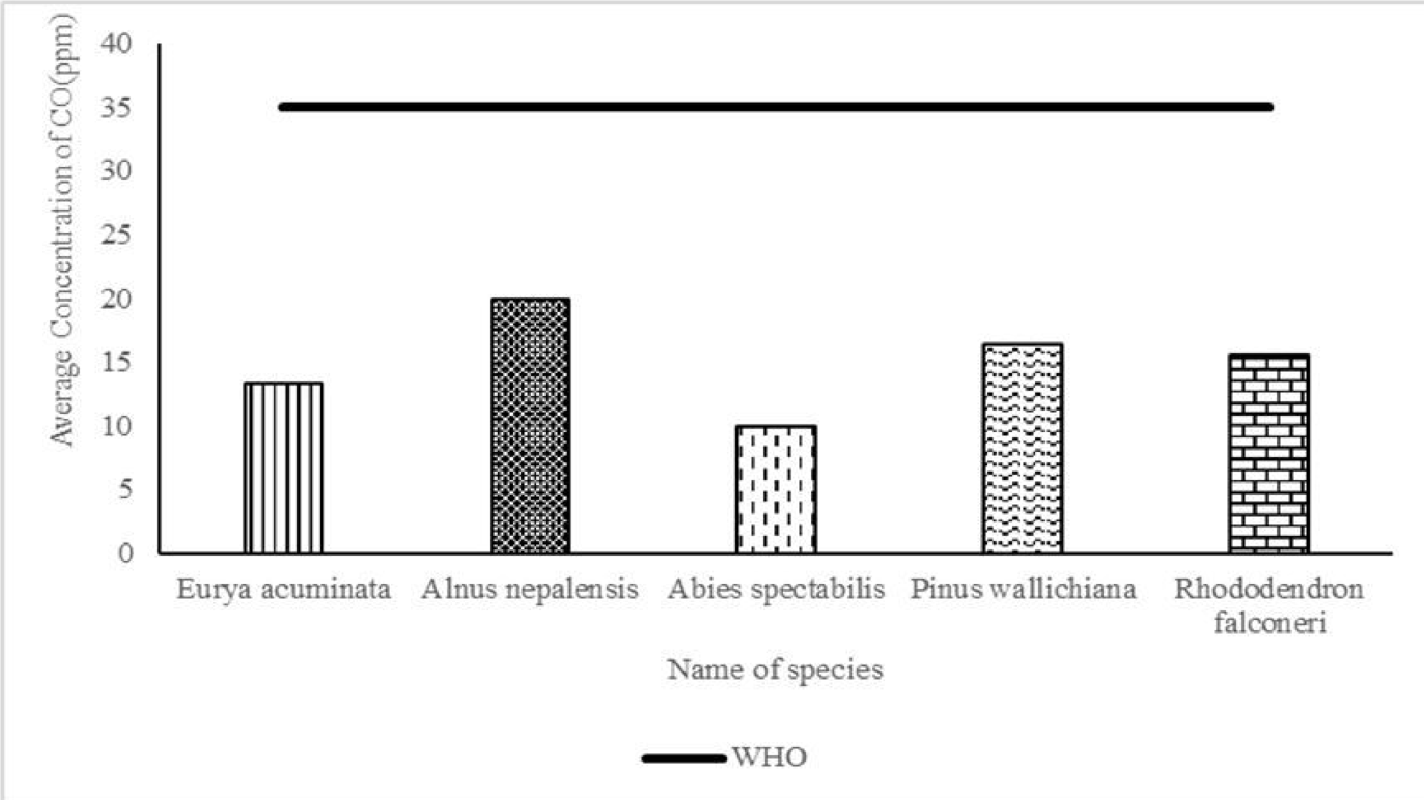

Figure 7

Average 1hour concentration of CO in households using TCS

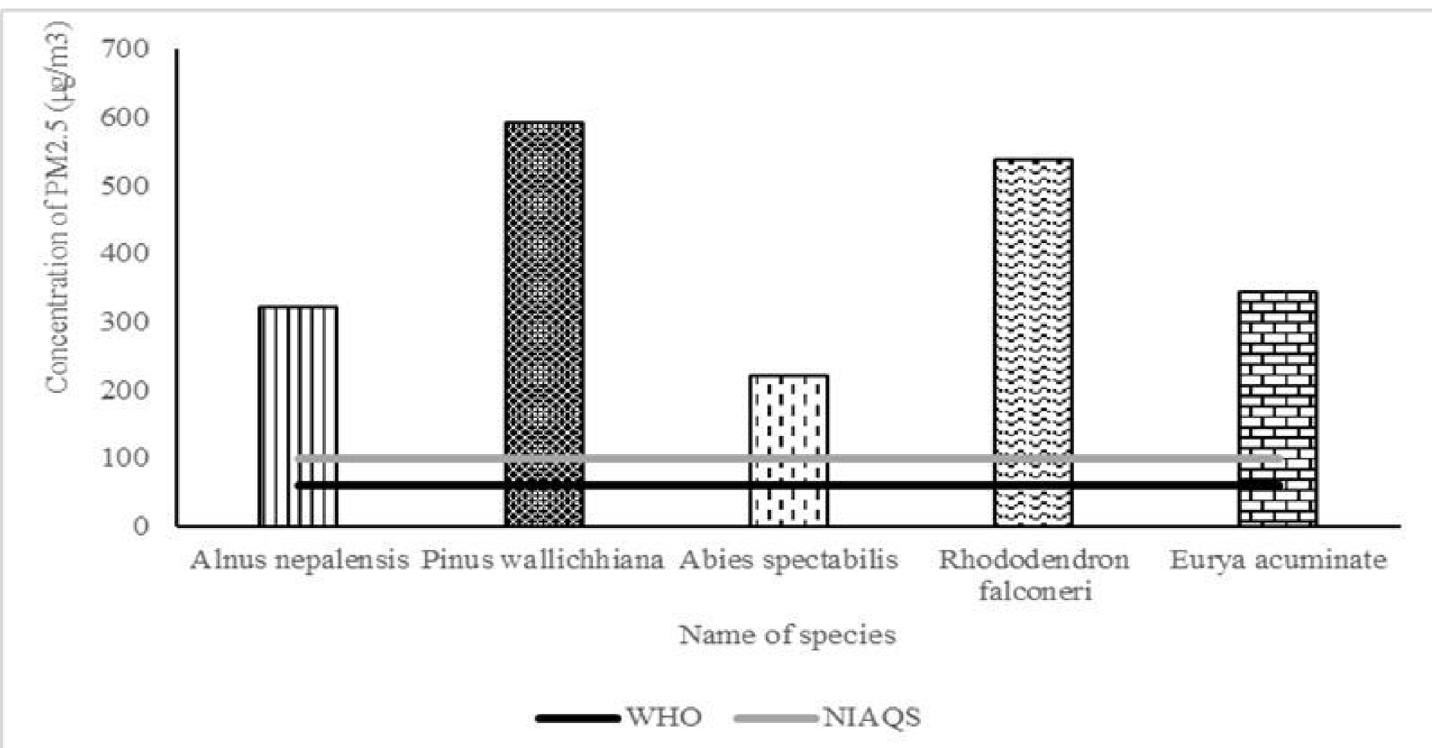

