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CASE STUDY

Estimation of landfill gas generation in a municipal solid waste disposal site by LandGEM mathematical model

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ABSTRACT: Anaerobic decomposition of organic compounds in landfills is responsible for generation of greenhouse gases. The present study aimed to determine the total gas and methane emission from a landfill located in Hamedan (west of Iran) from 2011 to 2030. LandGEM 3.02 model was used to estimate the gas emission with the volumetric methane percent of 60%, production potential of 107, and methane generation rate of 0.2. Spatial distribution of annual methane and total landfill gas emission rate in the study area at three decades were provided through ArcGIS software. The results showed that organic and food wastes had the maximum amounts in the solid waste stream (over 75%). The results showed that 4.371×10^8 m^3 methane would be produced after 20 years, mostly ($4.053\times10^6 m^3$) in the first year. In addition, methane production capacity in Hamedan landfill site was 107 m^3/Mg. According to the results, the maximum and minimum gas generation rates are in summer (the hottest season) and winter (the coldest season) respectively. The results of the LandGEM model represented that the total gas and methane generation rates will be significant in the first 10 years. The potential of rapidly degradable organic compounds for gas emission will be higher than that of slowly degradable organic compounds. The results obtained in the present study can be beneficially used in planning for energy production and other applications in landfill sites.

KEYWORDS: *Greenhouse gases; Landfill; Methane emission; Municipal solid waste. Waste management.*

INTRODUCTION

Development of technology and population growth lead to significant generation of solid waste. Most of the solid wastes dispose to the landfill sites. Landfill gases (LFGs) result from anaerobic degradation of solid wastes (Roodbari *et al.,* 2012; Ahmadian *et al.,* 2013; Jain *et al.,* 2014). Emission of these gases has a negative effect on the environment in various ways such as increased floods and droughts, acidification and eutrophication, large rainfall variability, increasing the amount of heat trapped, higher ambient carbon dioxide concentration, changes in floristic zones and warmer temperatures. In fact, emission of these gases could increase the risk of fire, endanger the human health (related to the climate change such as cardiovascular mortality, stress, respiratory disease, infectious disease and malnutrition linked to the crop production, failure, allergens and irritants), demolish the vegetation mass around the landfill, pollute the groundwater resources, globally affect the climate changes and produce unfavorable odors (Saleem 2014; Asgari *et al.,* 2017). Landfills have been considered as a major source of methane emission. 18% of the

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global anthropogenic methane emitted is attributed to the waste fraction. Methane is the major contributor in LFGs and its global warming potential is 28 times greater than CO_2. Methane is quantitatively ranked as the second gas of greenhouse gasses (18%) (Fourie and Morris 2004; Bruce *et al.,* 2017). Also, methane can cause explosion if reaches 5-15% of air volume. Heat value of methane is equal to one liter of white oil which is considerably high. Therefore, methane could be considered as a cost-effective option for electricity and/or heat generation (Thompson *et al.,* 2008; Weber and Stadlbauer, 2017). The major greenhouse gases include carbon dioxide, methane, nitrous oxide, water vapor, chlorofluorocarbon gases and ozone. Greenhouse gas (GHG) emission is usually depending on the organic fraction of solid waste and various types of organic wastes have a different degradable organic carbons (DOCs). Emission rate depends on waste composition, waste compaction, rate of the degradable organic fraction, leachate recirculation and environmental factors (Lou and Nair, 2009 ; Wangyao *et al.,* 2010b). Landfills are considered as a none-point source of pollution for methane emissions. Thus, methane emission has a spatial variability and measurement of this gas is not easy. Determining the amount of methane emission from landfills is essential to achieve the purpose of reducing GHGs emissions from none-source and source points. Some studies have assessed the rate of methane emission from landfills (Wangyao *et al.,* 2010a; Kritjaroen, 2011; Kalantarifard *et al.,* 2013; Chalvatzaki *et al.,* 2015). However, no study has been done to determine methane emission rate, total greenhouse gasses, and emission per capita for each gas from landfill sites in Iran. Estimation of methane emissions needed for national greenhouse gas inventories has been done based on waste quantity and composition (Kumar *et al.,* 2004; Krause *et al.,* 2016). Previous studies have shown that the greenhouse gases generated from 1-ton waste are 40-250 m^3 (Lou and Nair, 2009). Many mathematical models have been improved to determine the LFGs based on the various order (zero, first or second order) approaches in the recent years. A number of models have been developed to estimate the landfill gas emission from municipal solid waste disposal sites. These models include Vertical Radial Plume Mapping Optical Remote Sensing (VRPM ORS), Horizontal Radial Plume Mapping Optical Remote Sensing (HRPM ORS), tracer gases, inverse modeling, differential absorption light detection and ranging (LiDAR), LandGEM (US-EPA), Mimicrometeorological eddy covariance (EC) and flux chambers. However, these methods have some disadvantages such as lack of all emissions, small footprint, irregular topography, complexity, uncertainty in source area and high cost. LandGEM is the most conventional model used for LFG emission due to its simplicity and insensitivity to atmospheric instability (Amini *et al.,* 2013). LandGEM model is a first-order decomposition model (as a simple, relatively good data fit model) developed by the US. Environmental Protection Agency. This model has been specifically developed for determining the methane generation for inventory as well as compliance purposes. Therefore, the present study was to determine methane emission rate, total LFG, and emission per capita of the gasses from a landfill site located in Hamedan, Iran. LANDGEM model was employed to determine the emission rate. The present study was conducted to determine the emission rate of gasses in the coldest and hottest seasons in Iran in 2011, the potential rate and emission per capita of methane, total LFG, the potential rate of gas emission from organic compounds over 20 years (from 2011 to 2030), and the emission rates in two decades (2001-2011 and 2011-2031) by Arc-GIS software. This study has been carried out in Hamedan, Iran in 2011.

MATERIALS AND METHODS

Study area

The study was conducted on a landfill located in Hamedan, Iran. The solid wastes collected from five cities (Hamedan, Marianaj, Joraghan, Bahar, and Lalejin) were disposed in this landfill. Some information about landfill area such as groundwater level, annual precipitation rate, type of landfilling method, solid waste production per capita, and solid waste weight were collected to conduct the study. Also, the quantity and quality analyses of solid waste were obtained from The Ministry of Interior Affairs. In addition, the population in the above-mentioned cities was calculated by considering the selective growth factor and the factors influencing the population growth rate.

