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Estimating Methane Gas Generation Rate from Sanandaj City Landfill Using LANDGEM Software

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ABSTRACT

The main gas arising from landfills is methane. The greenhouse effect of methane is 21 times more serious than that of carbon dioxide. On the other hand, this gas has a significant potential for producing energy, so that in cases of application of a suitable technology, a considerable energy from this gas could be extracted and used. One of the mathematical models used for estimation of the amount of methane potential in landfills is LANDGEM software, which was applied in the present research study. This was a descriptive-cross sectional study in which first, the data related to the amount of waste generated, population and landfill characteristics were collected. Then, Sanandaj (study area) population was estimated for different years of the study period with respect to selective growth coefficient. In the last phase, constant value of methane emission and methane production potential in Sanandaj landfill were specified using LANDGEM software. As a result, potential capacity for producing methane in Sanandaj landfill was estimated as 170 $m^3 t^{-1}$ and the amount of output methane during 2018, 2023, 2028 and 2033 is supposed to be 205, 410, 549 and 671 $m^3 h^{-1}$, respectively. Indeed, production speed continues with a lower gradient from 2033 onward. Therefore, the results of current research can be used in designing and measuring the capacity of methane extraction systems from this landfill and in evaluation of Iran's contribution in global emission of greenhouse gases.

Key words: Carbon dioxide, gases, Iran, methane, refuse disposal, LANDGEM software

INTRODUCTION

Increasing growth of population and urbanization and subsequent development of industrial units have led to greater production of wastes and pollutants. The main environmental contaminants are Municipal Solid Wastes (MSW), million tons of which are daily produced worldwide. Regarding the economic and technological restrictions, it is not feasible to recycle all wastes and landfilling is the most common practice as a general solution all around the world to remove municipal wastes. One of the most critical issues to be considered in designing, implementation and exploitation of a sanitary-engineering landfill is decomposition of wastes and production of gases in landfills (Tchobanoglous *et al*., 1993).

Measurement of the emission rate of Green House Gases (GHGs) from landfill is essential to reduce uncertainties in the inventory estimates from this source. For example, methane emission from disposal site is considered as a chemical feedback effect to environment by significant GHGs, which, its control is a necessity. Increasing the concentration of methane has reduced the concentration of hydroxyl radicals ($^{\bullet}OH$) and increased the methane lifetime and the tropospheric ozone (Gardner *et al*., 1993).

Today, in the developed countries, landfills are being designed so that the maximum extractable energy is exploited to generate electricity and transfer the collected methane through pipelines to generators and turbines. However, developing countries such as China, Uruguay, Mexico, etc., are extracting gases from their landfills (Ebrahimi *et al*., 2006). Landfill gas (LFG) is obtained from a series of biochemical reactions, under aerobic and anaerobic conditions, on decomposable organic material existing in the wastes (Zamorano *et al*., 2007). This gas includes methane, carbon dioxide, hydrogen, volatile organic compounds, etc. (Kamalan *et al*., 2011), the main part of which contains methane (50-60% of volume) and carbon dioxide (30-40% of volume) (Chiriac *et al*., 2007). Methane is one of the most significant GHGs with the largest potential contribution in global warming (potential of 25-30 times more than carbon dioxide) and quantitatively, with a share of 18% is ranked as the second prevalent GHG (IPCC., 2007). One of the main sources of methane emission is landfill. Anaerobic degradation of wastes with the help of microorganisms in landfills leads to emission of methane and CO_2 in larger amounts and gases such as NO_x and H_2S in considerably less amounts (ATSDR., 1998; SWANA., 1997). Methane has a very high thermal value (heating value of a cubic meter of methane is nearly equivalent to that of a liter of kerosene) (Aydi, 2012), which makes it economically significant and valuable. In addition, in cases of failure to collect this gas and its entrance into the space in amounts of 5-15% of air volume, it explodes and causes damages (IPCC., 2007).

