



Evaluation and analysis of gaseous emission in landfill area and estimation of its pollutants dispersion, (case of Rodan in Hormozgan, Iran)

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Abstract

Background: The biogases are the mixture of gases produced through the microbial decomposition of organic waste which are amply observed in the landfills. The main purpose of this study was to estimate the emission rates of landfill gases such as carbon dioxide, methane and non-methane organic compounds (NMOCs) in the solid waste landfill of Rodan city in Hormozgan province.

Methods: All the necessary information such as population, geographic and climate of Rodan city were collected. Solid waste analysis was then conducted. Afterward, the LandGEM software is used in this study for the purpose of estimation of total biogas, methane, carbon dioxide and NMOCs emission from Rodan's landfill.

Results: The analysis of results showed that only 24.18% of the produced waste in this city is perishable. The calculations indicate that the peak of biogas production which is equal to 420 tons per year would be achieved in the year 2019. The production rates of carbon dioxide and methane in the same year would be equal to 308 and 112 tons per year respectively. The pollutants transmittance calculations in the vicinity of the landfill revealed that the maximum pollutant concentration is within the maximum distance of 200 m.

Conclusion: The results obtained in this study could be used for the purpose of design and installation of extraction or incineration equipment in the landfill of Rodan.

Keywords: Solid waste, Landfill, Biogas, Rodan city, LandGEM

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Introduction

In today's world, the waste compounds are addressed as environmental pollutants which would result in severe problems if not properly disposed. With this in mind, the waste disposal areas would play a vital role in the waste disposal networks which is the pivotal aspect of the general waste management strategy. The gas extraction equipment and energy consumption are presently the most significant component of the landfill areas (1,2). The disposed waste in landfill areas would be subjected to a variety of biochemical and physical reaction which could lead to the production and emission of substantial amount of gaseous components and liquids. Among these gasses, carbon dioxide and methane have significant importance due to their greenhouse properties (3). The installation of necessary equipment for the extraction of these gasses is essential in order to prevent their release into the atmo-

sphere (4).

Biogas is the mixture of gases produced through microbial decomposition of organic compounds in anaerobic conditions. Generally, the biogases are dominantly composed of 40%-75% methane and 15%-50% carbon dioxide in addition to little amounts of water vapor (5%-10%), hydrogen sulfide (0.005%-2%), less than 6% halogenic hydrocarbon, less than 1% ammonium, less than 0.6% carbon monoxide, 0%-2% nitrogen and minimal amounts of non-methane organic compounds (NMOCs) (5,6). Usually, for every ton of waste, about 250 kg of biogas is produced which can be consumed through extraction and treatment (7). Hajbagheri et al (5) introduced the LandGEM software and its applications in the calculation of the biogases production rates such as carbon dioxide, methane and NMOCs. Their evaluations revealed that the LandGEM software is a reliable and appropriate tool for the purpose



of estimating a wide range of gaseous compounds. They have also investigated the effects of the waste composition on the estimation accuracy of LandGEM software (5). Results indicated that 60% of the produced biogas in landfills of Shiraz was methane which would be financially beneficial if extracted. Omrani et al (8) have also conducted another study by using the LandGEM software which illustrated that the emission rates of methane and carbon dioxide from the landfills of Shiraz are equal to 24 and 60 m³/y respectively (8). Safari et al have also employed the LandGEM software to investigate the gases produced in the landfills of Mashhad. After the initial estimations, two disposal options which were incineration and energy production were investigated. The study results revealed that the environmental benefits would be significant despite high initial costs of energy production from methane (7). Zoghi and Ghavidel (4) estimated the rate of methane production in the municipal landfills by utilizing artificial neural networks. These researchers provided an estimation model for produced gases by considering parameters such as latex circulation and landfill properties. Mahvi and Rodbari (9) calculated the rate of produced biogases in the landfills of Shahrod using LandGEM software. The study results indicated that 488 m³ methane and 46 m³ carbon dioxide are released into the atmosphere from this landfill annually. Mahdipour et al (10) have also modeled the produced gases in the landfills of Ahvaz, Abadan and Dezfol. They have concluded that these landfills possess high potentials for producing substantial amounts of methane. The main purpose of this study was to estimate the gas emission rates in the landfill including carbon dioxide, methane and NMOCs in the municipal waste landfill of Rodan city located in Hormozgan province. In the first step, the required information such as waste composition and production rates were investigated. Then LandGEM software, developed by the United States Environmental Protection Agency (USEPA), was employed to estimate the emission rates of the produced gases. Lastly, the Screen View software was used in modeling the biogas emission. The results obtained in this study are applicable for the purpose of design and installation of gas extraction systems in the landfill. The study results have also illustrated the pollutant range of motion in the atmosphere and their concentrations within various seasons.