Description of Hamedan landfill site

The landfill site is located at 23 km to Hamedan. The landfill area is 164 hectares and its height is 1878 m above sea level. The distance between landfill site and main road is 2 km. The soil in this region is mainly of clay and schist rock type (Ghobadi *et al.,* 2013). The location of the study area in Hamedan, Iran is shown in Fig. 1.

Description of the LandGEM model

LandGEM software was introduced by the US Environmental Protection Agency (USEPA). This software is able to automatically model the rate of gas emission from municipal landfill sites. It can also determine about 46 pollutants existing in the landfill area. LandGEM model determines the annual emission rate through a first-order equation. The main parameters which should be provided for the model are k and L_0. Some assumptions or real data were considered to determine these parameters. In the present study, the real data obtained by field studies were employed to calculate the parameters. L_0 is the potential rate of methane generation capacity (m^3/Mg) in Hamedan landfill site. This parameter depends on the type and combination of solid waste dumped at the landfill site. According to IPCC standard defined in 1996, this parameter can be calculated according to Eq. 1 (Atabi *et al.,* 2014):

$$L_0 = MCF \times DOC \times DOCf \times F \times \frac{16}{12} \quad (1)$$

Where, MCF is methane correction factor and it was equal to 1 due to the 9-m depth of trench, and F is the fraction of methane in landfill gas (methane volumetric percentage in landfill gas) (60%). The DOC variable also shows the degradable organic carbon (m^3/Mg). It should be noted that the DOC has a wide range due to the difference in the combination of solid waste in different countries. Therefore, it is better to use the real data. DOC calculation is shown in Table 1 which includes a stoichiometric factor (16/12) too. DOCf is dissimilarity coefficient which depends on the temperature and can be calculated based on Eq. 2:

$$DOCf = 0.14T + 0.28 \quad (2)$$

Where, k coefficient refers to the decay rate which is defined as the biodegradation half-life of organic material in a landfill (1/year). Decay rate depends on the weather and can be determined by various methods. Decay rate can be computed by Eq. 3.

$$k = 3.2 \times 10 - 5(x) + 0.01 \quad (3)$$

Where, x represents an annual average precipitation for a certain period in the landfill area. Higher amount of k means that the methane generation rate at initial time increases faster and then decreases after a period of time. In fact, k depends on the moisture, available nutrients required for microorganisms, pH and temperature (Mehta *et al.,* 2002).

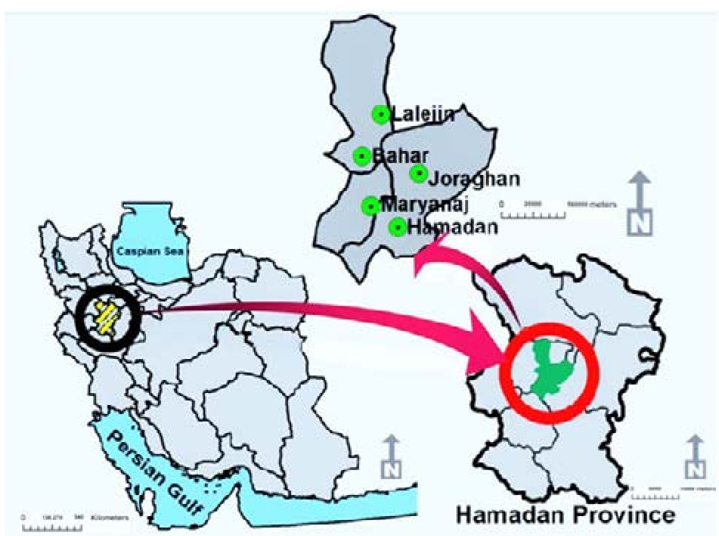


Fig. 1: The geographic location of the study area

GIS analysis

The methane emission rate and total greenhouse gasses in two decades (2011-2021 and 2021-2031) were modeled through Arc-GIS software in order to determine the emission rate. In this study, the rate of greenhouse gasses emission from the landfill site was estimated and the obtained results were displayed using the geographic information system (GIS).

RESULTS AND DISCUSSION

Determining weight of the solid waste

In order to determine the generation rate of methane and total greenhouse gases through LandGEM model, the weight of generated solid waste in a specific time should be carefully specified. Based on the guideline proposed in waste management practices, solid waste generation rate per capita in developing countries should be considered for 20 years. According to this guideline, the annual solid waste generation growth rates are 2% and 5 % (mostly depending on population). According to this rule and considering the cultural, economic and geographical conditions, the annual solid waste generation growth rate in the study area (Hamedan, Bahar, Joreghan, Merianaj, and Lalejin) was considered as 2%. Table 2 shows the rate of solid waste generation per capita within 2011 and 2030.

Composition of the solid waste in the study area

Composition of the solid wastes has a significant effect on the rate of landfill gas production. Table 3 shows the results of solid waste composition in the study area. According to the results, organic and food wastes have the maximum amounts in the solid

Table 1: Data used for DOC calculation

Waste types	Amount (%)	Degradable organic carbon (%) in fresh wastes	DOC
Paper and cardboard	2.25	22	0.005
Textile	2.32	11	0.0025
Wood	1.71	25	0.0042
Food wastes	75.75	38	0.287
Total			0.298

Table 2: Rate of solid wastes generation in the study area during 2011 to 2030

City	Year	Population	Generation per capita per day	Total weight (ton/y)
Hamedan	2011	524445	1.0251	196227.127
	2015	563237	1.1096	228113.237
	2020	615768	1.2251	375355.791
	2025	673238	1.2496	296887.747
	2030	736051	1.4934	401214.775
Bahar	2011	30193	0.853	9400.439
	2015	32554	0.923	10968.279
	2020	35776	1.019	13302.627
	2025	39296	1.126	16150.263
	2030	43173	1.243	19587.374
Lalejin	2011	16256	0.664	3939.804
	2015	17596	0.719	4617.807
	2020	19427	0.789	5594.684
	2025	21449	0.803	5807.970
	2030	23682	0.929	80302.304
Marianaj	2011	10521	0.632	2426.984
	2015	11388	0.658	2628.900
	2020	12574	0.749	3437.542
	2025	13882	0.814	4124.481
	2030	15327	0.879	4917.438
Joraghan	2011	12270	0.639	2861.793
	2015	13438	0.704	3532.429
	2020	15057	0.756	4154.828
	2025	16870	0.821	50553.507
	2030	18901	0.886	6112.394

waste stream (over 75%) and decompose quickly and generate gas. Therefore, solid waste management seems to be essential in this area. The composition of waste could affect the gases produced in the landfill. High amount of organic and food waste could accelerate the gas emission from landfill. In addition, plastic has a significant amount in the solid waste fractions.

