Accepting Renewable Technologies for Waste Management Promoting Sustainable Living Among Rural Habitats

F. Rajemahadik Chandrasen and A. Ghaste Akash

Abstract This paper elaborates on need of improvement in rural settings and its benefits after use of anaerobic digestion as renewable energy. The five villages under investigation have a human population of 12,217 and livestock of 8,141, which includes buffalo, goats, and hen. Among, livestock total waste discharged by buffalos is around 33 tonnes, goats discharge 3.5 tonnes, and hens per day discharge 400 kg of waste. Similarly, human population discharges near to 4 tonnes of excreta daily. This paper proposes a perspective for rural habitats reducing excess burden of sanitation, energy, fertilizers, and on health impacts. From the estimation of human excreta and livestock, both can generate biogas of 2060 m^3 daily using renewable techniques. Similarly, accepting improved sanitation may reduce the risk of human health after excretion and emission of air pollutant, lowering premature deaths. Practicing anaerobic digestion, accounts to fulfill fertilizer requirement of N, P and K of approximately 74 ha of land per year. Furthermore, air pollutants such as carbon monoxide (CO), sulfur dioxide (SO_2), oxides of nitrogen (NO_x), carbon dioxide (CO_2), methane (CH_4), and particulate matter (PM2.5 and PM10) could reduce to a greater extent. Biogas a renewable form can gain additional carbon credits to the rural community. Paper tries to present an overall positive viewpoint of such study in rural habitats of developing countries.

Keywords Biogas · Sanitation · Human health · Fertilizer · Economics

1 Introduction

In India, rural settings are still underdeveloped. Among 1,028,610,328 of total population of India, 72.18% reside in rural [1]. In addition, the population growth rate for India was 1.148% during the year 2016, suggests a decrease [2]. A scarcity of

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primary needs of inhabits in rural is still a challenge. Among all amenities, energy proves as the most confirmatory requirement, which directly connects with the economy and growth of country [3]. Recently in the year 2005 around 412 million of the Indian population was not having accesses to electricity [3]. Consequently, in villages, biomass is a primary source of fuel for day to day activities [4]. Apart from electricity, kerosene as a major fuel source is used for lightening in around 43.3% of rural habitats of India [5]. Rural and urban household both depend on fuel sources like kerosene and similar products to satisfy daily needs [6]. The use of alternative fuel to overcome household needs demonstrate after insufficient quality and electricity supply [7]. Studies suggest more than seven hundred million of the population in rural India consume biomass for cooking [8], along with kerosene [9]. Eventually, firewood of around 64%, 13% of crop residue and a similar quantity of dung are used as cooking fuel [10]. In addition, only 9% of economically stable households of rural India use commercially available fuels [9]. Apart from energy, open discharge of human feces is prominent in rural, people are still unaware of the risks of exposed excretion on their health [11]. In addition, appropriate sanitation facilities encompass good hygiene, safe water, good health and economic development [12]. Due to improper sanitation, surface water bodies get polluted, where fecal coliform count can reach up to 20,000 MPN/100 mL of the sample [11]. This may be cause for oral and communal diseases outbreak. Moreover, biomass burning can also cause health impact among rural. The major cause is deprived quality of indoor air (IAQ) in the kitchen and near vicinity depends on ventilation [13]. Poor quality of indoor air is the fourth major cause in the world for premature deaths [14] and respiratory diseases, caused after the release of harmful air pollutant by burning of solid fuel in the traditional stove or chulas [15]. Such crude practices increase the economic burden and reduce life expectancy [16]. Presently, active thinking on sustainable development using human excreta and livestock waste is in promotion [17]. The anaerobic treatment process can prove a better alternative in rural with upright technology [18]. This study demonstrates the potential of waste to energy, impacts of waste generated and its extension toward economy and health.

