Consumption of biomass fuels by rural households and estimation of their organic carbon in the Khulna region of Bangladesh

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Abstract

In this paper an attempt has been made to assess the consumption pattern of biomass fuel and estimation of organic carbon of those biomass fuels from the rural households in the Khulna region of Bangladesh. The consumption pattern of biomass fuel was assessed by Multistage Random Sampling techniques with semi-structured questionnaire. The study revealed that households consume different energy sources of which 97% households used various types of biomass fuel e.g. firewood, leaves, twigs and cow dung etc. Average monthly household biomass fuel consumption was 193 kg and average monthly expenditure is 5.86 (US$). The largest share of biomass fuel derived from firewood, which was amounted 105 kg per month. The major sources of biomass fuel were found in their home gardens and agricultural lands. These biomass fuels are mainly used for domestic cooking in the study area. Ten firewood species were identified as the most preferred for the most households in the study area. The organic carbon from the preferred biomasses was estimated by dry combustion method. Significantly higher organic carbon was found from wood biomass like *A. procera* and *A. richardiana*, while the lowest organic carbon was found in *C. nucifera*. In case of leaves biomass, significantly higher organic carbon was found in *A. saman* and *B. flabellifer* and lower from *M. indica* and *Z. mauritiana*. Besides wood and leaves biomass, the organic carbon from rice husk, rice straw and cow dung were also estimated, which are also used as low cost fuel in the rural households.

1. Introduction

In Bangladesh, the demand of energy is met from various sources, including biomass, electricity, natural gas, kerosene, diesel/gas oil, coal and others. The rural people of the country depend mainly on traditional fuels or biomass energy, namely wood, leaves, twigs, bark, roots, bamboo, shell and coir of coconut, agricultural residues such as rice husk, straw, jute stick, bagasse and cow dung for their domestic consumption [1]. Biomass plays an important and complex role in Bangladesh, particularly in rural areas where approximately 74.5% of the population lives [2].

The country has a relatively small forest coverage (about 15% of the total area of the country), but the actual tree coverage may not exceed 7–8% [3]. At the same time, the deforestation rate is the highest of any other country in the world [4]. Bangladesh is one of the densely populated countries in the world [5]. Due to the rising growth of population, the per capita energy consumption in Bangladesh increased from 5 GJ (gigajoules) in 1977 to 6.2 GJ and 8.98 GJ in 2009 and 2012 respectively [6–8]. Thus, the phenomenon of high population growth as well as growing energy demand reveals unlimited pressure on biomass. Nevertheless, most of the people in Bangladesh live in the rural areas [9], use biomass as their primary energy carries instead of using commercial fuel due to higher running cost and lower economy [10].

Most of the people in rural Bangladesh depend on biomass fuel for their cooking purposes [11]. On the other hand, large majority of the rural households in Bangladesh use relative inefficient cooking stoves for biomass based cooking, which emissions cause hazardous gases lead to indoor air pollution, human

health risks and high amount of substantial carbon dioxide (CO_2) emissions to the atmosphere [10, 12]. It is already known that the consequence of these additional CO_2 emissions causes the increase level of temperature to the atmosphere and lead to the global warming. Moreover, CO_2 emission would increase to an extreme level if the energy consumption has increased extremely [13]. IPCC revealed that building sectors including households, institutions etc. contribute as much as one third (30–40%) of greenhouse gas emission which can be compared to transportation and industrial sectors [14]. Thus, concern has been raised to study the emission of CO_2 due to human activity in developing country like Bangladesh, which is highly vulnerable to its negative effects.

Several studies revealed the status of consumption pattern of energy consumption and biomass fuel consumptions of different localities in Bangladesh depends on many socio-economic and demographic factors [15, 16, 12, 10, 17, 18]. Khulna is an important region in the south-western part of Bangladesh located approximate to world's largest mangrove forest the Sundarbans and Bay of Bengal. Khulna region is also suffering from high rate of population with low per capita income [19, 20]. Nonetheless, limited studies have been carried out regarding the biomass based energy consumption pattern especially in the household level. However, the utilization of biomass based energy through suitable biomass energy saving technologies in favour of environmental conservation is an urgent prerequisite [21]. Again, biomass is being utilized to generate renewable energy in many countries [22]. The study was carried out to find out the consumption pattern of biomass fuel and estimation of organic carbon from different biomass types in the rural households of Khulna region, Bangladesh.

2. Materials And Methods

2.1 Survey procedure and data collection

This study comprised a socio-economic survey on the household biomass based energy consumption pattern in the selected areas of Khulna region of the south-western part of Bangladesh. Bangladesh is divided into 64 districts (administration division managed by local government) and Khulna is an important district in the south-western Bangladesh (Fig. 1). It is located between 21°41' and 23°00' north latitudes and between 89°14' and 89°45' east longitudes [23]. The study was conducted through Multistage Random Sampling technique using semi-structured questionnaire from February 2018 to July 2018. Prior to the detail survey, a preliminary reconnaissance survey was conducted to overview the study area. Three *upazilas* (sub-district or sub-unit of district) namely Dumuria, Batiaghata and Paikgachha were selected randomly from Khulna district. The sequence of sampling was from upazila to union council (smallest rural administrative unit under upazila), from union to village, and then from village to households. Two unions from each *upazila*, two villages from each union and ten households from each village were randomly selected. Thus, in this study a total of 120 households, 40 from each *upazila* were selected randomly. The randomization was carried out using the random number table at every stage. In general the head of the household was interviewed containing a set of both closed- and open-ended questions related to the biomass fuel consumption. The respondent was asked to provide information on

monthly consumption and expenditure of biomass and non-biomass fuel, sources and end uses of different biomass fuel and preferred firewood species by the rural households.

In order to calculate the physical quantities of various energy consumption three physical units were used, e.g. kilogram (kg) for biomass, candle and briquette, kilowatt hour (kW-h) for electricity and liter (l) for kerosene and LPG.