Besides, the density of solid wastes in the study area is 268 kg/m^3. The density obtained in other studies in Iran has a good consistency with the density obtained in this study. For example, in a study conducted by Yaghmaeian et al., (2005) the solid waste density was reported as 255 kg/m^3. The difference in the amount of this variable is mainly due to the difference in the amount of precipitation and life style as well as different waste collection systems equipped with compaction and moisture.

Methane generation model

LandGEM as a first-order decomposition rate model was developed to estimate the landfill gas emissions generated during the decomposition of municipal solid waste (MSW). According to the information collected from Hamedan Meteorological Organization, the average temperature in 2011 was 12.21 °C. Also, the average temperatures in the coldest and hottest months of 2011 were 0.25 °C and 26.85 °C, respectively. Considering the above-mentioned conditions, the L_0 value calculated according to Eq.1 was equal to 107 m^3/Mg. Also, according to some calculations, the refractory organic compounds and easily degradable organic compounds were 26 and 62 m^3/Mg, respectively. Therefore, L_0 values in January and July of 2011 were 69 and 149 m^3/Mg, respectively. According to Eq. 3, the amount of k is considered to be 0.2 (1/year). Also, the k values presumed for refractory and easily degradable organic compounds were 0.02 and 0.18 (1/year), respectively. The potential rate of methane generation and total landfill gas emission during 2011 and 2030 in the study area are shown in Fig. 2. The highest amounts of total gas and methane emissions from Hamedan city predicted in 2030 were 6.01×10^7 m^3/year and 3.55×10^7 m^3/year respectively. The results of the LandGEM model as a mathematical model represented that total gas and methane generation rates in the first 10 years of landfilling were significant. The components of solid waste stream were the most important influencing factors on gas emission rate. The results of this study showed that the amount of gas emission was high and using gas collection system for this area is essential. The life style and consumption pattern affecting the component of solid waste were quite different in Iran than in other countries. The results found in the present were in good consistency with the results reported in a study conducted by Gioannis (2009) who investigated the trend of gas emission from municipal solid waste (Gioannis *et al.,* 2009). It should be noted that all gas emissions will have an increasing trend up to 2030 and then gradually decrease. This can be due to the emission rate decrease after the first 20 years as most of the organic fractions of solid waste would degrade during this time.

In addition, the potential rate of gas generation (methane, carbon dioxide, non-methane organic carbon (NMOC) and total gases) during 2011 to 2030 in the study area is illustrated in Fig. 3. It is necessary to mention that Hamedan region will have the highest

Table 3: Composition of solid wastes in the study area

City \ Fraction	Hamedan	Bahar	Joraghan	Marianaj	Lalejin
Organic and food wastes	75.51	75.78	75.81	75.95	75.75
Paper and cardboard	2.31	1.92	2.55	2.32	2.18
Rubber	2.94	3.39	3.19	2.19	3.00
Plastic	5.36	5.32	3.66	4.95	4.99
PET	2.84	2.95	2.37	2.41	2.41
Textile	2.35	2.75	2.29	2.63	1.58
Glass	2.01	2.66	2.23	2.88	2.90
Non-iron metals	2.26	1.27	2.05	1.10	1.03
Iron metals	0.49	0.27	0.19	0.29	0.23
C&D waste	0.96	0.82	0.56	1.56	2.25
Wood	1.94	1.54	1.70	1.38	1.73
Bread	0.18	0.45	0.54	0.87	0.60
Other wastes	1.88	1.58	1.14	1.23	1.37
Density (kg/m^3)	268.65	268.28	268.30	268.18	268.75

potential for generating gas rate per capita compared to other cities in the study area. This can be due to the high population of Hamedan contributing to the higher production of solid waste in this city rather than other cities.

Based on the results, $4.371\times10^8 m^3$ methane would be produced after 20 years, mostly ($4.053\times10^6 m^3$) in the first year. Considering the population growth rate and the solid waste production increase, the great potential of methane generation in the landfill site is highly expected. Furthermore, establishing a gas collection system in the landfill could help to recover energy, generate electricity and/or facilitate the combined heat and power generation (CHP). Gas collection system