Figure 8

Hourly average concentration of PM2.5 in household using ICS

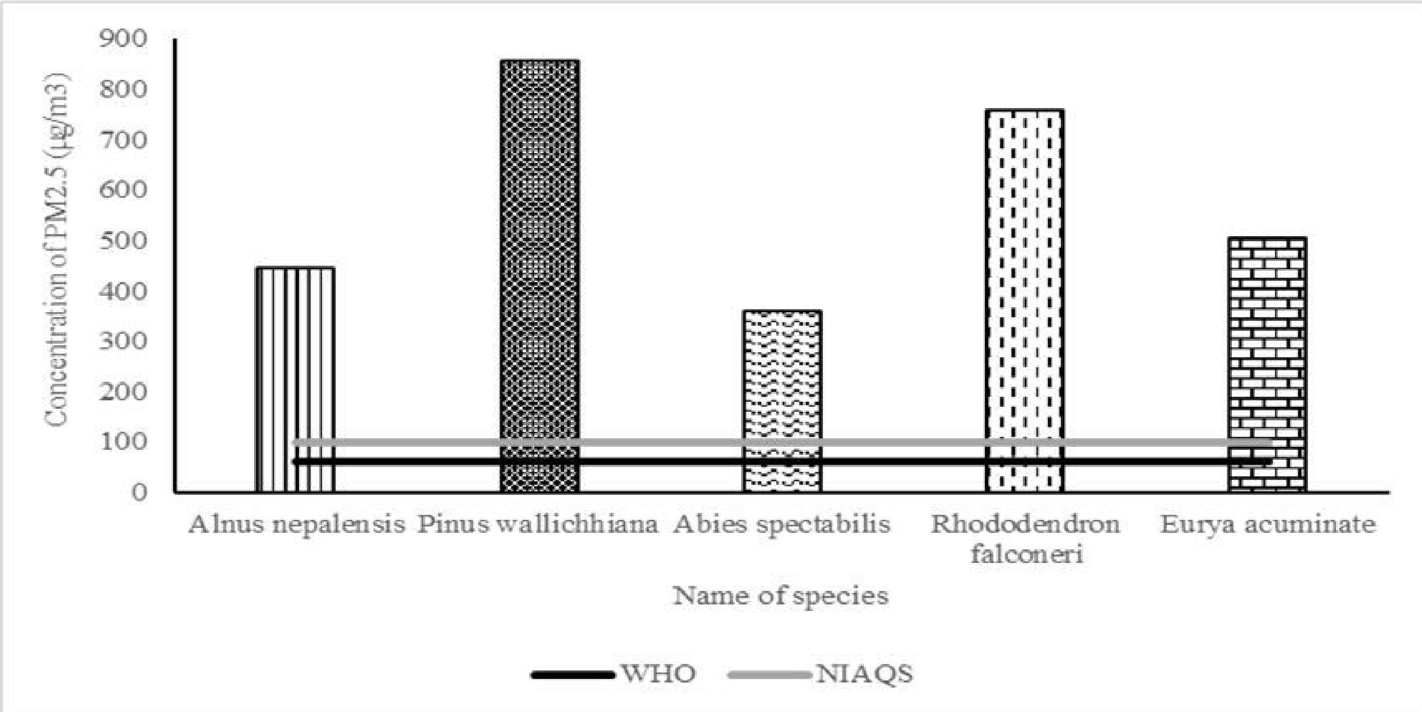

Figure 9

Hourly average concentration of