2.2 Estimation of organic carbon from biomass fuels

The biomass fuel samples including firewood and leaves of ten most preferred fuel wood species as well as rice husk, rice straw and cow dung were purchased from the local market to assess the organic carbon content. Fresh weight of each sample was recorded by an electric balance. The wood samples were grind into fine powder using a stone grinder. Then, it was dried in electric oven at 105˚C for 24 hours. The leaves and other samples (rice husk, rice straw and cow dung) were dried in electric oven at 80˚C for 72 hours. Then, the dried samples were grind into fine powder using a blender machine.

The porcelain crucibles were cleaned using distilled water and dried in an oven. The weights of the crucibles were recorded. Then, the oven dried grind samples were taken into pre-weighted porcelain crucibles and both the weight of these crucibles and samples were recorded. While every crucibles contained 1g of samples. The crucibles were placed in the muffle furnace and adjusted at 550 ˚C for 1hour. The crucibles with ash were weighted and percentage of organic carbon was calculated according to Allen et al. [24].

$$\text{Ash}\ (\%) = \frac{\mathrm{W_C} - \mathrm{W_A}}{\mathrm{W_B} - \mathrm{W_A}} \times 100$$

C (%) = (100 − % Ash) × 0.58 (considering 58% carbon in ash free biomass fuel)

Where, C = Organic carbon, W_A = Weight of crucibles, W_B = Weight of sample + Crucibles,

W_C = Weight of ash + Crucibles.

The data obtained from the organic carbon estimation of the biomass fuels were analyzed by one way analysis of variance (ANOVA) test using IBM SPSS Statistics 23 to determine the statistical difference followed by multiple comparisons. The results with $P < 0.05$ were considered to be significantly different.

3. Results

3.1 Consumption of biomass and non-biomass fuels

Biomass, electricity, liquefied petroleum gas (LPG), kerosene, candle and briquette were found as the energy used in the rural households of Khulna region. The study showed that households used different

energy sources like biomass 97%, electricity 90%, LPG 22%, kerosene 57%, candle 48%, and briquette 1.66% (Table 1). The average monthly consumption of energy was 192.53 (SE, 12.41) kg biomass, 64.65 (SE, 5.17) kW-h electricity, 1.84 (SE, 0.38) liter LPG, 0.74 (SE, 0.10) liter kerosene, 0.06 (SE, 0.01) kg candle and 0.08 (SE, 0.05) kg briquette per household in the rural areas of Khulna region.

Table 1
Consumption of biomass and non-biomass fuels in the Khulna region of Bangladesh

Name of the *Upazila*	Average consumption per month					
	Energy types					
	Biomass (kg)	Electricity (kW-h)	LPG (liter)	Kerosene (liter)	Candle (kg)	Briquette (kg)
Batiaghata	144.14 (11.41)	86.70 (8.48)	2.95 (0.87)	0.20 (0.04)	0.09 (0.02)	0.25 (0.17)
Dumuria	286.60 (28.92)	77.07 (10.49)	1.24 (0.59)	0.52 (0.12)	0.01 (0.00)	0.00 (0.00)
Paikgachha	146.87 (10.22)	30.20 (4.01)	1.33 (0.46)	1.51 (0.25)	0.07 (0.01)	0.00 (0.00)
Mean	192.53 (12.41)	64.65 (5.17)	1.84 (0.38)	0.74 (0.10)	0.06 (0.01)	0.08 (0.05)
% of households	97	90	22	57	48	1.66

Note: values in the parenthesis indicate the standard error of mean.

Although, the average consumption of biomass fuel per household per month was found higher as 286.60 (SE, 28.92) kg in Dumuria *upazila* in comparison to Batiaghata and Paikgachha *upazila* as 144.14 (SE, 11.41) kg and 146.87 (SE, 10.22) kg respectively. The access of grid electricity was found highest as 86.70 (SE, 8.48) kW-h in Batiaghata *upazila*, but such access was lowest as 30.20 (SE, 4.01) kW-h in Paikgachha *upazila*. In Paikgachha *upazila* most of the households was found to use solar energy. The electricity and solar energy were mainly used for lighting purposes in these areas. LPG was used as 2.95 (SE, 0.87) liter per household per month in Batiaghata *upazila*, while such uses were lower as 1.24 (SE, 0.59) liter in Dumuria *upazila*. On the average, the consumption of kerosene was highest as 1.51 (SE, 0.25) liters per household per month in Paikgachha *upazila*, but uses were reduced in Batiaghata *upazila* and Paikgachha upazila due to available electricity facilities. The monthly average consumption of candle per household in Batiaghata, Paikgachha and Dumuria *upazila* was only 0.09 (SE, 0.02) kg, 0.07 (SE, 0.01) kg and 0.01 kg. Briquettes are merely utilized in these areas, only reported from Batiaghata upazial estimated as 1.66% households (Table 1).

The consumption of different biomasses in the rural households of Khulna region of Bangladesh is presented in Table 2. Firewood (i.e. stems, branches), leaves and twigs, shell and coir of coconut, cow

dung, rice husk, crop residues (i.e. rice straw, pulses, anise, bagasse, jute stick) were found as the biomass for household energy use. It was found that firewood was used by 97% households, leaves and twigs by 82%, shell and coir of coconut 76%, rice husk 23%, crop residues 32% and cow dung by 68%. However, 55% of the households used multiple biomass materials (e.g. root, bark, shell and coir of fan palm and bamboos etc.) which are termed as 'others' (Table 2).

Table 2
Consumption of different biomass fuels by the households in the Khulna region of Bangladesh

Name of the Upazila	Average consumption per month						
	Biomass types						
	Firewood (kg)	Leaves and twigs (kg)	Shell and coir of coconut (kg)	Rice husk (kg)	Crop residues (kg)	Cow dung (kg)	Others (kg)
Batiaghata	80.00 (7.16)	14.00 (1.83)	7.20 (1.03)	1.09 (0.40)	8.25 (1.84)	30.75 (5.28)	2.85 (0.61)
Dumuria	166.00 (21.98)	24.85 (6.71)	13.30 (1.97)	2.20 (1.39)	8.10 (1.73)	66.50 (7.29)	5.65 (2.13)
Paikgachha	69.00 (5.01)	23.20 (5.37)	6.00 (0.77)	1.52 (0.54)	0.00 (0.00)	40.00 (4.57)	7.15 (1.54)
Mean	105.00 (8.77)	20.68 (2.93)	8.83 (0.83)	1.60 (0.51)	5.45 (0.90)	45.75 (3.61)	5.21 (0.90)
% of households	97	82	76	23	32	68	55
Note: values in the parenthesis indicates the standard error of mean							

