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Technical assessment of installed domestic biogas plants in Kavre, Nepal

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ABSTRACT

Domestic biogas technology is a promising source of renewable energy for cooking in developing countries. It is popular in Nepal's rural and peri-urban areas and can be scaled-up to replace solid fuel cookstoves. This study focused on the technical assessment of installed biogas plants such as structural components, pipelines and valves, stove and burner, biogas production and utilization, and effluent disposal system in 303 homes in Kavre district, Nepal. Furthermore, it evaluated the feedstock material's physical and chemical parameters to ascertain their implications on biogas production. The plants' problems were mainly due to faulty components and lack of proper operation and maintenance. About 18% of plants were nonfunctional, out of which 9% of the plants were damaged due to the 2015 mega-earthquake. The highest number of damages was found in the mixture of the inlet structure. About 55% of mixtures were nonfunctional. Almost 77% of users used cow dung and toilet waste either individually or in combination with animal urine as feedstock materials in the digester. The Carbon: Nitrogen (C: N) ratio of feedstock materials ranged from 5:1–24:1, with only 4% of samples measuring C: N greater than 20:1. Similarly, pH (7.7) levels were on the higher side.

1. Introduction

Biogas production from agricultural waste such as livestock manure, sewage sludge, crops residues, and other organic wastes are of increasing interest as it can reduce greenhouse gas (GHG) emissions and dependency on fossil fuels [1]. Anaerobic digestion of waste also holds great potential for manure stabilization, sludge reduction, odor control, and sustainable energy production [2].

In Nepal biomass is the major source of cooking energy. Despite numerous efforts by the government and other stakeholders to increase the share of clean cooking energy, nearly 69% of households in 2019 still relied on solid fuels for cooking. The proportion of solid fuel users is significantly higher in rural regions reaching more than 80% [3]. Biomass combustion for cooking and heating activities significantly contribute to household air pollution (HAP), the emission of greenhouse gases (GHGs), and the total burden of diseases. In Nepal, the 24-h PM2.5 concentrations have been found significantly higher in the kitchen using biomass fuel stove than in the kitchens using LPG or electricity (656 μg/m3 vs 101 μg/m3 and 80 μg/m3) [4]. A study conducted in the peri-urban area of Nepal has revealed biomass fuel stoves emitting fifty times more PM2.5 than biogas on a fuel energy basis and 230 times more Elemental Carbon (EC) [5]. EC released into the atmosphere can cause the climate to warm [6]. A study conducted among women in rural Nepal has found reduced systolic and diastolic blood pressure among those who used biogas compared with women that used biomass fuel [7]. Therefore, substituting solid fuel with biogas produced from anaerobic digestion of waste biomass can significantly reduce HAP and GHG emissions, contributing to climate change mitigation, environmental protection, and health benefits [5,7].

Domestic biogas systems are largely disseminated in Asian countries. Among these countries, Nepal is one of the intensely involved countries in promoting domestic biogas plants popularly known as Gobar Gas Company (GGC 2047) plant. Since 1975, the government of Nepal (GoN) has been keenly involved in distribution of small scaled domestic biogas plants [8]. Until 2020, the GoN has installed about 432,000 such plants in 66 out of 77 districts of Nepal. The average size of the plants is less than 10 m^3. Cattle dung

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are used primarily as an input for the biogas plants because of heavy reliance on agriculture and cattle rearing activities and the technology being limited to households use only [9]. The total theoretical potential of biogas production from livestock manure is 3043.58 million m^3/year (equivalent to 110 million Liquid Petroleum Gas (LPG) cylinder[1]), which is more than four times than the current consumption of LPG cylinders in Nepal and 20 times higher than the current generation of biogas from household biogas plants [10]. Despite having such a large number of household biogas plants its total share in clean cooking is about 3.2% only, which is very low. One of the main reasons for this could be a large percentage (10%) of biogas plants that are not functional due to technical (not having repair and maintenance) problems. In addition to the several technical and climatic problems on biogas plants, the energy generated from them has not been sufficient to meet the cooking energy requirements as a result most of the household have cooking fuel stacking with biomass and LPG. However, there is also dearth of information on the percentage of biogas plants that are not in use and has been replaced by LPG due to improvement of economic status of the people [10].