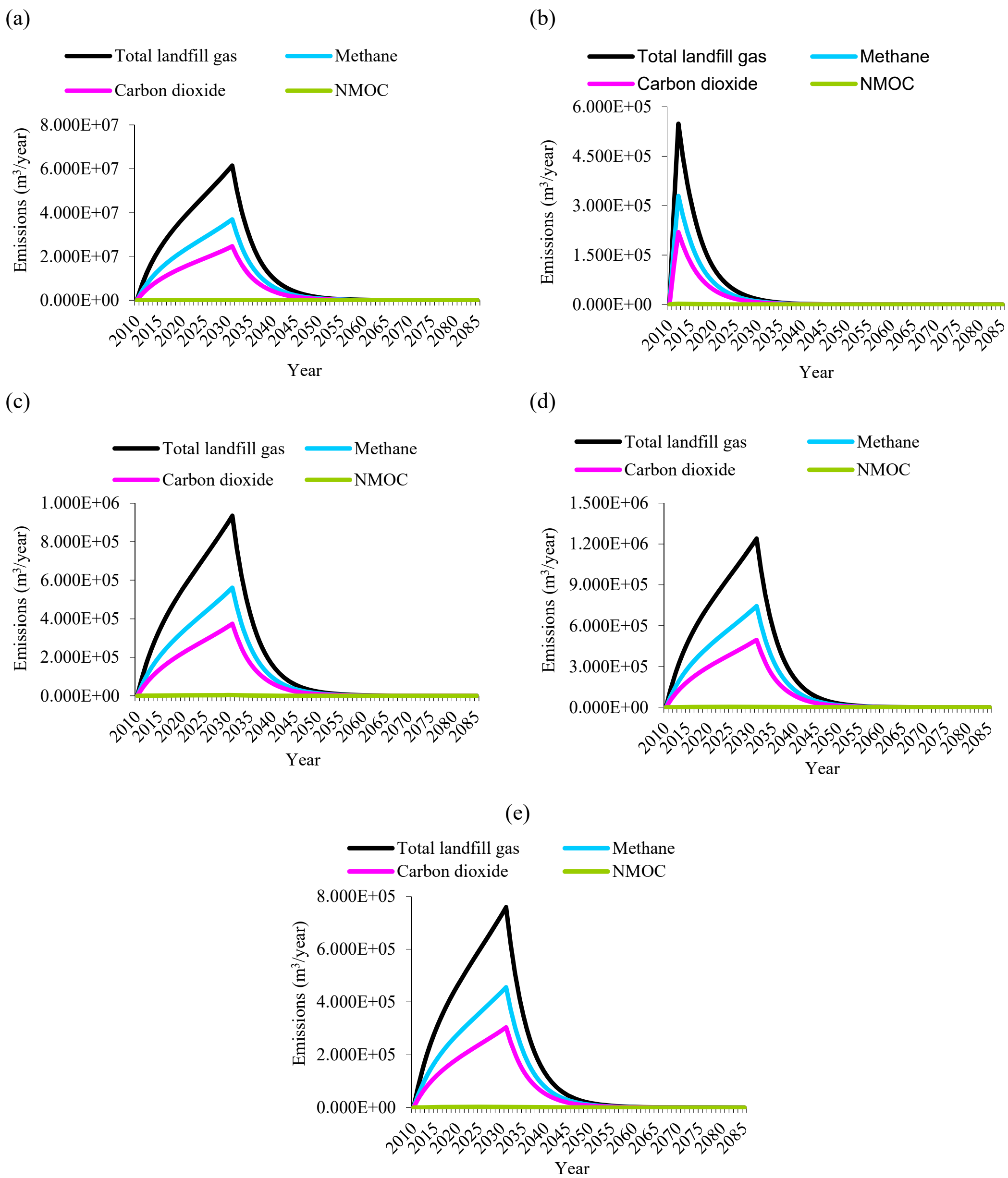


Fig. 2: The amount of gas emission from the study area during 2011 to 2030 (m^3 / year) in (a) Hamedan, (b) Bahar, (c) Joraghan, (d) Marianaj and (e) Lalejin

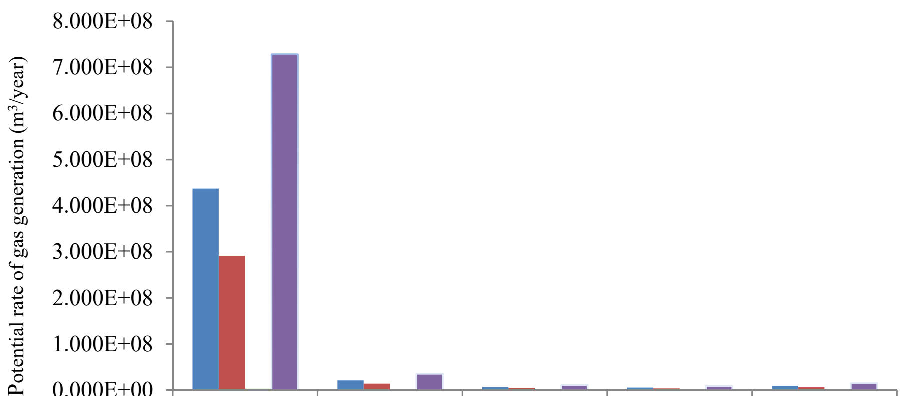
can contribute to significant reduction in carbon dioxide emission and other greenhouse gases (Thompson *et al.,* 2009). Based on the results of LandGEM model, methane emission rate will gradually decline after the first 20 years. This could be mainly due to the change of food to microorganism ratio. In addition, the type of solid waste components - which would decompose - can affect the amount of methane generation. Therefore, the microbial type, population and solid waste components are three important factors which determine the rate of gas emission from landfill sites. Similar results have been found in the previous studies (Wakadikar *et al.,* 2012; Sil *et al.,* 2014). According to the results obtained from the studied landfill, it is suggested to improve landfill management, set up gas and leachate collection systems, take post care actions for the landfills which are closed and use appropriate intermediate and final cover materials (impermeable covers) which capture greater amounts of methane. It should be mentioned that all gas emissions will gradually increase up to 2030 and then decrease. This can be due to decrease of food to microorganism ratio after 2030.

Modeling for rapidly and slowly degradable organic compounds

In general, the organic fraction of MSW can be divided into rapidly degradable compounds (decompose at 3 months to 5 years) and slowly degradable compounds (decompose at up to 50 years or more). The rapidly degradable compounds include putrescible (food waste), fines, sewage sludge, newspaper, cardboard, a portion of the garden wastes and incinerator ash. The slowly degradable compounds consist of rubber, leather, textiles and the woody portions of garden wastes. Figs. 4 and 5 show the results from modelling of gas emission rate in rapidly and slowly degradable organic compounds in the current study.

The potential of greenhouse gas emissions (m^3/year) from rapidly and slowly degradable organic wastes during 2011-2030 in the study area are shown in Table 4. Based on the results, the potential of rapidly degradable organic compounds for generating gas emission was predicted to be higher than that of slowly degradable organic compounds. These results were in agreement with the results reported in other studies (Amini *et al.,* 2013). According to the results of this study, maximum amount of gas emission will occur in the first 20 years. This finding is very important for landfill management and gas collection. Therefore, gas collection should be carried out for many years in the study area.