The average consumption of firewood was 105 (SE, 8.77) kg per household per month, whereas it was found to be highest as 166 (SE, 21.98) kg per household per month in Dumuria *upazila* and lowest as 69 (SE, 5.01) kg per household per month in Paikgachha *upazila*. The average household consumption of leaves and twigs, rice husk and cow dung was found, 20.68 (SE, 2.93) kg per month, 1.60 (SE, 0.51) kg per month, 45.75 (SE, 3.61) kg per month respectively, whereas such consumption in Dumuria *upazila* was highest as 24.85 (SE, 6.71) kg per month, 2.20 (SE, 1.39) kg per month and 66.50 (SE, 7.29) kg per month respectively and in Batiaghata *upazila*, it was lowest as 14 (SE, 1.83) kg per month, 1.09 (SE, 0.40) kg per month and 30.75 (SE, 5.28) kg per month respectively in Paikgachha *upazila*. The monthly average shell and coir of coconut was 8.83 (SE, 0.83) per household per month, whereas such consumption was highest as 13.30 (SE, 1.97) kg per household per month in Dumuria *upazila* and lowest as 6 (SE, 0.77) kg per household per month in Paikgachha *upazila*. No household reported to use crop residues for energy purposes in Paikgachha *upazila*. The reason is that most of the parts of such *upazila* used for shrimp

cultivation. However, the average consumption of crop residues per household per month in Batiaghata *upazila* and Dumuria *upazila* was 8.25 (SE, 1.84) kg and 8.10 (SE, 1.73) kg respectively.

3.2 Expenditure of biomass and non-biomass fuels

On the average, households spent US$ 5.86 (SE, 0.38) for biomass fuel per household per month followed by electricity, 3.75 (SE, 0.35); LPG, 1.71 (SE, 0.36); kerosene, 0.58 (SE, 0.08); candle 0.21 (SE, 0.03) and briquette 0.01 (SE, 0.01). The expenditure of biomass fuel was considerably high in Dumuria upazila as US$ 8.24 (SE, 0.93) per household per month. The expenditure of electricity per household per month was considerably highest in Batiaghata upazila as US$ 5.26 (SE, 0.59) and lowest as US$1.52 (SE, 0.23) in Paikgachha upazila. The average monthly households expenditure of LPG in Batiaghata, Dumuria and Paikgachha *upazila* was found US$ 2.79 (SE, 0.81), US$ 1.10 (SE, 0.53) and US$1.24 (SE, 0.43) respectively. The expenditure of kerosene per household per month was highest as US$ 1.17 (SE, 0.19) in Paikgachha *upazila* and for candle the expenditure was found highest as US$ 0.31 (SE, 0.08) in Batiaghata *upazila* (Table 3).

Table 3
Expenditure of biomass and non-biomass fuels by the in the Khulna region of Bangladesh

Name of the Upazila	Average expenditure per month (US$)					
	Energy types					
	Biomass	Electricity	LPG	Kerosene	Candle	Briquette
Batiaghata	4.82 (0.39)	5.26 (0.59)	2.79 (0.81)	0.16 (0.03)	0.31 (0.08)	0.03 (0.02)
Dumuria	8.24 (0.93)	4.46 (0.71)	1.10 (0.53)	0.40 (0.09)	0.08 (0.04)	0.00 (0.00)
Paikgachha	4.53 (0.28)	1.52 (0.23)	1.24 (0.43)	1.17 (0.19)	0.24 (0.05)	0.00 (0.00)
Mean	5.86 (0.38)	3.75 (0.35)	1.71 (0.36)	0.58 (0.08)	0.21 (0.03)	0.01 (0.01)

Note: values in the parenthesis indicates the standard error of mean

Among the different biomass fuels, the average expenditure per month for firewood was found US$ 4.03 (SE, 0.31) followed by branches, 2.16 (SE, 0.20); leaves and twigs, 0.44 (SE, 0.06); shell and coir of coconut, 0.13 (SE, 0.01); rice husk, 0.09 (SE, 0.03); crop residues, 0.14 (SE, 0.02); cow dung, 0.79 (SE, 0.06) and so on (Table 4).

Table 4
Expenditure of different biomass fuels in the Khulna region of Bangladesh

Name of the Upazila	Average expenditure per month (US$)						
	Biomass types						
	Firewood	Leaves and twigs	Shell & coir of coconut	Rice husk	Crop residues	Cow dung	Others
Batiaghata	3.46 (0.35)	0.29 (0.03)	0.10 (0.01)	0.06 (0.02)	0.23 (0.04)	0.52 (0.09)	0.09 (0.01)
Dumuria	5.78 (0.78)	0.53 (0.14)	0.19 (0.02)	0.13 (0.08)	0.21 (0.04)	1.15 (0.12)	0.16 (0.06)
Paikgachha	2.86 (0.22)	0.50 (0.11)	0.08 (0.01)	0.09 (0.03)	0.00 (0.00)	0.69 (0.07)	0.25 (0.05)
Mean	4.03 (0.31)	0.44 (0.06)	0.13 (0.01)	0.09 (0.03)	0.14 (0.02)	0.79 (0.06)	0.17 (0.02)
Note: values in the parenthesis indicates the standard error of mean							

The average monthly expenditure of firewood per household per month was found to be highest as US$ 5.78 (SE, 0.78) in Dumuria upazila and lowest as US$ 2.86 (0.22) in Paikgachha upazila. The average monthly household expenditure of cow dung and leaves and twigs was found highest as US$ 1.15 (SE, 0.12) and, US$ 0.53 (SE, 0.14) respectively in Dumuria upazila and lowest as US$ 0.52 (SE, 0.09) and US$ 0.29 (SE, 0.03) respectively in Batiaghata upazila. The monthly average household expenditure of shell and coir of coconut was highest as US$ 0.19 (SE, 0.02) in Dumuria upazila and lowest as US$ 0.08 (SE, 0.01) in Paikgachha upazila. However, the crop residues expenditure per household per month in Batiaghata and Dumuria upazila was US$ 0.23 (SE, 0.04) and US$ 0.21 (SE, 0.04) respectively, whereas in Paikgacha upazila such expenditure was found zero as no household uses crop residues as fuel (Table 4).