The domestic biogas plants implemented in Nepal are in general, a fixed-dome design popularly known as GGC 2047 plants, which are made of bricks and concrete. The GGC 2047 is an integrated system for biogas production and utilization that consist of five main categories: structural components, piping system, biogas utilization system, effluent disposal system and elements related to anaerobic digestion process. Anaerobic digestion process is highly dependent on various chemical and environmental factors such as the temperature, carbon: nitrogen ratio, pH, retention time, total solid and volatile solid content of the feedstock. The major problems that arise in the operation of biogas digesters are crack in structures due to low quality construction, leakages in pipelines, lack of maintenance, low biogas production and disruption of the anaerobic ecosystem [11].

Although, the GoN has installed more than 430,000 biogas plants in Nepal, there have been limited studies that provide information on the technical status and operation, and performance of installed domestic biogas plants. A technical assessment of domestic biogas systems in Nepal using fault tree approach found that piping systems have the highest fault probability and the use of digestate is often not effective [11]. Subedi discussed the current status of biogas and its contribution to employment, fuel, income generation and greenhouse gas (GHG) emissions reduction in Nepal [12]. Dhungana et al. investigated the mono digestion of food waste at an ambient temperature replicating operational parameters of domestic biogas plant [13]. Garfi et al. compared Chinese fixed dome and plastic tubular digesters (without greenhouse) implemented in India at an altitude of 1300 m [14]. Lohani et al. investigated the process stability and synergetic effect of co-digestion of food waste with sewage sludge and poultry litter [15]. Jabeen et al. examined the contribution of households' critical influence factors in biogas technology utilization in Panjab province of Pakistan [16]. Ttofa et al. discussed the environmental sustainability of the fixed dome domestic biogas plant operated in Egypt [17]. Nevertheless, there has been a gap in the information to discuss about the various aspects of technical assessments (structural components, piping system, biogas utilization system, effluent disposal system and elements related to anaerobic digestion process) of fixed dome domestic biogas plants and their role to reduce the operational performance of biogas plant. Therefore, studies that are aimed to fill these literature gaps in "field scale fixed dome domestic biogas plants" operated in Nepal and elsewhere are warranted.

To ensure the plants' successful operation during their lifetime and their future improvement, continuous technical and performance evaluation is required. Performance evaluation further helps enhance the sustainability of the system as well as consumer satisfaction if corrective measures are taken based on the scientific studies.

This study aimed to find the technical status of the existing domestic biogas plant and sense sort of operational condition of anaerobic digestion processes that are being operated in an ambient temperature condition. The study's other aims were to assess how the biogas system is being used and identify the key areas and components that need improvement for the optimum operation of the plants and biogas production.

2. Methodology

2.1. Overall methodology

The overall methodology of this study is as shows in Fig. 1. The flowchart indicates the methodological framework showing each step's input and output and it's linkage to the next step.

2.2. Study location and sample size

Nepal's geographical region is divided into three horizontal zones: Himalayas, Hill and Mountains, and Terai (plain areas). These three zones range from almost sea level in the south to the world's top elevation (i.e., Mt. Everest) in the north. There are seventy-seven districts within three geographic regions, among which Kavre district, situated in the hilly region, is one close to the capital city (i.e., Kathmandu). In the last 30 years, the GoN has installed many biogas plants to meet domestic cooking fuel needs in this district. The present study was part of a multi-year study, "Maximizing Benefits of Clean Cooking in Peri-Urban Nepal" [18]. The study aimed at increasing the uptake and assessment of clean cooking technologies' impact on the environment and health. The required sample size of this study was based on the total sample size needed for a four repeated measure analysis for systolic blood pressure for two groups (Biogas vs. solid fuel) with a significance level (α) of 0.05, the statistical power of 0.80, the effect size of 0.10 (medium), which was 350 in each group.