Methods

Future population estimation

The population of Rodan city was calculated between years 2016 and 2019 by considering the present population of the city and the population growth coefficient using Eq.1:

$$P_n = P_0 (1 + r)^n \quad (1)$$

where, P_n is the population in year n, P_0 is the population in the origin year, r is the average population growth rate and n is the number of years.

Geographic and climatic characteristics of Rodan

This study is conducted on the landfill of Rodan, Hor-

mozgan province. Based on the capitation conducted in 2011, the city comprised a population of 118 547 individuals. The landfill is situated 5 km away from the city. Based on the reports of Iranian climatology agency, the average precipitation within the course of 10 years in 2003 to 2013 is 208.12 mL per year and the average maximum temperature of the city is 39.3°C within the course of 10 years. Based on Talaiekhosani's report (11), the selection of existing coefficients and parameters in LandGems software including the methane production rate (k) and methane production potential capacity (Lo) is dependent on the climate of the area under study.

The climate of an area is indicated by the aridity index. The aridity index is used as an indicator to determine the level of dryness of the climate at a specific area. Although there are several aridity indices, but majority of them are not applicable for Iranian climate. De Martonne method (Eq. 2) was selected as the most compatible aridity index for Iran climate among the different methods used to determine the aridity index (Eq. 2) (11).

$$I = \frac{P}{(T+1)} \quad (2)$$

where I is the De Martonne dryness parameter, T is the average annual temperature in °C and P is the average annual precipitation in mm. The results obtained from Eq.2 are compared with Table 1 in order to determine the climate type.

Waste analysis method

All analysis was conducted by the municipal recycling agency of Rodan city in year 2012. The municipal authorities have attempted to obtain a set of samples from the city waste. Four waste transport trucks, with predetermined load capacity were selected for this purpose. These trucks dispose four loads of municipal wastes on a daily basis. The density of disposed waste is then determined in respect to its volume and weight. This process was repeated every month for a year. It is worth mentioning that no samples were obtained before and after holidays to insure the minimum possible error in sampling. A composite sample was also obtained in order to determine the quality and quantity of the solid waste including the percentage of perishable and non-perishable compounds, the percentage of organic and volatile organic matters and humidity which was based on standard methods (2).

Table 1. De Martonne dryness coefficient range and related climate type

Climate types	I
Dry	Smaller than 10
Semi dry	10 to 19.9
Mediterranean	20 to 23.4
Semi humid	24 to 27.9
Humid	28 to 34.9
Intense humidity	Higher than 35

Source: Reference 12.

Evaluation of gas emission rate

The gas emission rate of the landfill was evaluated using LandGEM software. The LandGEM software is developed by the USEPA. LandGEM is an automated tool used in estimating total biogas, methane, carbon dioxide and NMOCs from municipal solid waste landfills (11). This software is utilized for estimation of gases emission based on either site-specific data or default parameters. LandGEM has two groups of default parameters known as specifically inventory defaults and Clean Air Act (CAA) defaults. The CAA defaults have been developed based on federal regulations for municipal solid waste landfills. The CAA defaults are utilized to determine if a specific landfill requires the control of gases emission or not. The inventory defaults have been developed based on emission factors in environmental protection agency (11). A first-degree equation is provided by the software in order to estimate the rate of the produced gases Eq. 3.

$$Q_{CH_4} = \sum_{i=1}^n \sum_{j=0.1}^1 KL_0 \left[\frac{M_i}{10} \right] e^{-Kt_{ij}} \quad (3)$$

Where Q_{CH_4} is the produced methane in the calculated year (cubic meter per year, i is the step index in year, n is the year of origin-first year of operation, j is equal to 0.1 time increment in year, K is reverse of years of methane productions, L_0 is the methane production potential in cubic meter per ton, M_i is the disposed waste mass in year i in ton, and t_{ij} is the age of the j portion of the waste in the year i within the operation year. The characteristics of the Rodan landfill were then fitted into the model according to Table 2.