3.3 Sources of biomass fuel

In the study area, households in general collected biomass fuels mainly from their own homesteads and/or agricultural lands. It was also found that people collect biomass from local market. The study showed that 76.66% of the households collected stems from their own homesteads and/or agricultural lands, 25% from temporary market, 30% from permanent market and 10% from roadside plantation. About 65% of the households collected branches from their own homesteads and/or agricultural lands, 20% from temporarily market, 8.33% from permanent market and 13.33% from roadside plantation. Besides, stems and branches, cow dung was found the most prominent biomass fuel on the basis on its use. About 52% of the households collected cow dung from their own homesteads and/or agricultural lands, whereas 18.33% from temporarily market and 20% from permanent market. Only 70% of the

households used leaves and twigs as fuel collected from their own homesteads and/or agricultural lands, whereas 28.33% from temporarily market and 16.66% from roadside plantation (Table 5).

Table 5
Sources of biomass fuels for the rural households in the Khulna region of Bangladesh

Biomass types	Biomass sources indicated by percentage (%) of households			
	Temporary market	Permanent market	Homestead and agricultural lands	Roadside plantation
Stems	25	30	76.66	10
Branches	20	8.33	65	13.33
Leaves and twigs	28.33	-	70	16.66
Shell and coir of coconut	18.33	-	66.66	3.33
Rice husk	-	10	16.66	-
Crop residues	5	-	28.33	-
Cow dung	18.33	20	51.66	-
Others	11.66	1.66	45	3.33
Note: Some households use more than one source.				

3.4 End uses of biomass fuel

Table 6 showed the end uses of biomass fuels by the households in the study area. Most of the rural households used biomass fuel for domestic cooking. The biomass fuel were also used for paddy parboiling, molasses making and other purposes (i.e. making smoke in the cow shed). About 96.66% of the households used stems for domestic cooking, whereas for the same purposes, 85% used branches, 81.66% used leaves and twigs, 76.66% used coconut, 23.33% used rice husk, 33.33% used crop residues, 68.33% used cow dung and 53.33% used other biomass resources. For paddy parboiling, 3.33% of the households used firewood, 6.66% used branches, 8.33% used leaves and twigs, 10% used rice husk and 5% used crop residues. Making molasses, 8.33% households used firewood, 6.66% used branches and 5% used cow dung.

Table 6
End uses of different biomass fuels by the households in the Khulna region of Bangladesh

Biomass types	Percentage (%) of households use biomass		
	Domestic cooking	Paddy parboiling	Gur/molasses making
Stems	96.66	3.33	8.33
Branches	85	6.66	6.66
Leaves & twigs	81.66	8.33	-
Coconut	76.66	-	-
Rice husk	23.33	10	-
Crop residues	33.33	5	-
Cow dung	68.33	-	5
Others	53.33	-	-
Note: Some households use more than one source			

The study also found that about 2.25 tons biomass household^{-1} year^{-1} used for domestic cooking, whereas the biomass of only 0.02 tons used for paddy parboiling, 0.023 tons used for molasses making and 0.008 tons used for other uses (Fig. 2).

3.5 Tree species used as biomass fuel

A total of 54 tree species were identified by the respondents from the study area. Based on overall preferences, ten most preferred firewood species was identified by the respondents is presented in Fig. 3. Raintree (*Albizia saman*) was the most preferred tree species in the study area. Coconut (*Cocos nucifera*), Am (*Mangifera indica*), Mahagoni (*Swietenia macrophylla*), Tentul (*Tamarindus indica*), Akashmoni (*Acacia auriculiformis*), Tal (*Borassus flabellifer*), Boroi (*Ziziphus mauritiana*), Sil koroi (*Albizia procera*) and Chambol (*Albizia richardiana*) are also preferred by the households ranked after Raintree (Fig. 3). Households used both stemwood and leaves of these species as fuel purposes.

3.6 Estimation of organic carbon from biomass

3.6.1 Organic carbon from wood biomass

The estimation of organic carbon from the ten preferred wood biomass which is used as fuel of this study were conducted and present in the Fig. 4. The estimated organic carbon were 52.87 (SE, 0.07)% in *A. saman*, 52.22 (SE, 0.28)% in *C. nucifera*, 53.14 (SE, 0.05)% in *M. indica*, 56.38 (SE, 0.19)% in *S. macrophylla*, 53.94 (SE, 0.17)% in *T. indica*, 56.37 (SE, 0.18)% in *A. auriculiformis*, 56.27 (SE, 0.16)% in *B.*

flabellifer, 53.70 (SE, 0.15)% in *Z. mauritiana*, 57.58 (SE, 0.16)% in *A. procera* and 57.39 (SE, 0.21)% in *A. richardiana* respectively. From the statistical analysis (ANOVA) it was found that there is significant difference ($p < 0.05$) in the organic carbon among the ten wood biomass. From the multiple comparison test (Tukey's) it was also observed that significantly ($p < 0.05$) higher organic carbon was present in *A. procera* and *A. richardiana* and significantly ($p < 0.05$) lower organic carbon was present in *C. nucifera*.

3.6.2 Organic carbon from leaves biomass

The estimation of organic carbon from the leaves of the ten selected firewood species of the study area was conducted and present in the Fig. 5. The organic carbon content in the leaves were 54.67 (SE, 0.18)% in *A. saman*, 52.35 (SE, 0.02)% in *C. nucifera*, 49.19 (SE, 0.05)% in *M. indica*, 51.91 (SE, 0.24)% in *S. macrophylla*, 53.70 (SE, 0.17)% in *T. indica*, 52.35 (SE, 0.13)% in *A. auriculiformis*, 55.44 (SE, 0.38)% in *B. flabellifer*, 49.80 (SE, 0.25)% in *Z. mauritiana*, 53.50 (SE, 0.01)% in *A. procera* and 54.59 (SE, 0.07)% in *A. richardiana* respectively. From the statistical analysis (ANOVA) it was found that there is significant difference ($p < 0.05$) in the organic carbon content among the ten leaves biomass. From the multiple comparison test (Tukey's) it was also observed that significantly ($p < 0.05$) higher leaves organic carbon was present in *A. saman* and *B. flabellifer* and significantly ($p < 0.05$) lower leaves organic carbon content was present in *M. indica* and *Z. mauritiana*.