2.3. Data collection

Assessment of biogas digesters were conducted in 303 households in five wards of Panchkhal (Wards: 3,4,6) and Mandandeupur (Wards:7, 9) municipalities of Kavre district.

An in-depth survey was conducted using a structured questionnaire, which collected detailed information and technical data on the general status, biogas operation practice, and biogas plants' performance. Feedstock slurry samples from the twenty biogas plants' inlet chambers were also collected and analyzed for its physical and chemical attributes to ascertain its implications on biogas production. Another objective of this analysis was to have the cross verification of the respondent answer, especially on the performance of biogas plant, i.e., amount of biogas production, and to look for possible solution and recommendation to enhance the biogas production.

The survey and technical data were collected by the graduate students of the Kathmandu University, Kavre. The field team was carefully trained to examine the components of domestic biogas plant before the start of the study.

[1] Liquid Petroleum Gas Cylinder contains 14.2 kg LPG. 1 LPG cylinder equivalent 29 m^3 biogas.

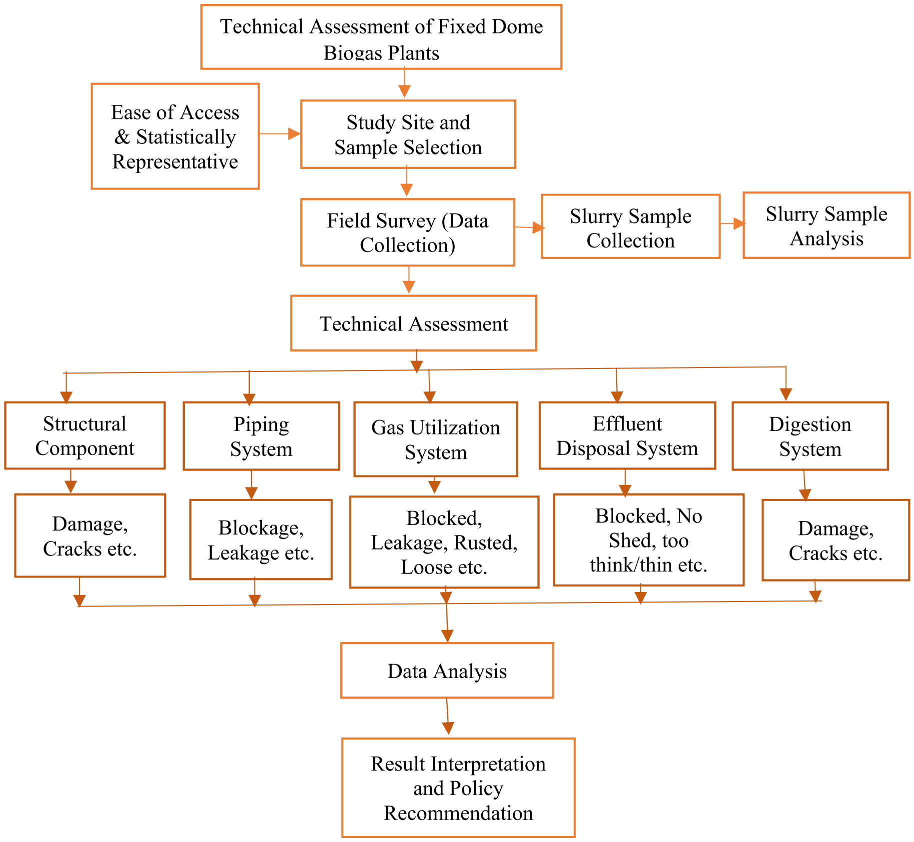

Fig. 1. Overall methods of the study.

2.4. Feedstock slurry sample collection

Grab samples of inlet feedstock slurry was analyzed for total solid (TS), volatile solid (VS), Carbon: Nitrogen (C: N) ratio, and pH. Dry plastic sample bottles of 200 ml were used to collect the samples. As far as possible, after the collection, samples were transported immediately to the laboratory for analysis.