PM2.5 in household using TCS

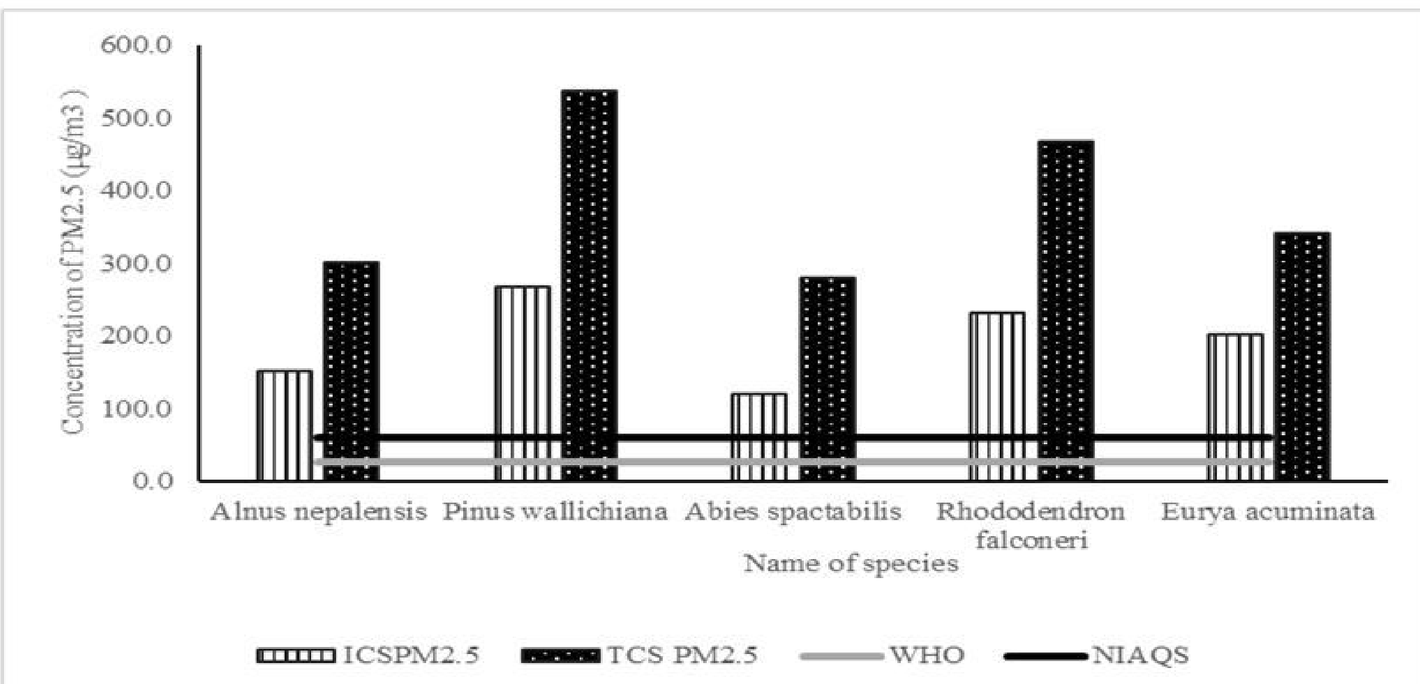

Figure 10

Averages of 8hours CO and 24hours PM2.5 concentration in houses with ICS and