NMOCs which produces some odorous, volatile organic compounds and harmful components will be



	Hamedan	bahar	joraghan	maryanaj	lalejin
CH4	4.371E+08	2.115E+07	6.561E+06	5.442E+06	8.854E+06
CO2	2.914E+08	1.410E+07	4.374E+06	3.628E+06	5.903E+06
NMOC	2.914E+06	1.410E+05	4.374E+04	3.628E+04	5.903E+04
total	7.284E+08	3.526E+07	1.093E+07	9.070E+06	1.476E+07

studied area

Fig. 3: Potential rate of gas generation (methane, carbon dioxide, non-methane organic carbon (NMOC) and total gases) during 2011 to 2030 in the study area

less than 2% of total gas emission rate. NMOC, even in low concentration, may have some adverse effects on the human health and environment, especially for the people living in the vicinity of the landfill. NMOCs can pose some environmental problems such as oxidant formation (ozone) and photochemical smog. Thus, collection of the generated gas from the landfill should be done to prevent the toxic gas from entering the atmosphere (Chalvatzaki and Lazaridis, 2010). It should be noted that proper estimation of the variables can pave the way to reach the best approaches. This study cam be helpful in estimating and predicting the activities and gas production in the future studies.

The effects of temperature on the gas emission rate

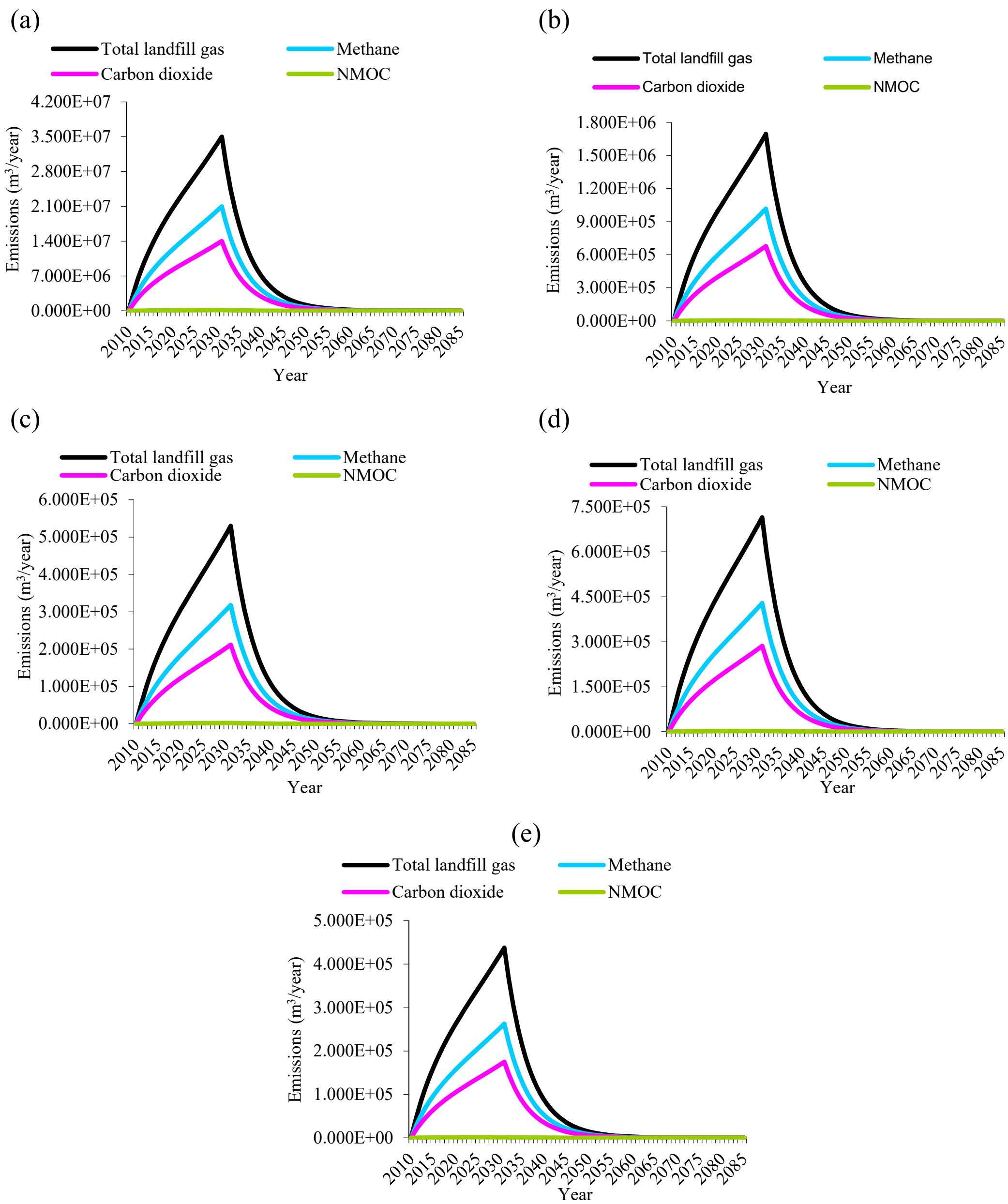


Fig. 4: Potential of gas emission from rapidly degradable organic compounds in (a) Hamedan, (b) Bahar, (c) Joraghan, (d) Lalejin and (e) Marianaj

were also evaluated. For this purpose, the gas emission was modeled in various seasons (Fig. 6). The increase of gas production rate is directly correlated with temperature. According to the results, summer (the hottest season) will have the maximum gas generation and winter (the coldest season) will have the minimum gas generation. This phenomenon would be due to the effect of temperature on microorganism activity. Maximum gas generation will take place in the highest temperature. Similar results have been reported in other studies. It should be mentioned that high amount of moisture in the solid waste may increase the gas generation rate (Moreira and Candiani, 2016). Due to the fact that the major part of gas generation is