2.5. Slurry sample analysis

The physical and chemical characteristics of slurry samples were analyzed using a standard laboratory method. The total solid (TS) and volatile solid (VS) were analyzed with oven drying and ignition gravimetric method (2540 C, American Public Health Association (APHA)). Carbon: Nitrogen (C:N) ratio was analyzed and calculated by using modified Walkley and Black, USDA Agricultural Handbook 60/Modified Kjeldahl, FAO, Fertilizer & Plant Nutrition Bulletin No. 19.

2.6. Technical assessment of the biogas plant

The technical assessment aimed at identifying the plants' technical faults and help adopt improvement approaches to avoid failures. To visualize the operational faults during the field survey, the plants' technical evaluation was structured into five categories, as shown in Fig. 2. The five categories of the systems concerning biogas production and utilization included: 1) structural components (inlet tank, outlet chamber, and digester), 2) piping system (gas pipeline and valve), 3) biogas utilization system (biogas stove and biogas lamp), 4) effluent disposal system (digestate storage and reuse), and 5) elements related to anaerobic digestion process (anaerobic digestion process, leakage, and varying loading rate).

Despite efforts, complete data could not be collected in some of 303 households due to the following reasons:

- Eleven stoves could not be assessed due to the absence of house owners.
- Twenty-seven stoves could not be assessed due to destruction of biogas plants by earthquake.
- Twenty-six stoves could not be assessed due to discontinue use of biogas for other reasons (moved to another house and abandoned biogas plant, stopped producing biogas, etc.).

3. Results

3.1. Biogas plant size and feeding material

The average family size among all the plant users was 4.5. Among the households surveyed, four different sizes of biogas plants ranging from 4 m^3 to 10 m^3 were found. However, a total of 256 (84.5%) plants were of 6 m^3 or larger and 18 were of size 4 m^3. The medium size plant of 6 m^3 seemed to be the most in demand. Almost 75% (228) of the total surveyed plants were of 6 m^3 size.

Among the surveyed households, 21 plants (21/239–9%) used cow dung only, 22 (9%) plants used toilet waste only, and 196 plants (82%) used cow-dung and toilet waste jointly as feeding material for the plant (Fig. 3). Also, 183 households (76.5%) collected animal urine in their animal shed and added them as feeding material to the biogas plant.