3.6.3 Organic carbon estimation in different biomasses

Besides wood and leaves biomass there are some other components such as rice husk, rice straw and cow dung generally used for cooking in households (Fig. 6). A comparative study among these biomasses showed that on the average 54.98 (SE, 0.16)% organic carbon present in firewood followed by 53.24 (SE, 0.15)% from leaves, 49.54 (SE, 0.03)% from rice husk, 50.79 (SE, 0.05) % from rice straw, and 31.40 (SE, 0.18)% from cow dung. So, it was observed that cow dung contain low organic carbon compared to other biomass fuel used in the study area.

4. Discussion

The present study showed that biomass fuel had predominantly used as the cooking fuels in rural households than any other form of commercial fuels. Besides biomass, electricity, LPG, kerosene and candle were used as commercial fuels in the study area corresponds with the previous studies in rural Bangladesh [10, 18, 25]. The average consumption of biomass fuel in the study area was found 192.53 kg per household per month, which is somewhat similar to the findings 218 kg per household per month reported by Hassan et al. [12] from four upazilas (Kalaroa, Nachole, Nakla and Chakaria) located in four distinct agro-ecological zones of Satkhira district, Bangladesh. Akther et al. [17] reported the higher quantity of average biomass fuel (665 kg per household per month) consumption in the countrified region of the Meghna floodplain zones of Narsingdi district, Bangladesh while, Miah et al. [18] found lower amount of biomass fuel consumption, including 66 kg per household per month at Chandanaish Upazila of Chittagong district, Bangladesh. So, the consumption pattern of biomass fuel greatly varies

according to different region. It was observed that among biomass fuels, firewood was the most preferred and largest sources. This trend of using firewood by the households was also reported in previous studies in the context of rural Bangladesh [26, 27, 11, 17, 12, 15, 28]. Cow dung was found as the next prominent biomass fuel, whereas its average consumption was 45.75 kg households^{-1} $month^{-1}$. This is in agreement with the findings of Hassan et al. [12]. The other regular used biomass fuels were leaves and twigs, shell and coir of coconut and crop residues in the study area. Such types of biomass fuel used in the study area have been corroborated with the findings of Rao and Reddy [29]; Miah et al. [18]; Akther et al. [17]; Hassan et al. [12]and Hassan et al. [15].

Biomass fuels were mainly used for domestic cooking, whereas it was partly used for other purposes. The present study revealed that above 97% of biomass fuel were used for domestic cooking and 0.83% used for paddy parboiling, which are closely related to the findings of Miah et al. [18]. The main sources of biomass fuel was the own homestead and agricultural land. FAO [30] stated that in the rural areas of Bangladesh, homestead forests meet more than 90% of firewood demand. It was observed that the financial crisis of the households was the main reason for using biomass fuel. Furthermore, reasonable price and local availability are the main reasons for comprehensive use of biomass fuel in the rural households. It has been reported that due to the poverty of the rural people biomass fuel catalyze the cost safety and most available sources of fuel for their cooking in Asia Pacific region [31], South Africa [32], India [29], Nepal [33] and Bangladesh [15]. The highest level of gaseous emission occurs due to the domestic cooking activity with relatively large-scale use of biomass fuel in rural areas, while commercial energy can be used as a standard to reduce such emissions [34]. Otherwise, majority of the rural households used inefficient cooking stoves in the study area, whereas Foysal et al. [10] reported that improved stoves can reduce large emission level.

The present study showed that significantly higher organic carbon was present in wood biomass of *A. procera* and *A. richardiana*. While, *S. mahagoni*, *A. auriculiformis* and *B. flabellifer* also high organic carbons but lower than previous two. Significantly lower organic carbon was found in *C. nucifera*. Thus, this can be a suitable firewwood species in rural areas from the organic carbon emission point of view. However, *A. saman*, *M. indica*, *Z. maurutiana* and *T. indica* also showed low organic carbon in its wood biomass. On the other hand, significantly higher organic carbon was found in the leaves biomass of *A. saman* and *B. flabellifer*. Then the leaves of *A. richardiana*, *T. indica* and *A. procera* also showed high organic carbon content. It was also found that significantly lower organic carbon content in the leaves of *M. indica* and *Z. maurutiana*. So, leaves of these species can be suitable for biomass fuel for environmental amelioration. It is important to note that biomas density has direct association with high carbon content [35] and, therefore, have higher calorific values [36, 37]. This study revealed that the presence of organic carbon in wood and leaves biomass of the same tree species were different thus the choice of biomass type can also be an important aspect. In this study it is also revealed that the amount of ash content has direct relation with the amount of organic carbon. In both the wood and leaves biomass, when the percentage of ash content reduced the percentage of organic carbon emission were increased. The present study also showed that wood biomass contain greater amount of organic carbon

estimated as 55.01% (carbon per gram) followed by leaves 52.75%, rice husk 49.54%, rice straw 50.79%, and cow dung 31.40%. So, cow dung can be an alternative to environmental friendly biomass fuels.

It is generaly assumed that in case of biomass fuel, the carbon emission will be reduced if the biomass contain lower organic carbon. It is well known that emission from biomass fuel and agricultural waste burning are the major source of ambient organic carbon [38] and considered one of the major source of atmosperic pollution [39].

5. Conclusion

Energy in the rural households comprises biomass and commercial energy, whereas their consumption pattern mainly depends on expenditure issues. Rural households involved with the highest use of biomass over commercial energy in the study area. Illusive running cost, lower economy and locally available biomasses causes the limited use of non-biomass energy in the rural households. A number of tree species was identified by the household as their preferred sources of biomasses like *A. saman*, *C. nucifera*, *M. indica*, *S. macrophylla*, *T. indica*, *A. auriculiformis*, *B. flabellifer*, *Z. mauritiana*, *A. procera* and *A. richardiana*. This study revealed that some species like *A. saman* and *C. nucifera* contain lower organic carbon in its wood biomass and *M. indica* and *B. flabellifer* also contain lower organic carbon in its leaves biomass. Different types of biomass fuels were responsible for different level of organic carbon content. Cowdung and crop residues contain lower organic content in comparison to wood and leave biomass. Selection of biomasses as fuel also considers the environmental sustainability as organic carbon is an important source of climate forcing from the combustion of biomass.