Modeling and predicting methane production and emission in landfills is very important in designing and exploiting such places. Indeed, measuring the amount of methane emissions from landfills can help to determine Iran's contribution in global emission of GHGs. There are different methods for assessing methane emissions including site assessment, field-testing and mathematical modeling. In a study conducted by Kavoussi *et al*. (2011), the results demonstrated that in 2016, 2021 and 2031, the gas production rate would be 140, 325 and 438 $m^3 h^{-1}$ and gas production will continue from 2026 with a slighter gradient. According to the latest research works, gas emission rate per ton of MSW is in the wide range of 120-300 m^3 (Bove and Lunghi, 2006). Every cubic meter of landfill gas emissions is capable of generating 5.9 kw h^{-1} energy, which is equivalent to 66% of energy obtained from the same amount of natural gas. After recycling and modification of properties, LFGs can be directly used in industry and to supply energy for gas turbines and electricity generators (Kavoussi *et al*., 2011). Several mathematical models have been developed among which, LANDGEM model is the most flexible one (Bove and Lunghi, 2006). United State Environmental Protection Agency (USEPA) developed this model; it presents a very precise estimation of methane amount produced over several years. This model is considered as an automatic estimation tool for modeling landfill gas emissions from MSW. This package uses a first order equation for modeling LFG. Using LANDGEM model in Central American areas, EPA estimated potential capacity of methane emission for different areas between 78-101 $m^3 mg^{-1}$ in 2006 (USEPA., 2012). Several authors have reported modeling approaches that focus on the biological and/or chemical degradation of waste that generates gas pollutants. Among these integrated models, LANDGEM modeling software developed for the environmental assessment of municipal solid waste landfills. The LANDGEM estimates the volume and composition of the generated gas throughout time because of the degradation of organic matter in the landfill (USEPA., 2012).

There are several methods for estimating the emissions from landfill sites such as site evaluation, field-testing and mathematical modeling (Chiemchaisri and Visvanathan, 2008; Di Bella *et al.*, 2011). In this study, mathematical modeling was applied for LFG emission from the Sanandaj landfill site. The LFG modeling is a forecasting model for gas production in the landfill site, which is based on the data of waste disposal in past and future. Such model will reveal the efficiency of the waste collection system. In addition, the model is an important step in developing a landfill project, which makes it possible to estimate the available recoverable amount of CH_4 as fuel energy over time (Scharff and Jacobs, 2006).

Sanandaj City, west of Iran, has a landfill receiving more than 300 t of waste every day. There is no facility provided for methane recovery at this place. Hence, this study aims at estimating capacity of methane extraction from Sanandaj landfill using LANDGEM software package.

MATERIALS AND METHODS

Study area: Sanadaj landfill with an area of about 35 ha dates back to 20 years ago and is located at a distance of 12 km from Sanandaj-Kamyaran road in a place called Kilak (adopted from a seasonal river named Kilak), where the wastes are weekly being buried under a layer of soil using Ravine method. A general schematic of the site and its location are presented in Fig. 1.

This is a descriptive-cross sectional study in which a mathematical software was used to estimate the methane rate generated at Sanandaj landfill. For this purpose, first the information concerning Sanandaj landfill was collected and the population over different years of study was