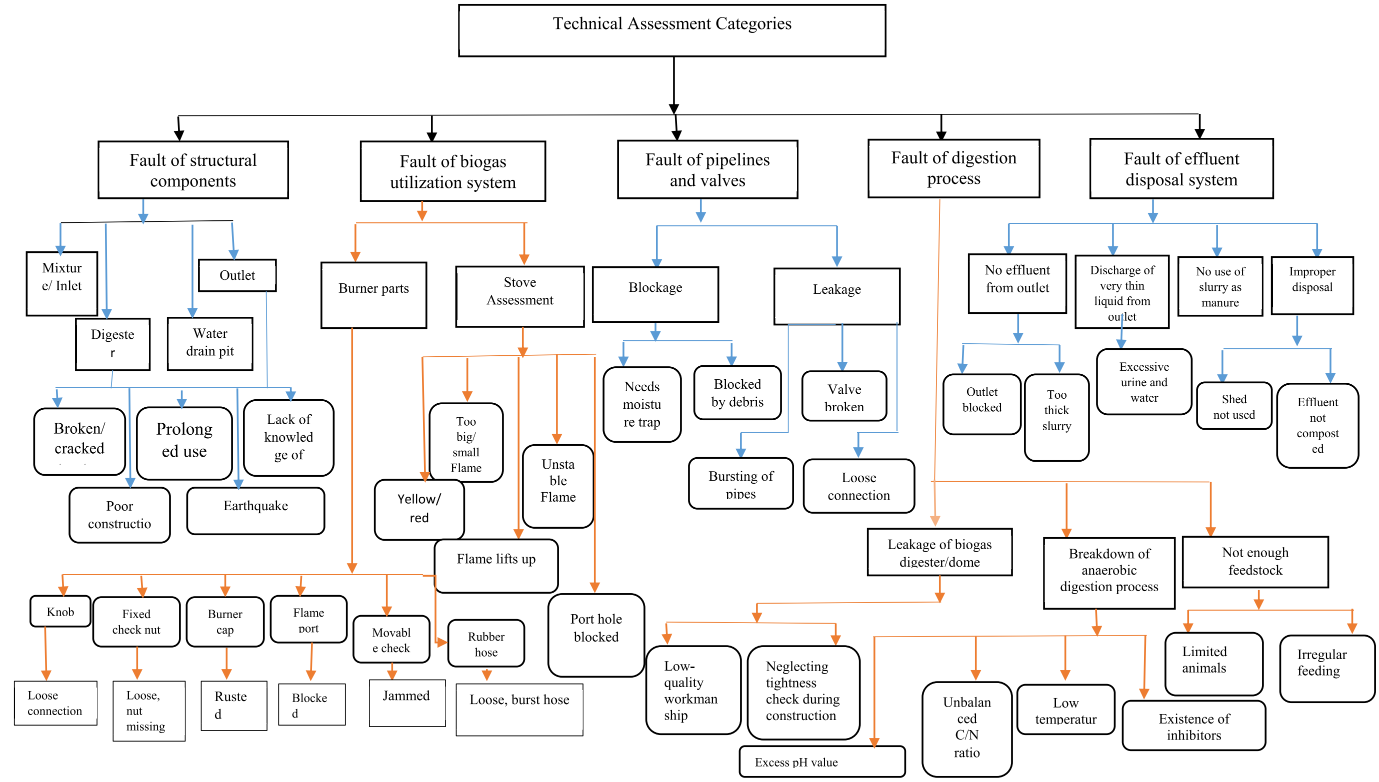

Fig. 2. Technical assessment strategies of household biogas plant.

Fig. 3. Toilet connected biogas plant.

Table 1
Number of stoves with different technical problems.

S. No.	Problem types	Number of stoves	Percentage (%)
1	Yellowish flame	9	3.8
2	A flame that lifts off	9	3.8
3	Flame extinguishing quickly	12	5
4	Flame too small	35	14.6
5	Flame too big	9	3.8
8	Unstable flame	20	8.4

3.2. Status of biogas stoves performance

The total number of stoves assessed was 239. There were no serious faults or damage in stove except a few general problems. Table 1 shows the number of stoves with different technical problems based on stove observation.

3.3. Status of pipelines and valves

Assessment of pipelines and valves of 292 biogas plants were done, out of which 239 plants were functional, and the rest were not functional. Table 2 shows the status of pipelines and valves of the functional and nonfunctional biogas plants. The highest number of problems was seen in water drainpipes. Since it is not a prerequisite structure for plants to function like inlet or digester, most families having issues with water drainpipe seem to have ignored it and many even did not know its location.

Fig. 4 shows the broken condition of mixture and stirrer whereas Fig. 5 shows the non-functional main valve of the biogas plant.

3.4. Status of biogas plant structure

The structural components of 292 biogas plants were surveyed, out of which 239 plants were functional, and the rest 64 plants were nonfunctional. Table 3 shows the repair and maintenance requirements of the number of specific structural components of the functional and non-functional biogas plant.

3.5. Status of biogas stove and its accessories

The condition of biogas stoves and its accessories of functional (239) biogas plants and additional 21 stoves and its accessories out

Table 2
Status of pipelines and valves of functional and nonfunctional biogas plant.

S.No.	Number of appliances need to be repaired				
	Functional biogas plant (239)			Nonfunctional biogas plant (53)	
	Components	Total number	Percentage (%)	Total number	Percentage (%)
1.	Mixture	112	47	48	91
2.	Main valve	43	18	45	85
3.	Gas pipe	13	5.4	47	88.7
4.	Water drain	34	14.2	44	83
5.	Rubber hose	29	12	12	22.6
6.	Gas taps	41	17	47	88.7
7.	Stove burner	5	2	46	86.8

Fig. 4. Broken mixture and stirrer.

Fig. 5. Condition of the main valve.

of nonfunctional 53 biogas plants were observed. Table 4 shows the number of components that need repair and maintenance to ensure efficient and safe operation of biogas stoves.