Statements And Declarations

Conflicts of interest I declare that the authors of this research have noconflict of interest.

Author Contributions This research work is the Master Thesis of the author Rahul Biswas. The field survey, sample collection, sample analyze and the draft manuscript was done by the author Rahul Biswas. Professor Arifa Sharmin supervised the field level study of the socio-economic survey on the household. Professor Md. Ashaduzzaman supervised the estimation of organic carbon from biomass fuels. Md. Akramul Islam was taken part with me in the field survey and help to analyze a part of data. All authors revised the final manuscript.

Data availability The data that support the findings of this study will be available from the corresponding author, Rahul Biswas, upon reasonable request.

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Figures

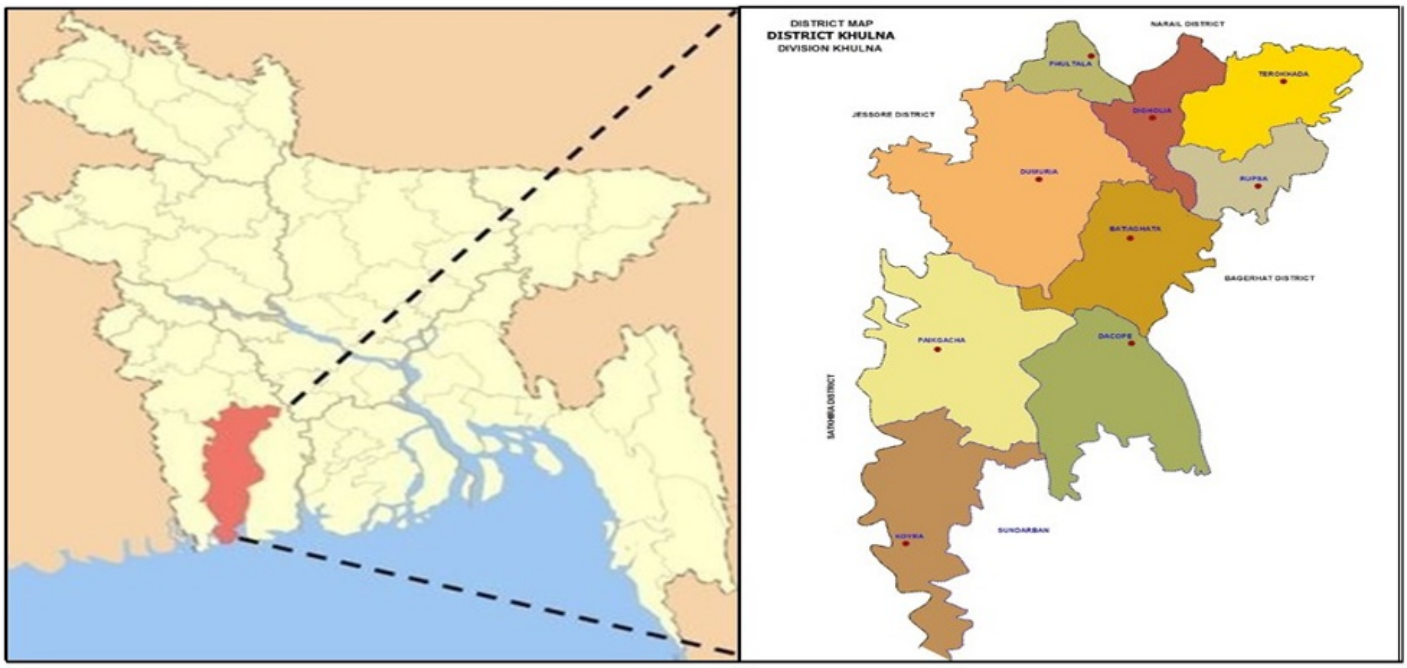

Figure 1

Map of the study area of Khulna district in Bangladesh (Source: Google maps).

