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Quantitative Study of Biogas Generation Potential from Different Landfill Sites of Nepal

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Abstract - *This research paper was study of waste composition and quantitative analysis of biogas generation potential with its recovery at Sisdole, Pokhara and Karaute Dada landfill sites (LFS) of Nepal. The waste management practice in LFS are significant deciding factors for the assessment of environmental impacts caused including the release of green house gases like methane, carbondioxide etc to the atmosphere, that could contribute significantly to global warming and climate change. The total waste disposed to Sisdole LFS, Pokhara LFS and Karaute Dada LFS are 410, 80 and 7.8 tons respectively. The waste composition was studied onsite with waste reduction method and analyzed for their composition. The organic component of wastes was found high as 61.6%, 52.5% and 65% at Sisdole, Pokhara and Karaute Dada LFS respectively. The biogas potential at these landfill sites were 12157.78 cum, 851.99 cum and 169 cum of biogas per day in Sisdole, Pokhara and Karaute Dada LFS respectively. 4.68, 0.33 and 0.07 MW energy per day can be generated from these amounts of biogas produced in Sisdole, Pokhara and Karaute Dada LFS respectively. Proper gas collection system can be the source of income from these landfill sites and help to mitigate the adverse impact of methane that is being released from these landfill sites.*

Keywords – *Biogas; Climate change; Global warming; Green house gases; Municipal solid waste*
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1. Introduction

Production of waste materials is an unavoidable part of human society. Since, the waste generated was very less in early times; disposal of municipal solid waste was easy as land available for disposal of wastes **[1].** More than eight million tons of solid waste is produced per day in developing countries. Over 95% of this waste is disposed off in landfills, open dumps, on riverbanks, directly into the sea, or just combusted on site because of insufficient waste collection and final disposal systems **[2]**. In most developing countries like Nepal, municipal solid wastes are disposed openly, which have always been known to generate greenhouse gases (GHG) **[3].**

Biogas produced during the anaerobic digestion of waste is primarily composed of methane and carbondioxide, with smaller amount of hygrogen sulphide and ammonia. Biogas can be cleaned to remove impurities and upgraded to pure bio-methane. It can then be used as a renewable transport fuel in vehicles designed to run on compressed natural gas (CNG) or liquefied natural gas (LNG). The greenhouse gas savings of bio-methane fuelled vehicles can be significant. Methane fuelled vehicles can also have extremely low emissions of local pollutants, including NOx and particulates (PM2.5 and PM10) when compared to modern petrol and diesel vehicles. However, as methane is part of the chemical processes in the atmosphere and is also a powerful greenhouse gas (about 22 times as powerful as carbon dioxide, CO2).

The objective of this study is to determine the biogas potential and energy recovery from Municipal Solid Waste of three landfill sites in Nepal (i.e. Sisdole Landfill Site, Pokhara Landfill Site and Karaute Dada Landfill Site). There is no provision of gas collection system at any of these landfill sites.

1.1 Study Area

In Nepal out of 191 municipalities only six municipalities have somehow managed landfill sites (LFS). Five municipalities have controlled dumping sites and remaining have roadside or riverside dumps. But none of these landfill sites have provision of gas monitoring pipes/wells and gas collection systems. The following study sites were selected for the current study because these sites represent somehow sanitary landfill and receives maximum amount of wastes. Pokhara, Karaute dada and Sisdole (PLFS, KLFS, SLFS respectively) are operational with intermediate age of LFS with 80 tons/day, 7.8 tons/day and 410 tons/day waste feeding capacity respectively. The detail descriptions of the sites are listed below in Table 1.

Table 1. Description of study LFS

Parameters	SLFS	PLFS	KLFS
• Sorting at site	No	No	Yes
• Provision of composting	No	No	Yes(not functional)
• Provision of selling reusable and recyclable waste	No	No	Yes
• Land filling type	Area	Area	Area
• Provision of spreading	Chain dozer	Chain dozer	Manually
• Provision of compaction	Yes	Yes	No
• Soil cover provision	Yes	Yes	Yes
• Soil cover	2-4 inch	2-4 inch	2-4 inch
• Littering problem	Dominant	Slight	No
• Odor problem	Dominant	Slight	Slight
• Industrial Contamination	Yes	Yes	Yes
• Medical Contamination	Yes	Yes	Yes
• Age	Intermediate (9)	Intermediate (9)	Intermediate (8)
• Waste feeding to LFS (tons/day)	410	80	7.8