3.6. Status of biogas and digestate uses

About 89.5% of biogas users said: "some gas" is produced throughout the year. However, only 17% of them told that the produced gas is enough for cooking all year around. Despite having enough biogas production to about 17% of households, almost all (238 out of 239 homes) household used mixed fuels. About 85% had liquid petroleum gas (LPG), 83% had firewood, and 13% had electricity as an alternative fuel. Besides, it was also found that on average households used biogas for 1 h 40 min in summer, and 45 min in winter. Most of the owner (>80%) were not satisfied with the performance of biogas plants meaning that cooking all breakfast, lunch, and dinner using biogas alone was not possible. In winter, the use was limited to boiling water, making tea, and cooking just one or two items.

Digestate is used as organic fertilizer. Ninety one percent of biogas plant owner said they use digestate as fertilizer, however, only 15% had built shed over the digestate pit to protect it from direct sun. Direct sun to diluted digestate could evaporate Nitrogen, Phosphorous and Potassium available in the digestate decreasing the effectiveness of the fertilizer. Table 5 shows the status of biogas and digestate uses in the surveyed areas.

3.7. Results of laboratory analysis of feedstock slurry

Inlet slurry of twenty biogas plants were analyzed for pH, Total Solids (TS), Volatile Solids (VS), and Carbon: Nitrogen (C: N) ratio. Table 6 presents the results of laboratory analysis of feedstock slurry (materials).

The average pH of the feeding material was 7.7 (SD: 0.6), which was slightly higher than the optimal range of 7.0–7.2 [19]. The average Total Solid (TS) and Volatile Solid (VS) of feeding material were 7.9% (SD 2%) and 70% (SD 2%) of TS, respectively, which were quite reasonable for the wet digestion system. Whereas, the average Carbon: Nitrogen (C: N) ratio was only 11:1, which was exceptionally low as the suitable range of C: N ratio for anaerobic digestion is 20–30 [20]. The lower range of the C: N ratio suggests that a high concentration of nitrogen was available in the feeding material, which could be due to a large amount of urine added to the feeding material, as observed during the household survey. As reported by the biogas owners, biogas' low yield could be due to the higher pH and lower range of the C: N ratio of feeding material.

3.8. Energy supply and demand

All households in the surveyed area holds on average 3 cattle and 4 goats. The average waste (cattle manure) in each households is about 30 kg per day. The theoretical potential of biogas production from 30 kg cattle manure is about 0.9–1.2 m^3 biogas.[2] The actual biogas production observed from the field study (an average of 2 months) was about 0.7 m^3 per day in summer which reduced up to 35% in winter. Daily average cooking energy consumption was

[2] 1 kg cattle manure can produce 300 L–400 L biogas.

Table 3
Status of structural components of functional and nonfunctional biogas plants.

S.No.	Number of structural components need to be repaired				
	Functional biogas plant (239)			Nonfunctional biogas plant (64)	
	Components	Total number	Percentage (%)	Components	Percentage (%)
1.	Inlet pipe	7	3	47	73.4
2.	Dome	4	1.7	44	68.8
3.	Digester	4	1.7	44	68.8
4.	Water drain pit	29	12	47	73.4
5.	Water drain pit cover	34	14.2	47	73.4
6.	Outlet	5	2	44	68.8
7.	Outlet cover	12	5	44	68.8
8.	Toilet	11	4.6	34	53

Table 4
Status of biogas stoves and its accessories of functional and nonfunctional plants.

S.No.	Biogas stove and its accessories need to be repaired				
	Functional biogas plant (239)			Nonfunctional biogas plant (21)	
	Components	Total number	Percentage (%)	Components	Percentage (%)
1.	Knob	59	24.7	17	81
2.	Fixed check nut	22	9	8	38
3.	Movable check nut	36	15	10	47.6
4.	Burner cap	12	5	9	42.9
5.	Flame port	10	4	13	62
6.	Rubber hose	29	12	12	57

Table 5
Status of biogas and digestate uses.