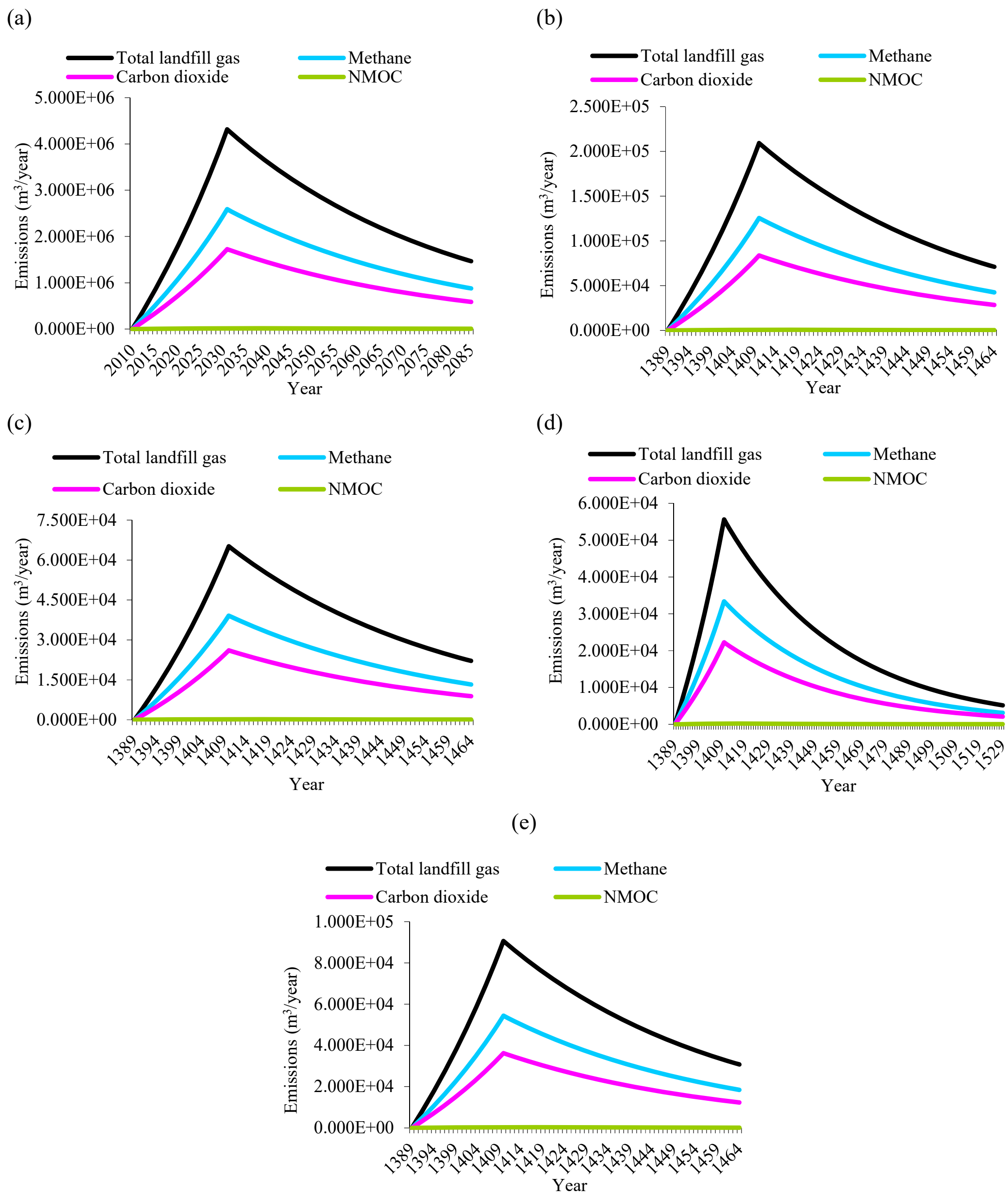


Fig. 5: Potential of gas emission from slowly degradable organic compounds in (a) Hamedan, (b) Bahar, (c) Joraghan, (d) Marianaj and (e) Lalejin

attributed to the biodegradable compounds in solid waste, separation of organic compounds at source should be considered as a useful approach towards reducing the rate of gas emission from landfill sites. According to the previous studies, temperature values in deep landfill and moderate water flux can reach 45 ºC. In addition, landfill temperature is predicted to stay above 30 ºC even if the ambient air is decreased to 0 ºC (Gioannis *et al.,* 2009).

GIS modeling

In this study, methane emission rate and total greenhouse gasses were modeled using Arc-GIS software in to evaluate the distribution of emission rate in two decades (2011-2021, and 2021-2031). The results of GIS images are shown in Figs. 7, 8 and 9.

Gas collection efficiency was considered to be zero in the present study due to lack of gas collection system in the studied landfill site. Methane production capacity in Hamedan landfill site is predicted to be 107 m^3/Mg. It is noteworthy that gas emission rate could be different in each country and city. In fact, the emission rate depends on the solid waste constitutes and is directly correlated with cellulosic compounds. Gas generation rate reported in other studies and places are found to be different due to leachate recirculation, moisture content, gas collection system conditions, covers, type of the landfilling and etc. Considering the fact that methane and carbon dioxide are the most dangerous gasses included in total greenhouse gasses, releasing these gases into the atmosphere should be prevented. Even

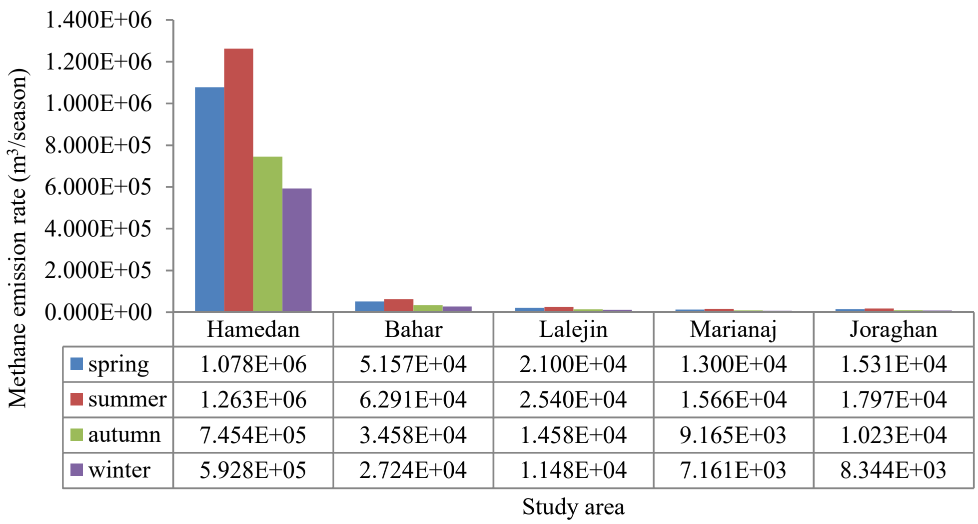


Fig. 6: Methane emission rate at different seasons in the study area

Table 4: Potential of greenhouse gas emission (m^3/y) from rapidly and slowly degradable organic wastes in the study area during 2011-2030