2. Materials and Methods

2.1 Sample Collection

The sample collection was done in January, February and March, 2014 in each LFS. The sampling was done for twice a month. The information regarding municipal landfill sites were collected from concerned municipalities. For determination of quantity of waste coming to landfill site, the vehicles were weighed with and without wastes. Weight of the wastes was calculated by finding the difference between initial (weight with waste) and the final weight (weight without waste) of vehicles. Density of waste was obtained by dividing the obtained weight of waste by volume of the waste. Log sheet about the transportation vehicle was observed for 25 days to get the information about the average number of trips done by vehicle in a day. Quantification of waste in a day was done by multiplying the average density of waste, volume of vehicle and average number of trips done by that vehicle in a day. For the composition study, waste reduction method was used, where the waste collected from a certain area was taken as sample. In this method, the waste was separated into four sections, first diagonal wastes were rejected and rest was mixed and again separated into four sections. Again the same process was repeated until the waste was approximately 100kg. This waste reduction study was done for 5 times at one sampling time. Then the average of 5 samples of waste as composition study was taken. The waste was separated into various components such as organic waste, paper, plastic, glass, construction material and others. Each separated components were weighed and devided by total weight and multiplied by 100 to obtain each component in percentage.

2.2 Laboratory Analysis

Lab analysis of the solid waste was done at NESS laboratory at Babarmahal and pollution control laboratory in Kathmandu University. For moisture content, oven drying method was used. This procedure is performed in the sample that has been oven-dried at 1050C and ground. The method quantitatively determines the dry matter content based on the gravimetric loss of free water associated with heating. For analysis of volatile solid, gravimetry method was adopted **[4].** Total Nitrogen was calculated using Kjeldahl Digestion method **[5].** Organic matter was calculated using Walkley and Black method in which the organic matter / carbon in the sample is determined by wet oxidation method. The moisture free sample is treated with potassium dichromate in acidic condition and heated to 150^{o}C for 30 minutes. The amount of organic carbon in the sample can be determined by measuring the amount of unreacted dichromate by titrating with standard ferrous ammonium sulfate. Then the C:N ratio was calculated dividing the organic carbon to total nitrogen.

2.3 Data Compilation and Analysis

Microsoft excel was used for compilation of data obtained in the field. Vehicle log sheet was observed to know the average no of trips done by each vehicle in landfill sites. These information were used for quantification of solid waste.

2.4 Calculation of Biogas Potential

The total waste reaching the landfill site was calculated, and percentage of organic fraction was measured at site. Percentage of Total Solids was calculated from moisture content of organic fraction. Volatile solid (VS) was determined at lab. Then the methane yield was calculated assuming 0.35 cum/kg VS **[6].** The calculation is done as:

[1]. Total waste that reaches to landfill or transfer station was calculated.
[2]. Moisture content (M%) was determined in lab by proximate analysis
[3]. Percentage of Total Solids was calculated from (100-M%)
[4]. Percentage of organic waste obtained from composition analysis was used for calculation of organic fraction of solid waste.
[5]. Percentage of Volatile solid in solid waste was determined from laboratory test at NESS laboratory Babarmahal, Kathmandu
[6]. Unitary method was applied to calculate the total Volatile solid in Total solid of waste.
[7]. Similarly by using 0.35Biogas yield (cu.m/kg VS) total biogas potential (cu.m/day) and per kg yield was calculated.

Calculation method

a. Total waste quantity in a day: W (tons)
b. Moisture content : M %
   $M(\%) = ((W1 - W2)/W1) \times 100$
   Where,
   W1 : Weight before ashed (Crucible+dried sample) – crucible
   W2 : Weight after ashed (Crucible+dried sample) – crucible
c. Organic waste = O% of organic fraction of waste* 1000 (kg)
d. Total Organic solid: TS= Organic waste × (100- M)% (kg)
e. Percentage of Volatile Solids: Vs%
f. Volatile Solid (VS)= Vs% × TS (kg)
g. Typical bio-gas (methane) yield: B (m3)= 0.35 (m3 / kg. of VS)
h. Bio-gas (methane) yield in day = VS × B (m3)
i. Energy generated per cubic meter of Biogas = 6 KWh
j. Percentage of methane in Total Biogas production = 65%
k. Energy generated in MW = (methane yield in day×6×100)/(65×1000×24)
l. Using MATLAB software the biogas generation equation is derived.

3. Results and Discussions

3.1 Quantification of Waste

The total waste coming to the study area was found to be 410, 78 and 7.06 tons/day at Sisdole, Pokhara and Karaute Dada Landfill site, as shown in table 2 below.