S. No.	Categories	Number of households	Percentage (%)
1	Gas produced all year around	214	89.5
2	Gas is enough for the whole year	42	17.5
3	User not satisfied with gas produced	197	82
4	Shed used for digestate	36	15
5	Digestate used as manure	218	91.2
6	Urine collection by a pipe	48	20
7	Urine collection in a ditch	162	68
8	Dome cleaned	46	19

Table 6
Chemical analysis of feeding material of the biogas plant.

Parameters	Number of samples	Average (SD)	Range (minimum-maximum)
pH	108	7.7 (0.6)	6–8.7
TS,mg/g	102	78.5 (30)	47–173.5
VS, mg/g	102	55.2 (23)	14–113.2
C:N Ratio	100	11:1	5:1–24:1

about 20 $MJ_{thermal}$ equivalent to 1 m^3 biogas, which was lower than the average demand of the households. The deficient amount of energy were supplied mostly from firewood (70%), and partly from LPG and electricity.

4. Discussion

Biogas systems fit very well into the Nepalese integrated farming system. It can provide clean energy for cooking and replace the use of solid fuel stoves in many homes. However, to obtain the best results with respect to biogas production, time to time inspection and evaluation of the plants and their components, and regular maintenance is crucial. Moreover, educating owners or operators about the importance of using the appropriate feedstock and the correct amount of feedstock input is equally important.

Both operational and structural problems can lead to the malfunctioning of the biogas system. Biogas systems build with higher quality material, and good masonry usually lasts for more than 25 years [21]. However, the choice or use of low-quality material, wear and tear of various mechanical parts, crack build on the civil structure, and delay in fixing such problems could cause the critical malfunction of the system. In the present study, the survey of 303 biogas systems in the study area provided valuable insight into the installed biogas plants' actual operational status and some possible causes for lower production of biogas. The most frequent problems were found with structural components such as cracks on the infrastructure, faulty knobs, check nuts, burner caps, valves, water trap, and mixture in the feedstock inlet of the biogas system. Most of the biogas systems observed also had long pipelines and low-quality pipes. Many mixtures were broken and lying on the ground.

Factors such as faulty components or damage in the structure affect biogas production, gas transportation to the stove, and gas leakage. Pipes are vital components and used to transport gas to the stove. The low quality of the pipes, spoilt valves, and poor water traps could cause gas leakage. The use of good quality accessories and the use of a water filter can improve performance. In addition, regular cleaning of water on the pipes could further enhance the performance of biogas.

The mixture, which is used to agitate the inlet feedstock slurry, plays an important role in biogas production. The feedstock needs to stir mechanically, and it should be done regularly, at least every two days. The stirring helps to breakdown the substrate, stimulate bacterial activity, and break the scum layer. If the slurry is not stirred, then the organic matter could be formed at the slurry surface that can restrict gas flow through the slurry to the gasholder. About 47% of faulty mixture in the present study suggests that in some way biogas plant is not getting sufficiently mixed and uniform particle sized substrate impacting an aerobic digestion process and biogas production. Holliger et al. (2016) suggested that particles should be less than 10 mm in diameter and/or length for an effective anaerobic digestion process [22].

The inclusion of a robust stirrer within biogas package and educating owners about the importance of regular agitation of feedstock material could improve biogas' performance. Similarly, periodic cleaning of the digester by removing the settled sludge and organic solids could help improve the system.

The anaerobic digestion is sensitive to the feedstock materials and C:N ratio. Most of the owners or operators were aware of the importance of using the correct amount of feedstock. The average liquid to biomass waste ratio was 1:1, but the composition of feedstock material had an excess amount of animal urine. The Carbon: Nitrogen (C: N) ratio of most of the feedstock was far below the desired range of 20–30. The high value of nitrogen in the feedstock enhances the production of ammonia gas that could increase the pH, which could be detrimental to the micro-organisms. On the other hand, the increase in carbon content gives rise to more carbon dioxide formation and lower pH value. In the present study, the feedstock's pH value was slightly high than the desired level (~7) [19].