Area	Methane generation	Carbon dioxide generation	NMOC	Other gases
	Rapidly degradable compounds			
Hamedan	2.446E+08	1.631E+08	1.631E+06	4.077E+08
Bahar	1.180E+07	7.868E+06	7.868E+04	1.967E+07
Joraghan	3.660E+06	2.440E+06	2.440E+04	6.100E+06
Maryanaj	3.086E+06	2.057E+06	2.057E+04	5.143E+06
Lalejin	5.020E+06	3.347E+06	3.347E+04	8.367E+06
	Slowly degradable compounds			
Hamedan	2.353E+07	1.569E+07	1.569E+05	3.922E+07
Bahar	1.138E+06	7.588E+05	7.588E+03	1.897E+06
Joraghan	3.520E+05	2.346E+05	2.346E+03	5.866E+05
Maryanaj	3.044E+05	2.030E+05	2.030E+03	5.074E+05
Lalejin	4.951E+05	3.300E+05	3.300E+03	8.251E+05

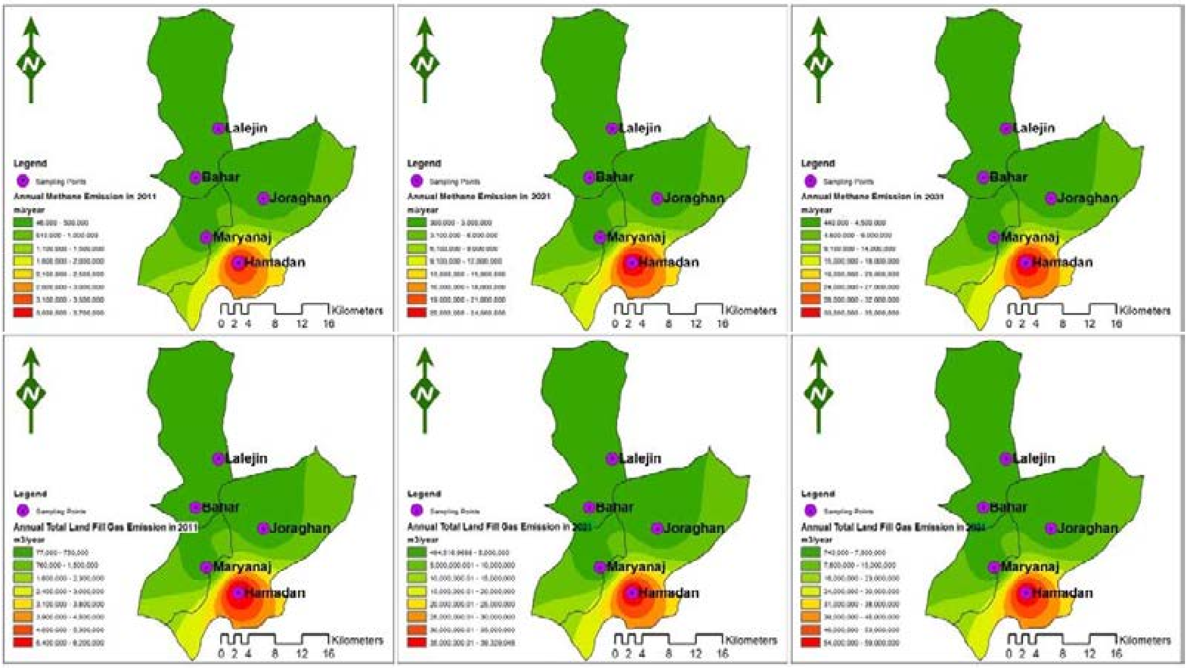


Fig. 7: Spatial distribution of annual methane and total landfill gas emission in two decades (2011-2021 and 2021-2031) in the studied area