2 Materials and Methods

2.1 Study Area

Villages located are within 50 km toward south of major city Kolhapur and around 30 km distance from national highway (NH-4). These five villages share common boundaries and are closely grouped with each other. The rural settings selected for the study are as follows Benikre, Haladi, Haldvade Karanjivane, and Doulatwadi. Figure 1, shows the location (16° 37′N Latitude and 74° 27′E Longitude) of the selected study site.

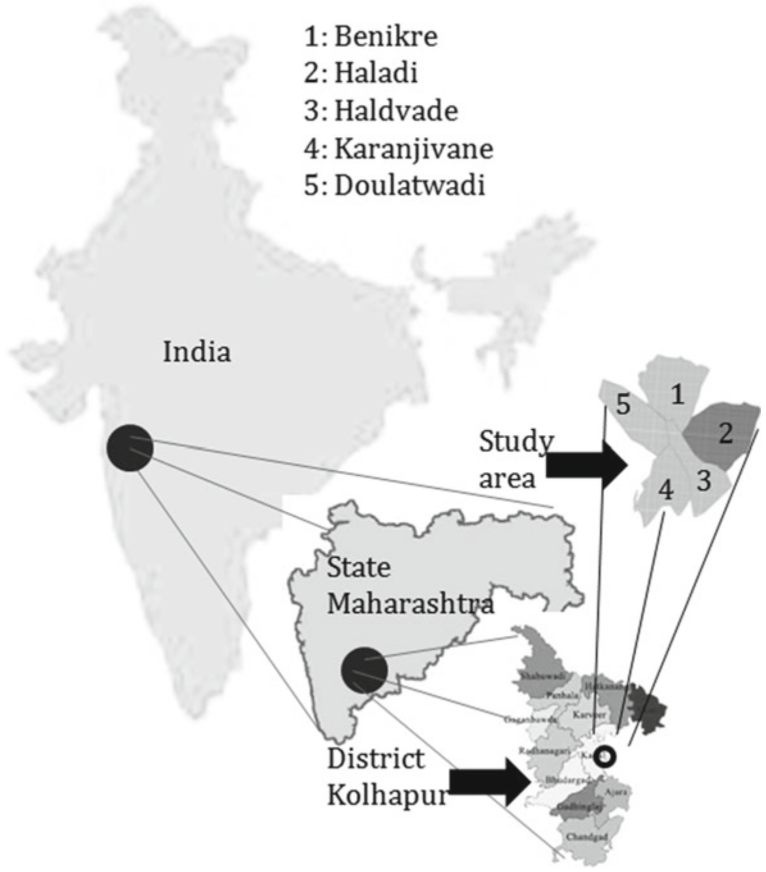

Fig. 1 Location of the study area

2.2 Data Collection

After identification of site, data was collected on the population and livestock of villages for study. The population of five villages is 12,217 among 1,432 households. The livestock of 2,214 buffalos, 1,927 of goats and 4,000 of hens were noted. Table 1, shows data on human, habitat, and livestocks. Data required for calculations and assumptions scripted in this paper are from the literature survey.

Table 1 Details of village population and livestock

Name of village	Population	Households	Buffalo	Goats	Hens
Haldwade	2019	212	408	321	1000
Haladi	3952	413	650	421	1000
Benikre	2099	227	396	310	0500
Karanjivane	3044	431	443	451	1000
Doulatwadi	1103	149	317	424	0500
Total	12,217	1432	2214	1927	4000

2.3 Calculations

Biogas from human excreta:

$$Q_{\mathrm{wP}} = P \times F_P \tag{1}$$

where Q_{wP} is Quantity of Waste (kg/C/day), P is human population (capita) and F_P is considered as 0.4 factor for waste/head day [19].

$$G_{\mathrm{YP}} = Q_{\mathrm{WP}} \times F_{\mathrm{PG}} \tag{2}$$

where G_{YP} is Gas Yield (m^3/day) and F_{PG} is considered as 0.028, factor for gas evolution/head day [19, 20].