In general, animal urine is rich in nitrogen, which could enhance gas production when mixed with appropriate amount of cow dung. Compared with animal waste, human waste has a meager C: N ratio (25:1 vs. 3:1) [23]. During the home visits, 9% of biogas users were found using only toilet waste as feedstock material. These results indicated that an inadequate supply of feedstock material may be resulting in the occurrence of inhibitory effects on the anaerobic digestion process and in a lower production of biogas, as reported by some biogas users. To resolve these issues and enhance biogas production, the owner should lower the urine addition in the feedstock or look for the possibility of co-digestion of different substrates. Co-digestion produces a positive synergetic effect and balances the nutrients that may be deficient in mono digestion and improve system stability and methane yield [24].

5. Limitations

The present study has some important limitations. Significant limitations include the small sample size and the generalizability of some research findings. For example, the study was conducted in 303 households and limited to two municipalities with similar geographical characteristics. In contrast, biogas digesters are widely used in 66 out of 77 districts with different geographical characteristics. This limitation raises the issue of the generalizability of the results of this study. Some of these limitations could be addressed in the future by conducting a study with diverse sample covering at least three regions of Nepal (mountains, hills, and plain areas).

6. Conclusion and recommendations

The present study has identified a few areas that need improvement to enhance biogas production and the effective utilization of digestate in the study area. The present study's findings can serve as a baseline for further studies as this study was conducted in limited areas. This study is the first to gather valuable information on the status, performance and reasons for the non-functionality of the installed biogas in the Panchkhal and Mandandeupur municipalities. Such information might help relevant stakeholders/authorities prepare a strategy and intervention plan for suitable repair and maintenance, adequate training to the users on how to handle the plant, and perhaps a possible change in design for the effectiveness of the plant. Based on these findings, the following recommendations to owners and biogas agency are made to improve the overall performance of the installed biogas plants in the surveyed areas:

Biogas owner

- Most of the biogas digesters surveyed showed structural damage. Repair and maintenance of major structural components, stoves, and burner accessories, pipes, and valves could help sustain the system's performance.
- A suboptimal composition of feedstock can reduce biogas performance. Many households have been found using excess animal urine in the feeding material. Reducing the amount of urine and increasing the water level in the feeding material can help improve anaerobic digestion processes and enhance biogas production. In addition mixing co-substrate for example food waste, goat droppings and poultry litter enhance biogas production.
- Put sufficient feedstock into the plant (it varies as per plant size), which may need to be changed for summer and winter seasons as the organic loading rate varies for summer and winter due to higher retention time needed in winter.
- Compared to the summer season, biogas yield is lower during the winter. Mixing feedstock material with lukewarm water during the winter can improve the biogas yield. Similarly, the construction of a greenhouse over the biogas plant can enhance biogas production in winter.
- The biogas slurry (digestate) is a valuable fertilizer. Direct sun exposure to digestate can evaporate Nitrogen, Phosphorous, and Potassium available in the digestate and decrease the effectiveness of the fertilizer. Putting the shed near the slurry outlet can protect the nutrient component and prevent the loss of minerals.

Biogas agency

- The success of biogas technology and long-term adoption depends on the proper operation and maintenance of the system. The biogas system's life, performance, and adoption rate could be improved by offering basic training on operation and maintenance to the owner or plant operator from time to time. Further, the development and dissemination of educational materials to users on proper care and operation can help the biogas system's life and adoption.
- Upon installing the biogas system, the technical issues are left to the owner/user to resolve. The national biogas agency can establish a focal point/organization to hear the biogas user's questions or grievances. The biogas agency could also increase the number of local technicians to maintain the existing biogas

units, and establish after-sales services outlets, providing repairs near the community where most homes have biogas plants.

- The existing small, fixed dome biogas design is almost thirty years old. The system only works well at altitudes up to 1500 m. The biogas agency can promote research and development of more efficient and productive biogas systems.

CRediT authorship contribution statement

Sunil Prasad Lohani: Conceptualization, Methodology, Formal analysis, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Dhiraj Pokhrel:** Conceptualization, Methodology, field survey, Visualization. **Sankalpa Bhattarai:** Methodology, field survey, Writing – review & editing. **Amod K. Pokhrel:** Conceptualization, Methodology, Data curation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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