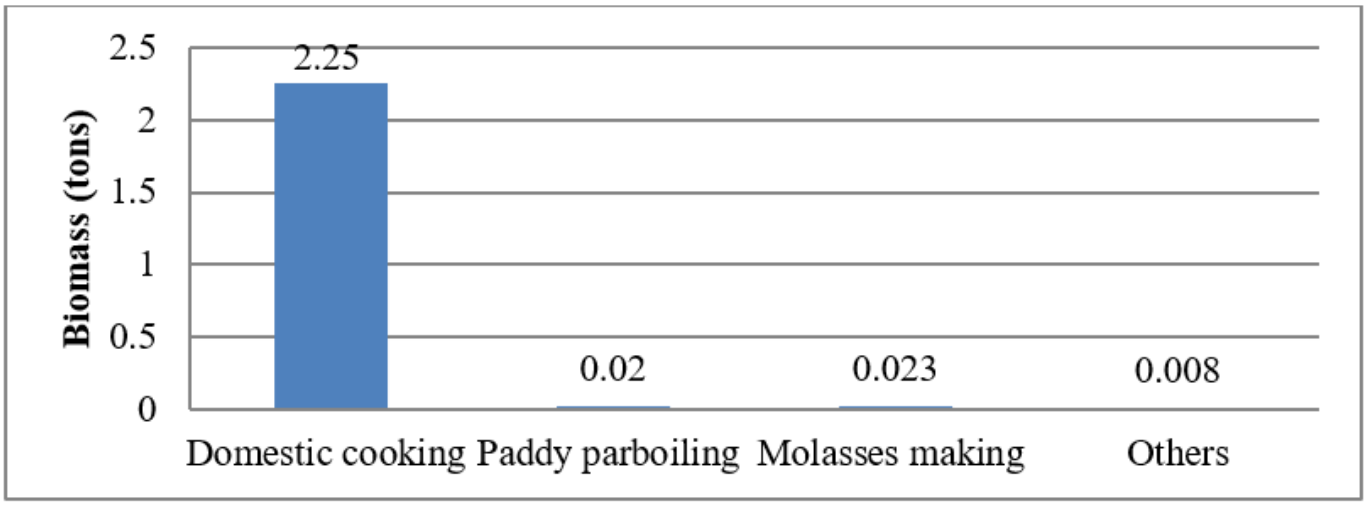

Figure 2

Biomass fuels used for different purposes in the Khulna region of Bangladesh

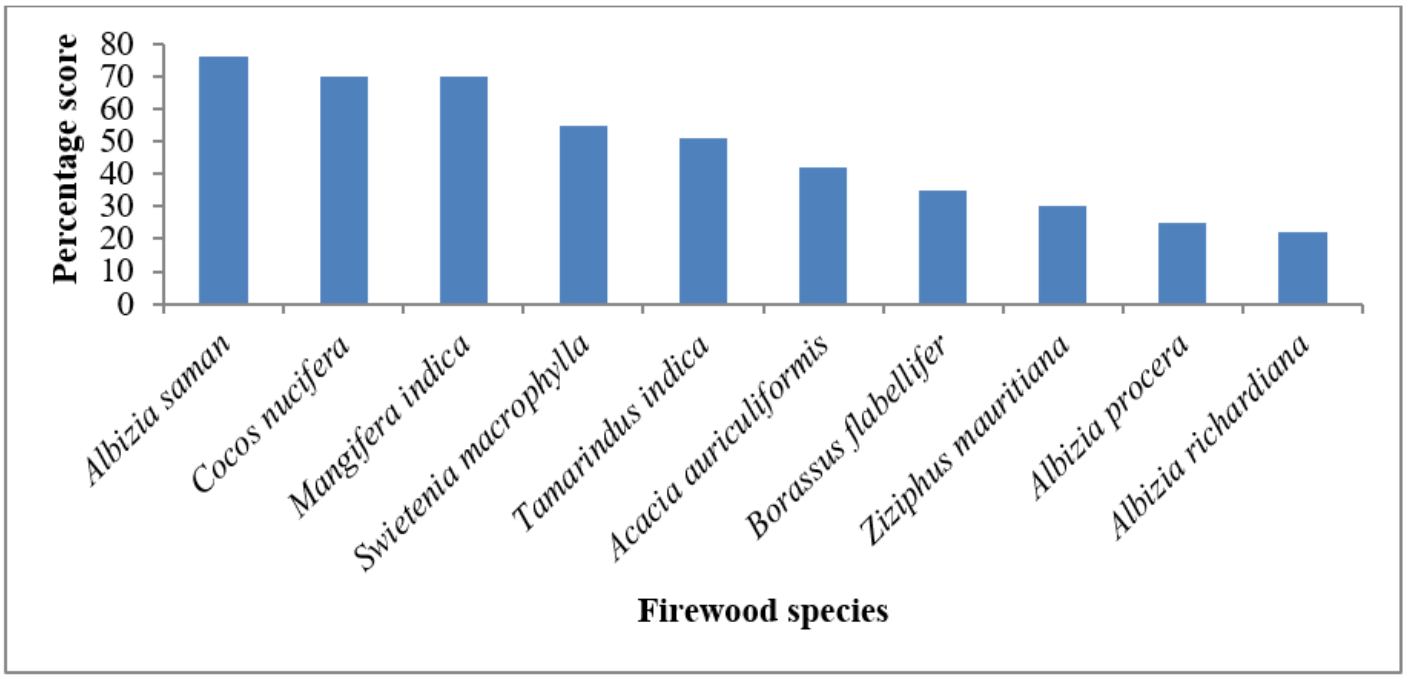

Figure 3

Preferred species used as fuel by the rural households in the Khulna region of Bangladesh

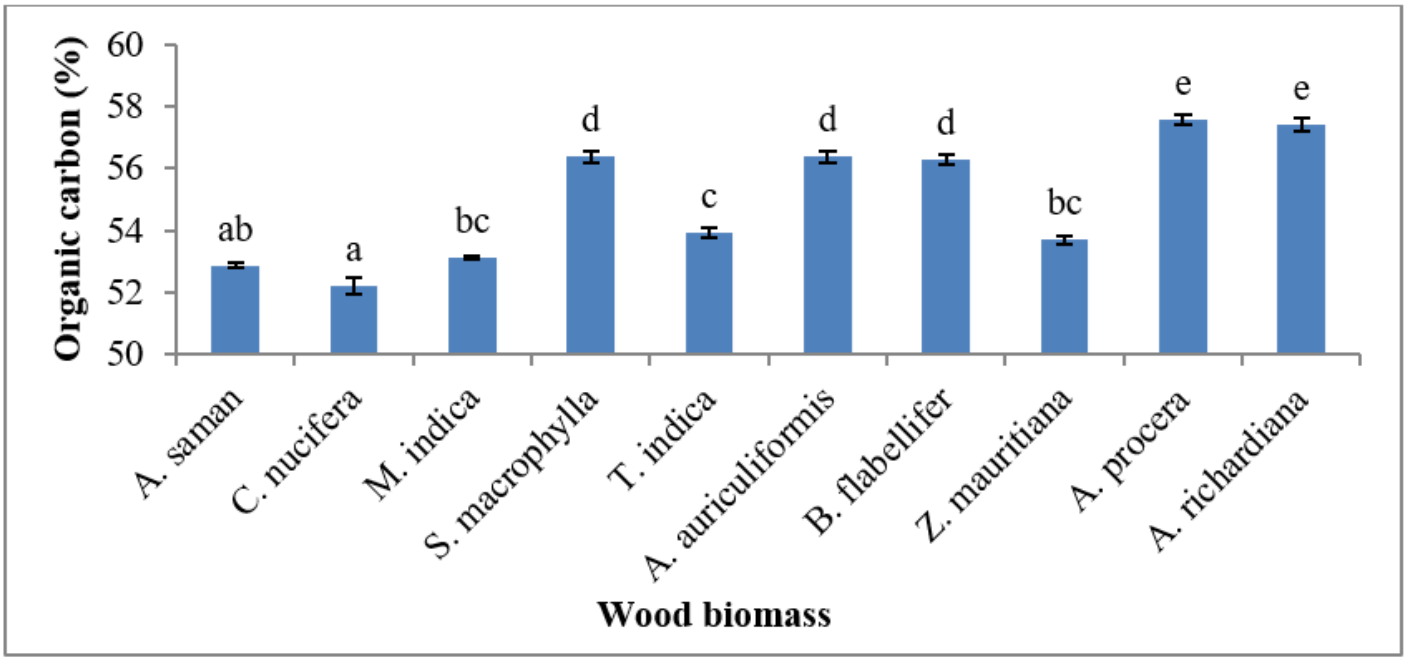

Figure 4

Percentage of organic carbon in wood biomass used in the Khulna region of Bangladesh