Results

Climate of Rodan

The Rodan's landfill is located in a plain area with hills and

vegetation such as mesquite, lotus and sorrel. Registered statistics of synoptic station in the course of 10 years from 2003 to 2013 were analyzed in order to determine the precipitation quantity of this region. Table 3 presents the average precipitation rates during various seasons of the year. The average annual precipitation was equal to 208.12 mm. The average temperature of Rodan was 39.3°C. Based on the De Martonne coefficient of 5, the climate classification is said to belong to a dry climate type. Wind statistics in the course of 2003 to 2013 was utilized to determine and analyze the wind speed. The average wind speed was 3.4 m/s in July and the minimum speed was 2.5 m/s in September. The average wind speed throughout the year was 2.95 m/s. The location of Rodan's solid waste landfill is shown in Figure 1.

Waste qualitative analysis

The percentage of the waste compositions are variable based on the region, economic and social conditions of the people, the geographic location, climate, seasons, and the waste recovery rate (legal or illegal) (2). Therefore, in order to achieve an accurate evaluation, a separate analysis of the solid waste in every region is needed throughout the course of the various seasons. The important fact is that the solid waste produced in various regions of a city

Table 2. The characteristics of the Rodan landfill

Parameter	Value	Unit
Year of the operation start	2009	Year
Year of the operation shutdown	2019	Year
Calculate the operation shutdown model?	No	-
Methane production rate (K)	0.05	Year ⁻¹
Methane production potential (L_0)	170	Ton per cubic meter
Concentration of NMOCs	4000	ppmv as hexane
Methane components	50	% by volume

Table 3. The average precipitation in the range of 2003 to 2013

Title	Month											
	March	April	May	June	July	August	September	October	November	December	January	February
The average of total precipitation(mm)	15	1	0.5	0.5	2.2	0.02	0	3.1	6.4	3.4	54	7.3

Source: Reference 13.



Figure 1. A satellite picture of Rodan's solid waste landfill.

could have significant differences in respects to their composed material. Table 4 illustrates the average percentage weight of different fraction of the wastes in Rodan. As it is presented, the perishable organic components account for 24.18% of the entire wastes in the city. Plastic and rubber constitute 28.07% of this city wastes. Paper and glass constitute 8.26% and 6.05% of the wastes, respectively. Hence, the application of the recycling process in this city could result in the recovery of a large portion of plastic, rubber, paper, cardboard, metal and glass. The humidity of the waste has also been estimated to be 16.53%.

The waste production quantity

The Rodan's landfill was established in 2009 and is still under operation until 2019. After the closure, a new site will be selected based on the general waste plan studies. Studies reveal that the annual waste production rate in Rodan is 402 g/capita/day. The annual waste production rate is illustrated in Table 5. Based on Table 5, 54 824 tons of waste is disposed in this landfill in the course of 10 years of operation.

The production of biogas

Biogas is a mixture of carbon dioxide, methane and NMOCs. The rate of the produced biogas is dependent on the volume of the disposed waste in the landfill. LandGEM software has been introduced as an appropriate model to estimate the rates of biogases production such as carbon dioxide, methane and NMOCs. Hajbagheri et al (5) showed that the LandGEM software is a reliable

Table 4. The average weight percentage of the waste components in Rodan

Type	Percentage of the components
Perishable organic compounds	24.18
Paper, cardboard and box file	8.26
Plastic and rubber	28.07
Glass	6.05
Metal	3.85
Bones	1.65
Textile	13.76
Wood	8.81
Apartment waste	4.95
Others	0.42

Table 5. The population of Rodan and the waste production rate during 2009 to 2019

Year	Population	Weight of the produced waste (ton/day)	Weight of the produced waste (ton/year)	Waste production rate (g/capita/day)
2009	30 789	12.3	4490	399
2010	31 404	12.6	4599	401
2011	32 032	12.8	4672	399
2012	33 285	13.3	4855	399
2013	33 784	13.4	4891	396
2014	34 291	13.7	5000	398
2015	34 805	13.9	5074	400
2016	35 327	14.4	5256	407
2017	35 857	14.4	5256	401
2018	36 395	14.6	5329	401
2019	36 941	14.8	5402	400

and appropriate tool for the purpose of estimating a wide range of gaseous compounds (5). As it is shown in Figure 2, the produced biogas is increased through the rise of the disposed waste mass. After the landfill closure in 2019, the waste production would be decreased but not ceased. Based on our calculation, the biogas production would continue for 150 years after the operation shutdown until 2169. The maximum biogas production in the landfill after the closure is achieved in 2020 which is equal to 420 tons per year. It is necessary to prevent the emission of NMOCs into the atmosphere because biogases contain little amounts of these gases which are toxic and carcinogenic (2). Presently, the Rodan landfill lacks any biogas extraction equipment. Thus, it is essential to design such