Biogas from Buffalo waste:

$$Q_{\mathrm{WB}} = P_B \times F_B \tag{3}$$

where Q_{WB} is Quantity of Waste (kg/Buffalo/day), P_B is Buffalo population (capita), and F_B is considered as 15, factor for waste generation/head day [19].

$$G_{\mathrm{YB}} = Q_{\mathrm{WB}} \times F_{\mathrm{BG}} \tag{4}$$

where G_{YB} is Gas Yield (m^3/day), Q_{WB} is Quantity of Waste (kg/Buffalo/day), and F_{BG} is considered as 0.04 (factor for gas evolution/head day) [21].

Biogas from Goat waste:

$$Q_{\mathrm{WWG}} = P_G \times F_G \tag{5}$$

Whereas Q_{WWG} is Quantity of Wet Waste (kg/Goat/day), P_{G} is Goat population (capita) × F_G is considered as 1.8 (factor for wet waste generation head day) [19].

$$Q_{\text{DWG}} = Q_{\text{WWG}} \times F_{\text{GG}} \tag{6}$$

where Q_{DWG} is Quantity of Dry Waste (kg/Goat/day) and F_{GG} is considered as 0.4 (factor for dry waste generation/head day) [22].

$$G_{\text{YG}} = Q_{\text{DWG}} \times F_{\text{GGY}} \tag{7}$$

where G_{YG} is Gas Yield (m^3/kg of dry mass day) and F_{GGY} is considered as 0.35–0.61 (factor for gas evolution/head day) [23].

Biogas from Hen waste:

$$Q_{\text{WH}} = P_H \times F_H \tag{8}$$

where Q_{WH} is Quantity of Waste (kg/Hen/day), P_{H} is Hen population (capita) and F_{H} is considered as 0.18 (factor for waste/head day) [19].

$$G_{\text{YH}} = Q_{\text{WH}} \times F_{\text{HG}} \tag{9}$$

where G_{YH} is Gas Yield (m^3/kg day) and F_{HG} is considered as 0.011 (factor for gas evolution/head day) [19].

Calculation for air pollutant emissions:

$$E_P = Q_F \times F_E \tag{10}$$

where E_P is Emission of Pollutants, Q_F is the quantity of fuel consumed and F_E is the emission factor.

3 Results and Discussion

3.1 Biogas Generation from Human Excreta

Biogas generated from five villages sharing common boundaries is 136.82 m^3/day (Eqs. 1 and 2). Furthermore, Table 2 estimates population discharging wet waste, dry waste, and yield for biogas. The methane (CH_4) fraction in biogas is assumed as 60, and 40% of CO_2 [24]. Whereas, gas has the potential to generate 82.1 m^3 of methane (CH_4) fraction. Where, density of methane is 0.75 kg/m^3, which equals to 61 kg of CH_4. This is equivalent of either 907.93 kWh of electricity or 22,447.5 kg of LPG annually. Moreover, proper maintenance and adoptions of modern technology can increase the yield of biogas for future needs [16].

Table 2 Details of gas yield generated from human waste

Name of village	Haldvade	Haladi	Benikre	Karanjivane	Doulatwadi
Population (C)	2019	3952	2099	3044	1103
Gas yield (m^3/kg day)	22.61	44.26	23.51	34.09	12.35

Table 3 Details of biogas from buffalo waste

Name of village	Halawade	Haladi	Benikre	Karanjivane	Doulatwadi
Buffalo (C)	408	650	396	443	317
Gas yield (m^3/kg day)	244.8	390	237.6	265.8	190.2

Table 4 Details of biogas from goat waste

Name of village	Halawade	Haladi	Benikre	Karanjivane	Doulatwadi
Goats (C)	321	421	310	451	424
Gas yield (m^3/kg day)	100.1	132.62	97.65	142.1	131.27

Table 5 Details of biogas from hen waste

Name of village	Halawade	Haladi	Benikre	Karanjivane	Doulatwadi
Hens (C)	1000	1000	500	1000	5000
Gas yield (m^3/kg day)	1.98	1.98	0.99	1.98	0.99