Table 2. Quantification of solid waste at different LFS

LFS	**Waste quantification (Tons/ day)**
SLFS	410
KLFS	7.8
PLFS	80

3.2 Composition of waste

Composition of solid was determined by waste reduction method and the result obtained is listed below in table 3 and figure 1.

Table 3. Percentage composition of solid wastes at different LFS

Composition/LFS	SLFS	PLFS	KLFS
Plastic	10	12	8
Paper	10	10	11.5
Glass	5	6	3
Rubber	3	4	2
Textile	3	4	2
Metals	0.4	1.5	0.5
Cons.&Demolition	4	6	6
Organic	61.6	52.5	65
Others	3	4	2

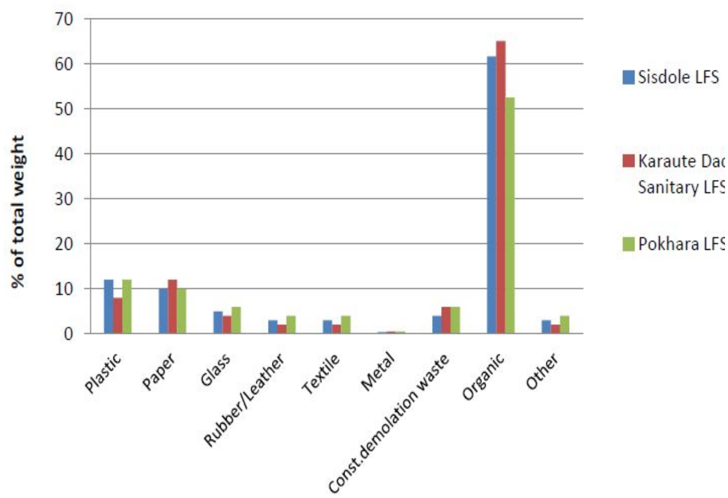

Figure 1. Waste composition study at different LFS.

Figure 1 shows that the percentage of organic content of solid waste is relatively greater in all three landfills with the least percentage of 52.5% at Pokhara LFS to 65% in Karaute Dada and 61.6% in Sisdole LFS. The percentage composition of plastic ranged from 8-12, paper 10-11.5, glass 3-6, rubber 2-4, textile 2-4, metal 0.4-1.5, construction demolition 4-6 and others 2-4. Glass, plastics, rubber, leather and textile were relatively higher in composition at Pokhara LFS. This may be due to the fact that larger number of tourists at the city consuming more packed foods and the living standard of the people in Pokhara is also high than that of the other area. Organic, plastic and paper content of the waste are higher at all the landfill.

3.1.1 Volatile Solids (VS).

Volatile solids also called as "organic solids" are that fraction of total solids which can be burnt (volatilized) in the muffle oven at 520°C. Only the volatile solids can be broken down by anaerobic digestion. Karaute Dada has highest value of Volatile solid and Pokhara has the lowest value. Average value of volatile solids for Sisdole, Pokhara and Karaute Dada are 44.41%, 39.63%, 58.47% respectively.

3.1.2 Moisture:

High water contents are likely to affect the process performance by dissolving readily degradable organic matter. Average value of Moisture for Sisdole, Pokhara and Karaute Dada Landfill Site are 69.03%, 85%, 82%respectively. This can also imply that the compaction is not done properly at Pokhara and Karaute Dada Landfill Site.

3.1.3 C:N ratio.

Values of C:N ratio of Kathmandu, Pokhara and Karaute Dada Landfill Site were 18.82, 19.03 and 19.62 respectively. These values are near to 20 which is best for anaerobic digestion of organic waste. Microbial decomposers obtain many nutrients from the composting materials but carbon (C) and nitrogen (N) are the nutrients that affect the process the most. Microorganisms primarily use carbon compounds as an energy source and ingest nitrogen for protein. If ratio is high, then low nitrogen will slow decomposition and if low then excess nitrogen is lost through gas as ammonia and also produce odor problem. The C/N ratio of 20–30 may provide sufficient nitrogen for the process. [7] suggested that a C/N ratio between 22 and 25 seemed to be best for anaerobic digestion of fruit and vegetable waste.

3.1.4 Estimation of biogas potential.

Potential of biogas was obtained from the method as described above in methodology section. The total biogas generations from each study sites are presented in table 4 below.