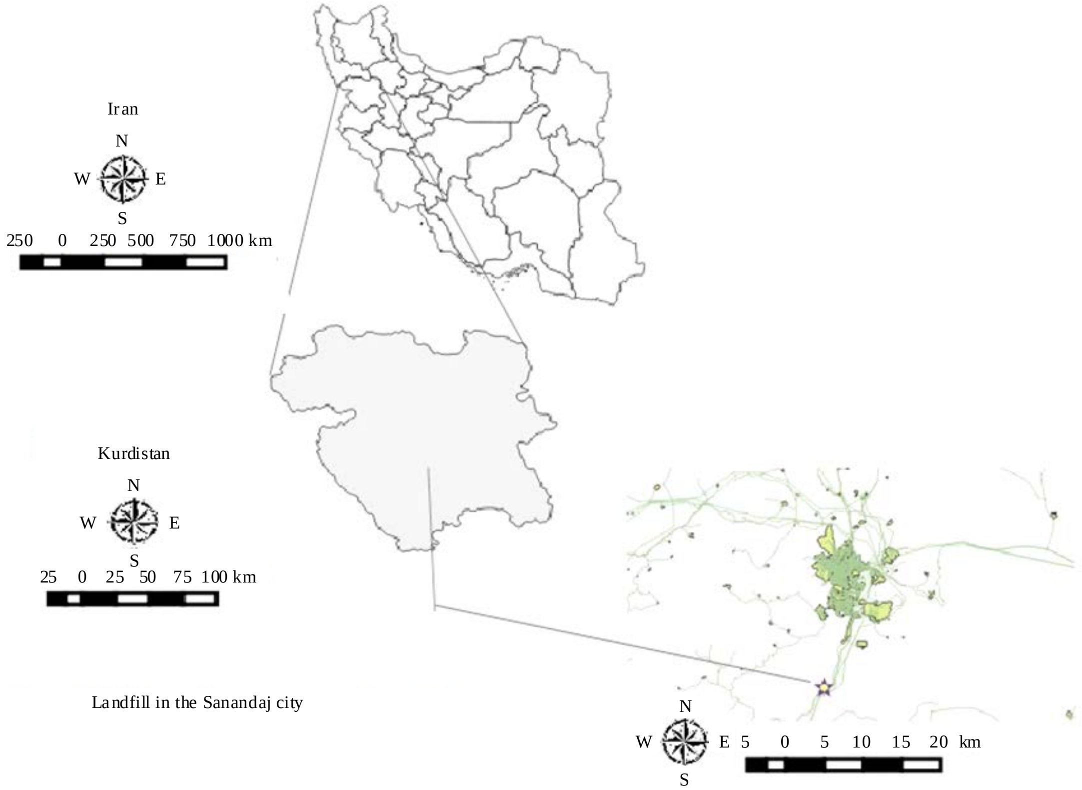

Fig. 1: Location of Sanandaj landfill

calculated based on selective growth coefficient and by considering effective factors on growth rate. Then, the constant value of methane emission and potential of methane production at Sanandaj landfill was obtained using the data collected about the site including groundwater level, soil type, landfill handling, precipitation and the coverage soil. Next, the input data was inserted into LANDGEM software and the amount of methane emissions was calculated over different years of study.

LANDGEM data analysis: The LANDGEM uses first-order decomposition equation to evaluate annual gas emissions in landfills. The respective formula is presented in Eq. 1:

$$QCH_4 = \sum_{i=1}^{n} \sum_{i=0}^{1} KL0 \left(\frac{Mi}{10} \right) e^{-Ktij} \tag{1}$$

Where:

QCH_4 = Estimated methane generation flow rate (in cubic meters per year)
i = 1 year time increment
n = Year of the calculation-initial year of waste acceptance
j = 0.1 year time increment
k = Methane generation rate ($year^{-1}$)
Lo = Potential methane generation capacity (m^3 mg^{-1})
M_i = Mass of solid waste disposed in the ith year (mg)
t_{ij} = Age of the jth section of waste mass disposed in the ith year (decimal years e.g., 3.2 years)

In order to calculate methane emissions, two parameters k (methane production rate constant) and L_0 (potential methane production capacity) were used. Parameter K is a function of waste composition, nutrients ability to produce methane, its pH and temperature, the value of which changes between 0.003-0.21. In order to calculate the amount of organic carbon resulting from biological decomposition of the wastes, Eq. 2 is used:

$$(Ocb)_i = (Oci) \times (fb) \times i \times (1-ui) \times Pi \tag{2}$$

Where:

$(Ocb)_i$ = Amount of biologically decomposable organic carbon and the ith components of wet waste
$(fb)_i$ = Biologically decomposable component of Oci, kg total carbon/kg decomposable carbon
U_i = Amount of humidity in ith component of the waste, kg ith component of wet waste/kg water and
p_i = Wet weight of ith component of the waste, kg total weight of waste/kg weight of ith component

When calculating decomposable carbon of wastes in landfill, it should be considered that this value depends on the landfill temperature (Ebrahimi *et al*., 2006). This is stated in the form of Eq. 3, where, T is the temperature of landfill in Celsius:

$$(Ocb)i = oci \times 0.014T + 0.28 \tag{3}$$

Table 1: Calculated YLFG based on the components of waste in Sanandaj

Materials	Ui (kg H_2O/kg)	Oci (kg C/kg)	(Fb)I (Kg biodeg. C/kg)	P_i (%)	Yi (Lit gas/kg MSW)	YLFG
Putrescible	0.60	0.48	0.8	71.50	700.0	143.53
Paper and cardboard	0.08	0.44	0.5	9.29	250.0	8.78
Rubber and plastic	0.02	0.70	0.0	11.43	0.0	0.00
Textiles	0.10	0.55	0.2	2.10	150.0	0.58
Glass	0.03	0.00	0.0	2.52	0.0	0.00
Metals	0.03	0.00	0.0	3.43	0.0	0.00

152.89 m^3 mg^{-1} = 168 ton YLFG = 1.867(Oci) (fb) i (1-Ui) PiYi

In addition, estimating biologically decomposable organic carbon, it should be kept in mind that a small amount of such materials is removed from landfill by leachate (particularly in the acidic phase in which latex production is high). Therefore, the output carbon should be subtracted from initial decomposable organic carbon. On the other hand, for each mole of consumed organic carbon, a mole of gas is generated. One mole of gas, at standard temperature and pressure conditions, occupies 22.4 L of volume. As a result, one mole of organic carbon produces 22.4 L gas, the weight (w/w%) of which is stated as follows:

$$CH_4+CO_2 \text{ L gas} = 1 \text{ g of organic carbon (at standard pressure and temperature)} \quad (4)$$

Combining Eq. 3 and 4 gives Eq. 5 to calculate yielded gases of landfills:

$$\text{YLFG} = 1.867(\text{Oci})\times(\text{fb})\times i\times(1\text{-ui})\times \text{Pi}\times(\text{lit gas/kg MSW}) \quad (5)$$

where, YLFG indicates the yielded gases. Gas production time is the same of gas production period in landfills. All the above parameters for different components of wastes and calculation method for yielded gas in landfill are given in Table 1.

RESULTS AND DISCUSSION

According to public census in 2011, population growth rate in Sanandaj is 1.77%. Based on waste management plan in Sanadaj, the period of the selected plan for Sanandaj landfill is 20 years. In order to calculate methane emissions amount via LANDGEM program, the weight of wastes generated over different years of plan period must be suitably evaluated. According to estimations of Pitchel (2014), per capita waste generation rate in developing countries over a 20 years horizon is annually 2-5% depending on the population of the city and this rate is assumed 2% for cities with population smaller than 500,000. Table 2 presents the population, per capita waste generation and total weight of wastes disposed of in Sanandaj City during the plan period.

The mean percentages of dry and volatile decomposable organic wastes in Sanandaj were 31.5 and 68.5, respectively. Waste density was calculated to be 449.99 kg m^{-3}. According to the climatological data, the mean annual precipitation in Sanandaj is 282 mm. Moreover, this area has annual humidity of 50% and some farms irrigated by groundwater are located downward the landfill. From geological aspect and soil granulation, the soil in the study area is mainly schist and clay with strong swelling property and the layer underlying the soil is impermeable. The area groundwater level is about 15 m and natural conditions of the area have prevented from formation of stone or alluvial aquifer. For this reason, no water source or spring is seen in this basin. Meanwhile, a 1500 m access road 12 m in width has been formed inside the landfill. Based on field-testing, Oleckno index calculated for the site was 28, which is 24-42, indicating suitability of the selected site (Salimi *et al*., 2013) (Table 3).