3.2 Biogas Generation from Livestock

Livestock such as buffalo, goat, and hens assessed for energy are according to Tables 3, 4 and 5. These Tables 3, 4, and 5 provide data of the quantity of livestock, wet waste, dry waste, and biogas yield produced daily among five villages. Biogas from five rural livestock shows that buffalo can generate 1,328.4 m^3, goat's about 603.74 m^3 and hens estimates about 8 m^3 of biogas daily. This totals to 1,940.14 m^3 of biogas daily or 7,08,151.1 m^3 annually (Eqs. 3–9). Where methane fraction in biogas can be estimated up to 1,377.5 m^3/day or 502787.28 m^3 annually [23].

3.3 Impact of Crude Practices in Rural

Air pollution:

During day-to-day activities kerosene, dung cake, agricultural residues, and firewood which are burnt, emits air pollutants [carbon monoxide (CO), oxide of nitrogen (NO_x), Sulfur dioxide (SO_2), volatile organic compounds (VOC), and particulates (PM)] [25–27] including greenhouse gases such as CO_2 and CH_4 leading to human health issues [28]. During the 1990s, a total of 59% of fuelwood, dung cakes around

18%, and crop residue of 23%, was burnt in rural [29]. Majorly, kerosene as sources of fuel is consumed about 5 L/Household/month or 4.1 kg/Household/month [30], also 340 kg of firewood/Household/months [31]. Similarly, 113 kg/household/month of dung cakes and 69 kg/household/month of crop residue is consumed [32] in rural. The burning of fuels emit pollutants depending on the rate of consumption and type of fuel sources used. Five of villages which are under investigation have estimated potential to emit 1.77% of NO_x, 0.62% of SO_2, 82.80% of CO, 5.84% of VOC, 2.50% of PM_{10} and 1.97% of $PM_{2.5,}$ respectively; 1.44% of CO_2 and 3.06% of CH_4 of total weight percent of emission per year (Eq. 10) (Tables 6 and 7). These estimated values of pollutants are based on the consideration that, out of 1432 rural households, 6.5% use kerosene, 52.5% use firewood, and 9.8% use dung cake in their daily activities [5].

From Tables 6 and 7, a monthly requirement of fuel source and emissions after usage of estimated fuel source from rural houses, is calculated based on previous assumptions. Furthermore, carbon monoxide (CO) emission has the highest share of 82.80%, after methane (CH_4) and the lowest is sulfur dioxide (SO_2) emissions. In addition, greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) liberated with concentrations of 5.62×10^3 tonnes/year and 11.96×10^3 tonnes/year, respectively.

Health impacts: excretion and biomass burning

Human and animal waste discharge are responsible to introduce pathogens in the surrounding environment [36]. Impacts of these pathogens on humans and animals are caused either from drinking water, food [37, 38] or through carriers (e.g. flies). Nath (2003) reported, around 60–80% of diseases caused by fecal contamination and unhealthy sanitation. Health impact and deaths are prominent in undeveloped habitats around rural because of improper sanitation [39]. Therefore, proper sanitation can minimize health hazards in cost-effective way of promoting sustainable development [40, 41]. The possibility of risk count may decrease to 1.63 billion because of improved sanitation [42] from 2.5 billion of causalities suffering from diarrhea, help elevating economic growth [43]. In addition, most of the Indian rural communities use kerosene and biomass for cooking on low efficient stoves [44]. Such practices are a reason for 0.6 million of premature death per year in India [45]. From studies, rural population leads to a risk of respiratory and cardiovascular problems because of the high concentration of PM_{10}, $PM_{2.5,}$ and CO [46]. Furthermore, emission of SO_2, CO_2, CH_4, VOC, NO_x, $PM_{10,}$ and $PM_{2.5}$ creates an unhealthy environment for the individual within the vicinity for a maximum duration of emitted pollutants [47]. Moreover, women in India have chronic lung disease, asthma, and bronchitis, who cooked food on biomass fuel in homemade mud stove [48]. These above considerations may lead to a reduction in life expectancy of adults and children's, enforcing economic crunch on the rural population. Thus, biogas can mitigate lower emissions environment compared to the burning of biomass.