Table 4: Estimation of Biogas potential

LFS	Age of LFS (yrs)	Waste at LFS (tons/ day)	Mois-ture Conten t (M%)	% of orga-nic waste (O%)	Amount of organic waste (Tons)	Total Organic Solids (TS) in kg	%of Volatile solids	Amount of Volatile solid in Organic waste (kg)	Biogas yield (cu.m/ kg VS)	Estimate d biogas (cu.m/ day)	Estimated biogas per kg of total waste (lit/kg/ day)
SLFS	9	410	69%	61.6	252.56	78,293.6	44.41%	34,770.19	0.35	12,169.57	29.68
PLFS	10	80	85%	52.5	40.95	6,142.50	39.63%	2,434.27	0.35	851.99	10.92
KLFS	9	7.8	82%	65	4.589	826.02	58.47%	482.97	0.35	169.04	23.94

Table 4 can be interpreted as, higher the moisture content of the waste lower the production of the biogas as the total organic solids decreases. But only moisture content is not the factor that affects the biogas production, volatile matters also does. Higher the volatile content then higher the production of biogas. So the actual production of the biogas is accordingly with those factors. Figure 2 below shows the comparative production of biogas due to those factors in respective landfill site. This graph can be used for how much moisture content and volatile solids are necessary for the production of given value of Biogas Generation.

For example: to produce 20 l/kg/day of Biogas we should need about 85% (from figure 2 below) of moisture content and about 52.5% (from figure 2) of volatile solids.

Further, the relation of Biogas Generation with moisture content (M %) and percentage of volatile Solid Content (V%) can be expressed as:

Total organic solids = Amount of organic waste * (100 - M%)

And,

Amount of volatile solids = Total organic solids * V%

Estimated biogas = Amount of volatile solids * Biogas Yield

From these it gives the relation,

Biogas Generation per kg of organic waste

= (1-(M%)/100) (V%)/100 * Biogas Yield

This expression calculates the biogas generation from the waste with any composition of moisture content and percentage of volatile solids in total organic solids. This is Biogas Generation Calculation Equation. This equation gives that the Biogas Generation is maximum when the

volatile solids are maximum in organic solids having minimum moisture content.
Figure 3 is the graph for the calculation of the biogas generation of any composition (moisture content and volatile solid content). Here the Biogas Generation Equation is divided into two part.
Part 1:

Z1= = (1 -(M%)/100)*10 ……………………… (i)

Where 10 is scale coefficient.
Part 2:
Z2= (V%)/100 * Biogas Yield*100………… (ii)

For above graph Biogas Yield is in m^3/kg and taken as 0.35 (methane production) for this graph and 100 is scale coefficient.