Weighted value of the wastes generated over several years of study plan could be inserted. As well, there is a column called collection system efficiency related to those landfills with an active gas collection system. As such a system does not exist in Sanandaj landfill, its amount for several years is assumed zero. Table 5 shows the results of evaluation of methane emissions values during several years of study plan in Sanandaj landfill.

Table 2: Population, per capita waste generation and total weight of the waste generated in Sanandaj city during the years of the study plan

Year	Population (g)	Per capita waste generation	Annual weight of waste (t)	Year	Population (g)	Per capita waste generation	Annual weight of waste (t)
2014	395563	781.17	112785.00	2024	471425	880.88	151573.55
2015	402564	790.60	116168.55	2025	479770	891.53	156121.45
2016	409689	800.17	119654.30	2026	488262	902.30	160804.40
2017	416941	809.84	123243.345	2027	496904	913.20	165628.605
2018	424321	819.62	126940.43	2028	505699	924.25	170597.35
2019	431831	829.53	130748.84	2029	514650	935.42	175715.38
2020	439475	839.56	134671.13	2030	523759	946.73	180987.075
2021	447253	849.70	138711.315	2031	533029	958.17	186416.45
2022	455170	859.97	142872.68	2032	542464	969.75	192008.98
2023	463226	870.37	147158.875	2033	552066	981.47	197769.41

Table 3: Description of the supplementary input data to run the LANDGEM (Part I)

LMOP central America biogas model V. 2 July, 2007
Projection of biogas generation and recovery
Sanandaj landfill-Iran

Country	Iran
Site-specific waste composition data?	Yes
Year opened	2014
Estimated growth in annual disposal	3.0%
Average annual precipitation	282
Average landfill depth	15.0
Site design and management practices	2
Methane content of landfill biogas adjusted to	50%
Methane Correction Factor (MCF)	1.0
Fast-decay organic waste methane generation rate (k)	0.18
Slow-decay organic waste methane generation rate (k)	0.020
Potential methane generation capacity (L_0)	170.0
Fast-decay organic waste L_0	68.5
Slow-decay organic waste L_0	31.5

Table 4: Input data page to the LANDGEM program for Sanandaj (Part II)

Year	Metric tonnes disposed	Cumulative metric tonnes	Collection system efficiency (%)
2014	47,523	47,523	0
2015	48,943	94,466	0
2016	50,410	144,876	0
2017	51,921	196,797	0
2018	53,480	250,277	0
2019	55,086	305,363	0
2020	56,736	362,098	0
2021	58,439	420,538	0
2022	60,192	480,730	0
2023	61,999	542,729	0
2024	63,860	606,589	0
2025	65,777	672,366	0
2026	67,747	740,113	0
2027	69,779	809,892	0
2028	71,873	881,765	0
2029	74,029	955,794	0
2030	76,250	1,032,044	0
2031	78,537	1,110,581	0
2032	80,895	1,191,476	0
2033	83,322	1,274,798	0

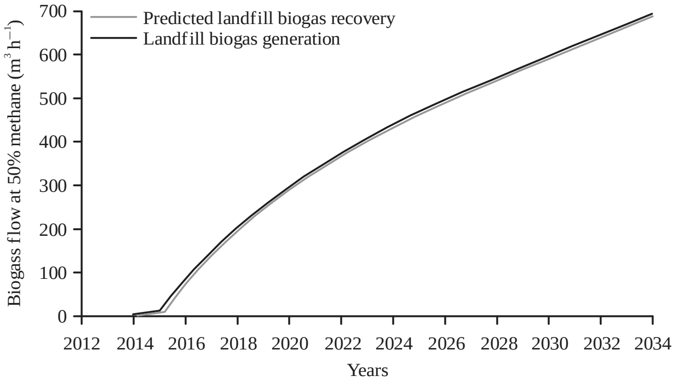

Fig. 2: Amount of gas emission from Sanandaj landfill from 2012-2033 (m^3 h^{-1})