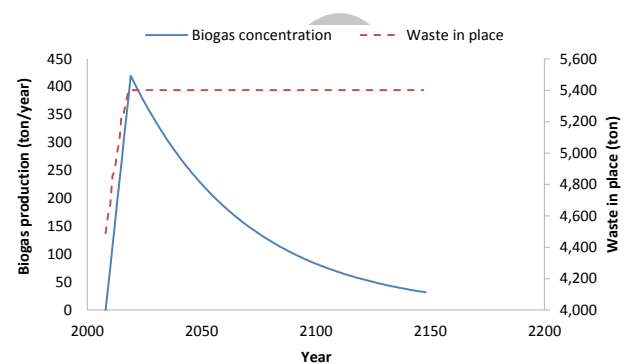


Figure 2. Amount of biogas production in Rodan's landfill between 2009 and 2169.

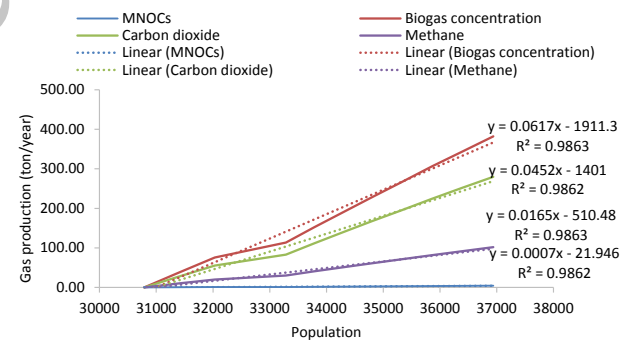


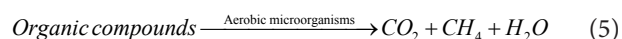
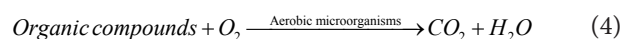
Figure 3. The relationship between population and gas production rate in the Rodan's landfill.

system.

Figure 3 presents the relationship between the population and the total biogas, carbon dioxide, methane and NMOCs production rates. The presented relation could be utilized in estimating the produced gases in the landfill.

Carbon dioxide and methane production

Carbon dioxide and methane are among the important greenhouse gasses. Carbon dioxide is a colorless and odorless gas which plays a vital role in sustaining life on earth. The average concentration of carbon dioxide in the atmosphere is approximately 0.00756 g/m^3 . Volcanoes and hot water springs are the natural sources of carbon dioxide. Although in comparison to manmade sources, their capacity is very limited. Microorganisms are capable of producing carbon dioxide through anaerobic and aerobic processes (Eqs. 4 and 5). However methane is only produced through anaerobic processes of organic matter decomposition by microorganisms.



This study revealed that high levels of methane and carbon dioxide are released into the atmosphere from the Rodan's landfill (Figure 4). Omrani et al (8) illustrated that 60% of the produced biogas in the landfills of Shiraz was methane which would be financially beneficial if extracted. They have also carried out a study by using the LandGEM software which illustrated that the emission rate of methane from the landfills of Shiraz is equal to $24 \text{ m}^3/\text{y}$ (8). The emission rate of carbon dioxide of Rodan's landfill from 2009 to 2169 is presented in Figure 3. As it is shown, the production and emission rate of carbon dioxide and methane is increased with the increase of the disposed waste in the landfill which would reach its maximum in 2020, a year after shutdown. In 2020, the carbon dioxide and methane production rates will be equal to 308 and 112 tons respectively. Although, it is often suggested to convert the produced carbon dioxide into biomass by algae and utilize it as raw material for biodiesel, however none of the proposed methods are financially cost effective (14). Based on our calculations, after 11 years of operation, the Rodan's landfill would emit 1537 tons of carbon dioxide and 560 tons of methane into the atmosphere. Presently, the cost of every ton of liquid carbon dioxide is 12 dollars. Thus revenue of 18 444 is achievable after 11 years of operation by selling the carbon dioxide. It is worth mentioning that the initial costs for equipment and purification must also be considered in decision making. However due to the existence of ample impurities in the produced biogas, the cost of purification will appear to be very high. Methane accommodates more utilization methods when compared to carbon dioxide. One of these is energy production. Approximately 0.00165 MW of energy is achievable per every cubic meter of methane. It is estimated that throughout the years of operation, the Rodan's landfill

would produce only 1 MW of energy. No energy recycling approach is proposed for this landfill since the electric charge produced in this landfill is significantly low. It is proposed to burn the produced methane in order to inhibit the emission.