Table 6 Type of fuel burnt and emission factors

Fuel source	Total consumption (kg/month)	NO_x	SO_2	CO	VOC	PM_{10}	PM2.5	CO_2	CH_4
Kerosene	381.63	2.3 [33]	4 [33]	1.8 [33]	0.5 [33]	0.3 [33]	0.3 [35]	2.41 [18]	NA
Fierwood	255,612	2.2 [25]	0.7 [25]	99.3 [34]	7 [33]	3 [33]	2.1 [35]	1.83 [18]	3.9 [18]
Dung cakes	15857.96	0.8 [25]	1.4 [25]	99.3 [18]	7 [18]	3 [18]	6.5 [35]	NA	NA

NA not available

Table 7 Form of fuel burning and emissions concentrations

Fuel source	Total consumption (kg/month)	NO_x	SO_2	CO	VOC	PM_{10}	$PM_{2.5}$	CO_2	CH_4
Kerosene	381.63	877.75	1526.5	686.93	190.815	114.5	114.5	919.7	NA
Fierwood	255612	562,346	178928.4	25,382,272	1,789,284	766,836	536,785	467,770	996,887
Dung cakes	15857.96	12,686	22201.14	1574695.5	111,006	47573.88	103,077	NA	NA
Emissions (kg/month)		575,911	202656.04	26,957,654	1900480.82	814524.38	639,977	468,690	996,887
Emission (10^3 tonne/year)		6.91	2.43	323.49	22.81	9.77	7.68	5.62	11.96

NA not available

Fertilizer usage

Biogas slurry is considered equal to dung added in a biogas plant, having nutrients such as 1.4–1.8% of Nitrogen (N), 1.1–1.7 of Phosphorous (P), and 0.8–1.3% of Potassium (K) on dry weight basis [49, 50]. Consumption of such nutrient is widely practiced in agriculture as fertilizer. In India, $N = 58.7 \times 10^3$ tonnes and $P = 6.9 \times 10^3$ tonnes was consumed in the year 1950–51, whereas in year 2013–14 it increased the usage to $N = 16750.1 \times 10^3$ tonnes, $P = 5633.5 \times 10^3$ tonnes and $K = 2098.9 \times 10^3$ tonnes [51]. The dry matter to the weight of slurry is assumed as 7% and rest of 93% is water [52]. A single biogas unit of 1 m^3 requires 25 kg dung and an equal amount of slurry is discharged [53, 54]. Therefore, 1 m^3 biogas digester estimates to produce a slurry of 25 L/day. Furthermore, 24.5 of N g, 19.25 g of P and 14 g of K nutrients are generated from 1 m^3 of biogas unit per day [18]. Therefore, 1923.27 m^3 of biogas is generated daily from five villages, achieves a potential to produce 47.12 kg of N, 37.02 kg of P, and 27 kg of K. This accounts to 17.19 tonnes of N, 13.5 tonnes of P and nearly 10.0 tonnes of K, annually.

3.4 Economic Benefits

Fertilizer

The fertilizer demand increased from 100.33 kg/ha/year in 2002 to 170.98 kg/ha/year in 2014 in India [55]. This consumption will rise in near future for maximum production of food. This may mitigate the requirement of fertilizer from slurry of biogas. Based on the literature, nutrient available in form of fertilizer can be utilized for approximately 74 ha of land per year among five villages [56]. This practice can give an economic benefit of the amount of $10,782 USD/year, mitigating 22,347 kg of CO_2 equivalent per kg of N produced and 4,680 kg of CO_2 equivalent per kg of P and K produced [18]. Similarly, for the production of fertilizer from biogas slurry of livestock can gain US$270/year as carbon credits among five villages.