Table 5: Estimation of methane gas production in different years of the plan period for Sanandaj landfill

			LFG generation		
Year	Disposal rate (mg yard^{-1})	Refuse in-place (mg)	m^3 h^{-1}	m^3	mm Btu h^{-1}
2014	47,523	47,523	0	0	0.0
2015	48,943	96,466	10	6	0.2
2016	50,410	146,876	84	49	1.5
2017	51,921	198,797	149	88	2.7
2018	53,480	252,277	205	121	3.7
2019	55,086	307,363	255	150	4.6
2020	56,736	364,098	300	176	5.4
2021	58,439	422,538	340	200	6.1
2022	60,192	482,730	376	221	6.7
2023	61,999	544,729	410	241	7.3
2024	63,860	608,589	441	259	7.9
2025	65,777	674,366	470	276	8.4
2026	67,747	742,113	497	293	8.9
2027	69,779	811,892	524	308	9.4
2028	71,873	883,765	549	323	9.8
2029	74,029	957,794	574	338	10.3
2030	76,250	1,034,044	598	352	10.7
2031	78,537	1,112,581	623	366	11.1
2032	80,895	1,193,476	647	381	11.6
2033	83,322	1,276,798	671	395	12.0

Figure 2 indicates that in 2018, 2023, 2028 and 2033, the gas production rate is estimated to be 205, 410, 549 and 671 m^3 h^{-1}, respectively. Production speed will continue with a slighter gradient from 2033 onwards. The results of current study indicated that the amount of methane production in Sanandaj landfill with 47523-83322.2 t of wastes will vary between 10-671 m^3 h^{-1}. However, studies conducted in rich metropolitans show that total peak of annual methane production from Oblogo No. 1 and Mallam No. 1 dumpsites (in Ghana) is estimated more than 17000 t (Keelson, 2013). In another study in Malaysia, the amount of methane production calculated in the beginning of the plan was 4.436E^{+02} mg/year. After reception of buried wastes, the maximum methane production about 4.17E^{+03} occurred during 2012-2015 (Kalantarifard and Yang, 2012). In El Salvador, the amount of methane production in its landfill with annual wastes between 175000-262000 t varied between 380-3680 m^3. The amount of methane production calculated for El Salvador was larger than that for Sanandaj because precipitation and humidity in the waste and consequently potential production of methane was higher in El Salvador. In addition, increasing humidity in the wastes in El Salvador leads to a larger gradient of methane production curve over several years. Gas collection efficiency in this study was considered 0% because active gas collection systems in burying phase were not considered (Boland, 2001). This value was assumed 0% in studies conducted in El Salvador, Mexico, Belize, Costa Rica, Guatemala and Honduras indicating lack of active gas collection systems in their landfills (Anderson, 1998). Potential capacity of methane production for Sanandaj landfill obtained 170 m^3 t^{-1}, while this amount in El Salvador was 91 m^3 t^{-1}. United Nations Development Program (UNDP) has proposed per capita waste for citizens of developing countries between 500-900 g day^{-1} (USEPA., 2012). In current study, per capita waste production for Sanandaj residents obtained 782 g, which is consistent with the proposed values.

CONCLUSION

The present study deals with estimation of methane extraction from Sanandaj Landfill using LANDGEM software. This research suggests that the amount of methane calculated in landfill can be considered in energy generation programs and other applications of LFGs and determine Iran's contribution in global emission of greenhouse gases arising from the wastes. In addition, a methane collection system could be designed and implemented for landfills based on the calculated amount of methane to prevent from its collection, probable explosion and leakage in landfills. Such plans could help decision makers and authorities to have eco-friendly policies for having healthy cities and environment.

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