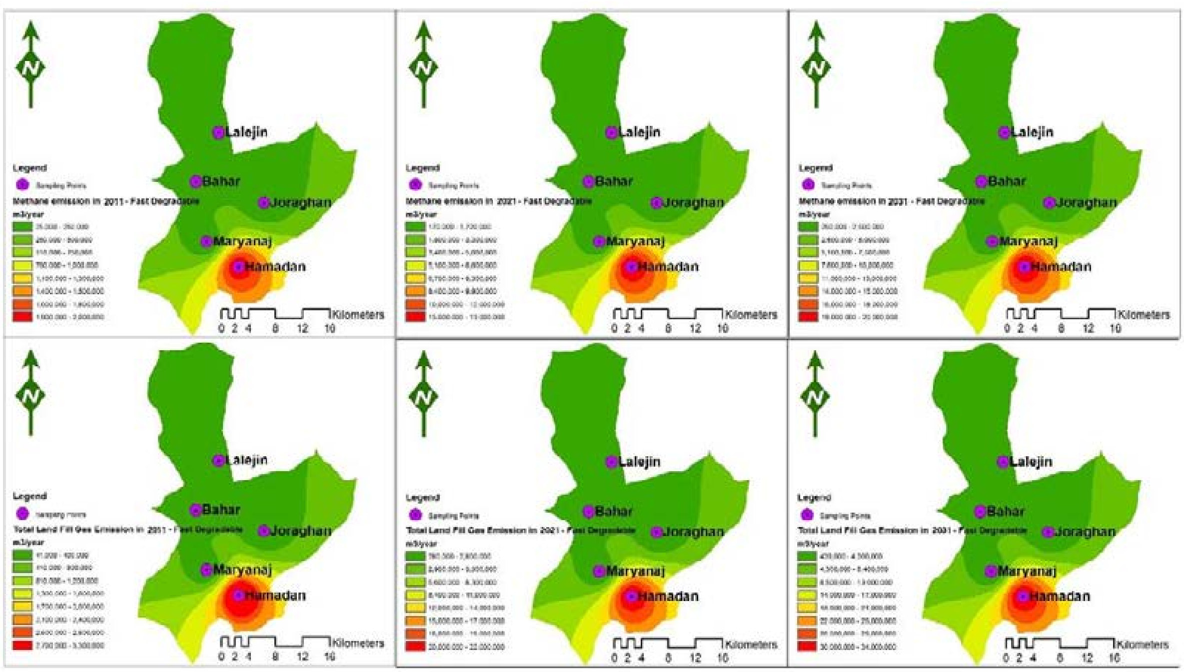


Fig. 8: Spatial distribution of rapidly degradable organic compound, methane and total landfill gas emission in two decades (2011-2021 and 2021-2031) in the study area

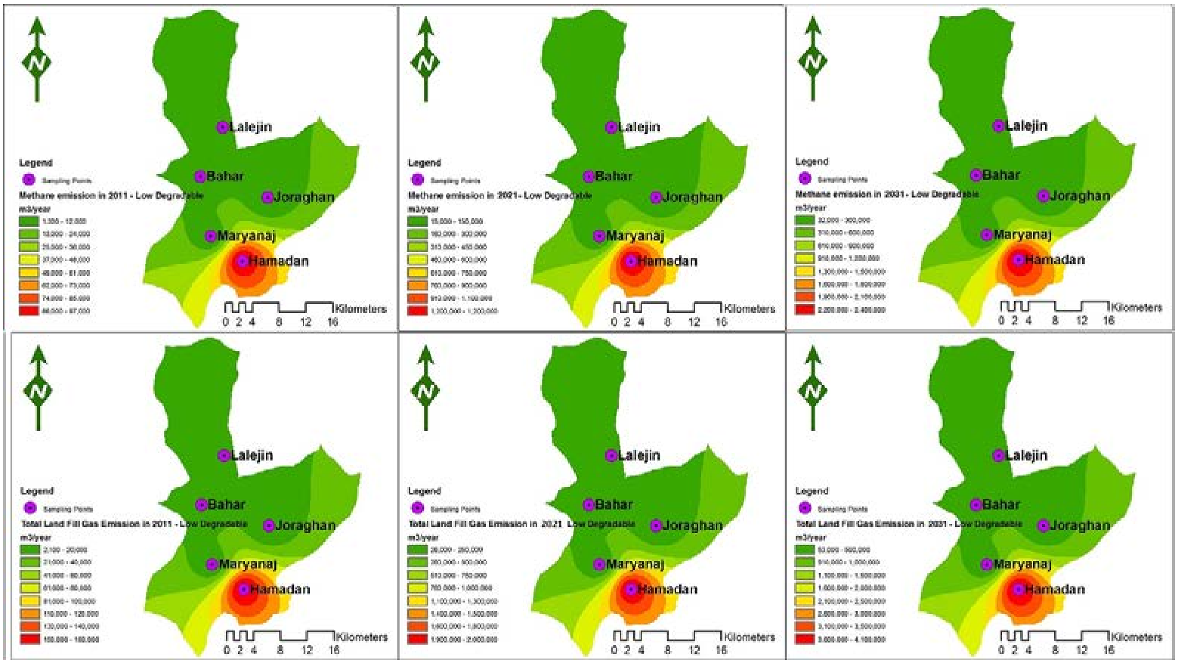


Fig. 9: Spatial distribution of slowly degradable organic compound, methane and total landfill gas emission in two decades (2011-2021 and 2021- 2031) in the study area

if the methane collection system is not efficient in economic terms, methane should be collected or at least be burned in order to prevent its release into the atmosphere. Prediction of gas generation by LandGEM is highly related to the environmental factors such as temperature and moisture. To achieve this goal, more data from landfill (such as existence or absence of gas collection system as well as the amount and composition of gas generation) are required. In addition, more information about site and landfill condition should be provided and studied for long-term.

CONCLUSION

The results of the present study can be usefully applied in planning for energy production and other applications in landfill sites. They can also be employed to determine Iran's role in global emission of greenhouse gases from landfill sites. Furthermore, these results can be efficiently used in designing methane collection systems to not only prevent methane explosion, but also use methane as an alternative energy source. Density of solid wastes was 268 kg/m3 in the study area. Methane emission rate and total greenhouse gases from a landfill site located in Hamedan, Iran were determined in a 20-years period from 2011 to 2030 using LandGEM model. Based on the results, 4.371×108 m^3 methane will be produced after 20 years, mostly (4.053×106 m^3) in the first year. In addition, methane production capacity in Hamedan landfill site will be 107 m^3/Mg. According to the results, summer (the hottest season) will have the maximum gas generation and winter (the coldest season) will have the minimum gas generation. The potential of rapidly degradable organic compounds for gas emission would be higher than that of slowly degradable organic compounds.

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CONFLICT OF INTERESTS

The author declares that there is no conflict of interests regarding the publication of this manuscript.

ABBREVIATIONS

C&D waste	Construction and demolition wastes
CHP	Combined heat and power generation
CO_2	Carbon dioxide
ºC	Centigrade degree
DOC	Degradable organic carbon
DOCf	Dissimilarity coefficient
EPA	Environmental Protection Agency
F	Fraction of methane in landfill gas
GHG	Greenhouse Gasses
GIS	Geographical Information System
IPCC	Intergovernmental Panel on Climate Change
k	Decay rate coefficient
kg	Kilogram
km	Kilometer
L_0	Potential rate of methane generation capacity
LFG	Landfill Gas
m	Meter
m^3/Mg	Cubic Meter per megagram
m^3/y	Cubic Meter per Year
MCF	Methane Correction Factor
MSW	Municipal Solid Waste
NMOC	Non-Methane Organic Carbon
US	Unites State
x	Annual average precipitation

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