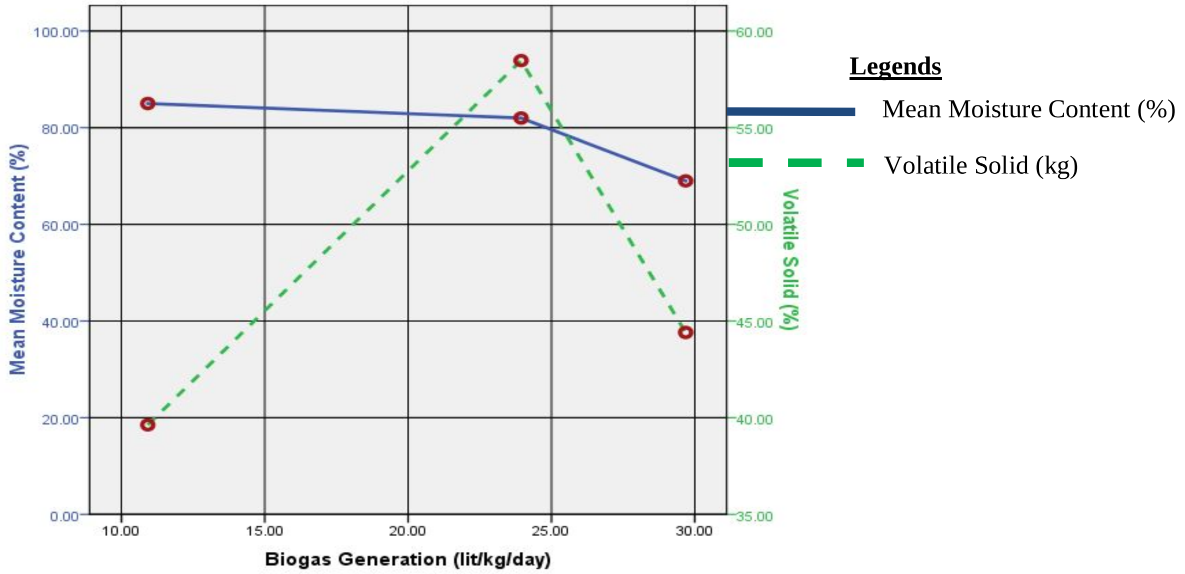

Figure 2. Comparative presentation of biogas generation

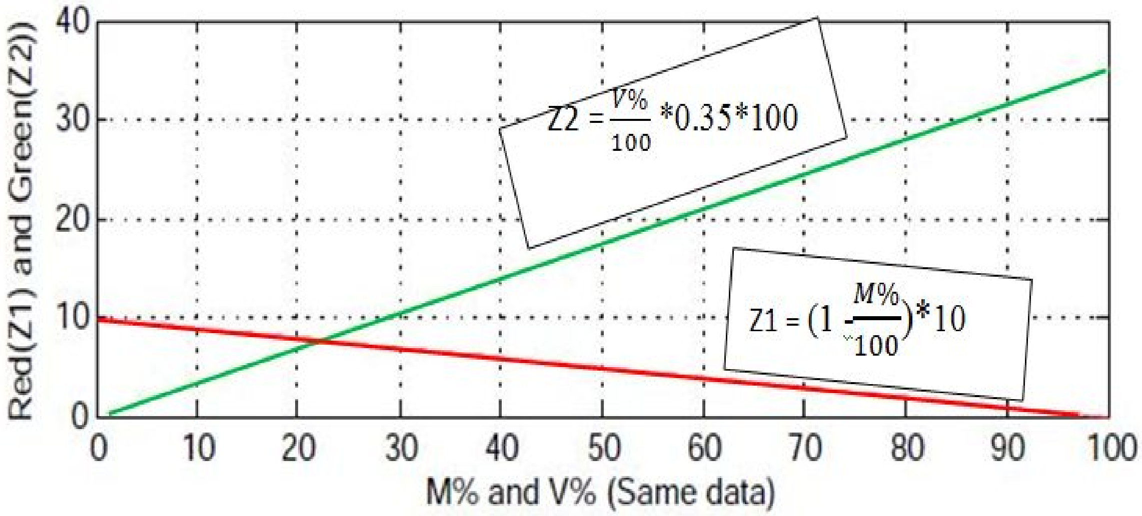

Figure 3. Biogas Generation Calculation based on moisture and volatile solids

Both the equations (i) and (ii) are linear and plotted using MATLAB, keeping Z1 and Z2 in ordinate and moisture content (M%) and percentage of volatile materials (V%) in abscissa. In above graph red line is for equation (i) and green line is for equation (ii). Now, after finding out the M% and V% from laboratory test, Z1 is obtained from the graph, ordinate of equation (i) for given M% and Z2 is obtained from graph, ordinate of equation (ii).
Then Biogas generated can be expressed as;

Biogas Generated (lit/kg/day) = Z1*Z2

3.1.5 Energy potential of generated biogas

Biogas has average caloric value of 21-23.5 MJ/m^3 and has a potential of electricity generation of 6 kwh/m^3 **[8].** Total biogas contains 50% to 75% of methane **[9]** produced from biodegradable matters. Here we take in average 65% methane of total biogas produced and the energy generated from the total biogas is 6 KWh/m^3 **[8].** From those considerations we can generate (table 5) 4.68 MW electricity from Sisdole LFS whereas 0.33 MW and 0.7 MW from Pokhara and Karaute Dada LFS respectively. Following table represent the electricity generation potential from each LFS as energy recovery.

Table 5. Energy generation from different LFS

LFS	Estimated methane (cu.m/day)	Energy generation per m3 (KWh)	% of Methane in overall Biogas	Power production per day (MW)
SLFS	12,169.57	6.00	65%	4.68
PLFS	851.99	6.00	65%	0.33
KLFS	169.04	6.00	65%	0.07

Generation of electricity (resource recovery) also reduce the emission of Green House Gas (GHG). Methane has a Global Warming Potential (GWP) of 12.4 for life time 86 for 20 years span and 34 for 100 years span, as carbon dioxide is base line for GWP and taken as 1 **[10].** This can address the global issue of climate change.

4. Conclusions and Recommendations

There is a huge potential of biogas recovery at these landfill sites of Nepal (i.e. 12157.78 cum, 851.99 cum and 169 cum of biogas at Sisdole, Pokhara and Karaute Dada Land Fill Sites respectively). These gas are not recovered, hence a large amount of methane is released to the environment that can contribute a lot to climate change. The composition of waste coming to LFS was seen mostly to be consisting of organic waste averaging so the provision of composting and/or energy recovery from waste can help the site in increasing the life of LFS and decrease the environmental impact of landfill site. Monitoring of t environmental parameters like air, water and soil is rarely conducted, which needs to be done at regular interval.

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