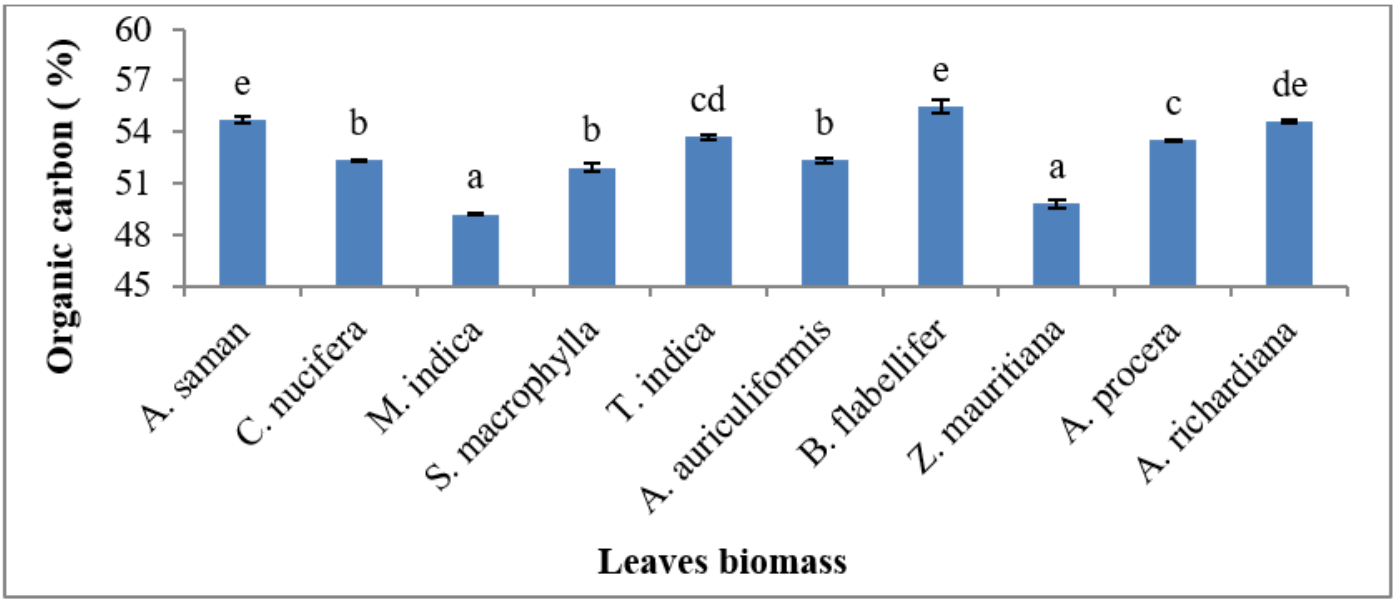

Figure 5

Percentage of organic carbon in leaves biomass used in the Khulna region of Bangladesh

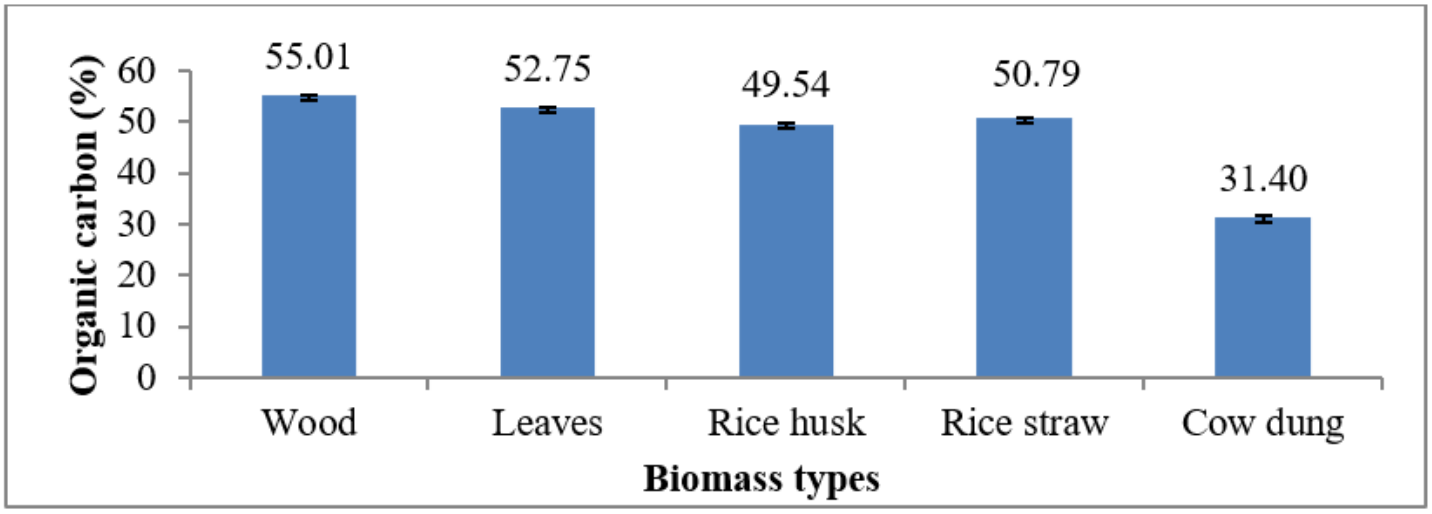

Figure 6

Percentage of organic carbon in different types of biomass used in the Khulna region.