Biogas:

In concern to liquid waste generated and disposed within rural requires major attention. Moreover, accepting sustainable technologies such as anaerobic digesters for treatment of liquid waste, estimates 1923.27 and 136.82 m^3 of biogas daily from livestock and human excreta, respectively. If the collection efficiency of dung is considered as 50% for livestock, it can generate 961.63 m^3 of biogas per day. This totals to 1098.45 m^3 of biogas per day from five villages investigated. From scenario, 1432 households required 381.63 kg of kerosene, 25,5612 kg of firewood, and 15,857.96 kg of dung cakes per month (Table 6). A 1 m^3 of biogas may replace 14.17 kg of kerosene, 105 kg of firewood, and nearly 370 kg of dung cakes of their monthly requirement [57]. The study estimates around 26.57 m^3 of biogas could substitute, demand for kerosene among 6.5% of total household in rural for a month. Similarly, demand for firewood exchanged with 683.45 m^3 of biogas for 52.5% of total households depending on wood as fuel per month. A monthly dung cake requirement may fulfill by replacing 44 m^3 of biogas for the remaining 9.8% of rural households. Therefore, the total demand for month accounts to 754.02 m^3 of biogas. The fact is energy demand estimated is just 2.28% of biogas generated per month from five rural habitats. The overall calculation seems to have the potential to generate daily 2350.68 kWh of electricity from 97.71% of remaining biogas [58]. Biogas can save around US160$/month on kerosene [59] and prevent from burning of 255.612 tonnes of firewood and 15.85 tonnes/month of dung cakes. In addition, biogas mitigates indoor and outdoor air pollution reducing the emission of greenhouse gases. In this case study, NO_x can be reduced by 575.91 tonnes/month, SO_2 by 202.65 tonnes/month, CO by 26957.65 tonnes/month, VOC by 814.6 tonnes/month, PM_{10} by 814.6 tonnes/month and $PM_{2.5}$ by 573.37 tonnes/month. An opportunity to gain carbon credits by mitigating CO_2 and CH_4 of 468.68 tonnes/month and 996.88 tonnes/month, respectively. This sustainable process can gain up to US4686.8$/month from CO_2 and US209334.8$/month from CH_4 as carbon credits for rural settings [18].

Health:

Accepting biogas in the backyard can improve the health of family by reducing the risk of diseases such as worms, bacterial, and viral infections caused after daily excretion [60]. Furthermore, biogas can decrease the risk of health caused by burning of primary fuels, of women's, children's and adults at habitats [61]. Among family members in rural, who spend a maximum of their time in the kitchen are females between 16 and 60 years spend 5 h, children's below 15 years spend 1.4 h and male spend 2.4 h in the vicinity of the cooking area [62]. Use of primary fuel can cost US$1.5 to US$10 per month per family for breathing and eye-related diseases [63]. Besides, economic impact due to illness in 1982 was around US$34/head/year [64]. Sustainable thinking can help improve losses (economic, health and death) occurred after improper sanitation and erroneous in the usage of fuels in rural habitat. Total cost could reduce to 60% after accepting biogas technology [63].

4 Conclusions

Five villages investigated can gain major profits by accepting biogas. Active thinking and expression of interest in initial investment in a rural setting can develop a better model for future crisis. From the above studies, it is clear; if such models are developed in developing countries, it may reduce environmental, economic and health impacts. This will also reduce individual investment in fertilizer and energy. Initial investment to start a model can benefit everyone including climate change. From the above investigation, it concludes that a total of 1098.45 m^3 of biogas per day is generated among five villages. The overall energy demand of five villages, which is satisfied using kerosene, wood, and/or cow dung is just 2.28% of total biogas generated per month. Similarly, around 2350.68 kWh of electricity can be generated daily from remaining 97.91% of biogas. This has the potential to reduce Tonne of gas released from primitive practices. Such practice of accepting advance technology can reduce the burden on the health of family and economy. Furthermore, from biogas units among five villages can produce fertilizer to satisfy the demand of 74 ha per year. The overall analysis of such a model can give a win-win situation for rural India.

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