The Production of NMOCs

The NMOCs are the collection of chemical compounds with different chemical structure but with similar behavior in the atmosphere. NMOCs are produced and emitted from wide range sources such as burning, solvents, anaerobic decomposition of organic compounds and production stages (11,13). NMOCs could also result in the formation of tropospheric ozone which poses much health risks for humans. Several other NMOCs including benzene or 1,3 Butadiene are also highly dangerous for humans (14,15). Large portions of the NMOCs are among the volatile organic compounds (VOCs) which are highly dangerous. The production rate of NMOCs within the years of 2009 and 2169 are presented in Figure 5. As shown in Figure 5, the levels of NMOCs are increased with the increase in the disposal rate of waste in the landfill of Rodan. However, after 1 year of landfill closure, the production rate of NMOCs would significantly decline. The climax of NMOCs production rate is observed in the year 2020 which is one year after the shutdown and 4.82 tons of these compounds are released into the atmosphere. Although the levels of NMOCs in the atmosphere are very small, its inhibition is highly essential due to its high toxicity.

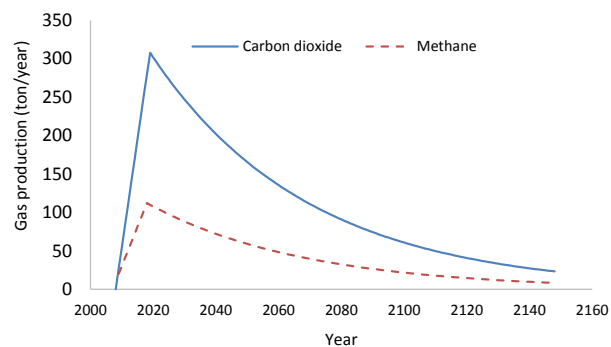


Figure 4. The carbon dioxide and methane production rates in 2009 to 2169

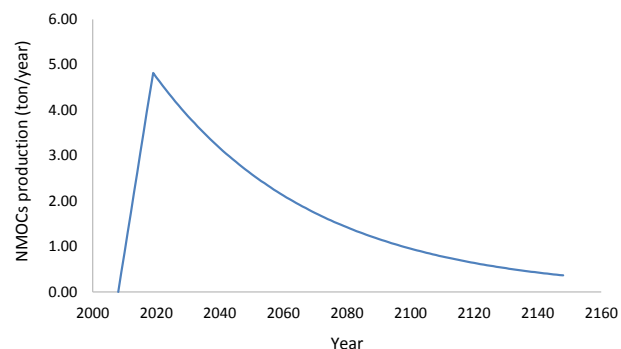


Figure 5. The NMOCs production rate within the years of 1387 to 1527.

Table 6. The emission rate of NMOCs in 2016 in the landfill of Rodan

Gas/Pollutant	Emission rate (ton/year)	Gas/Pollutant	Emission rate (ton/year)
Total landfill gas	266.8	Dichlorobenzene - (HAP for para isomer/VOC)	0.000274
Methane	71.2	Dichlorodifluoromethane	0.017190
Carbon dioxide	195.5	Dichlorofluoromethane – VOC	0.002378
NMOCs	3.063	Dichloromethane (methylene chloride) – HAP	0.010570
1,1,1-Trichloroethane (methyl chloroform) - HAP	0.000569	Dimethyl sulfide (methyl sulfide) – VOC	0.004306
1,1,2,2-Tetrachloroethane - HAP/VOC	0.001641	Ethane	0.237800
1,1-Dichloroethane (ethylidene dichloride) - HAP/VOC	0.002111	Ethanol - VOC	0.011060
1,1-Dichloroethene (vinylidene chloride) - HAP/VOC	0.000172	Ethyl mercaptan (ethanethiol) - VOC	0.001270
1,2-Dichloroethane (ethylene dichloride) - HAP/VOC	0.000361	Ethylbenzene - HAP/VOC	0.004340
1,2-Dichloropropane (propylene dichloride) - HAP/VOC	0.000181	Ethylene dibromide - HAP/VOC	0.000002
2-Propanol (isopropyl alcohol) - VOC	0.026710	Fluorotrichloromethane - VOC	0.000928
Acetone	0.003613	Hexane - HAP/VOC	0.005054
Acrylonitrile - HAP/VOC	0.002971	Hydrogen sulfide	0.010900
Benzene - No or Unknown Co-disposal - HAP/VOC	0.001319	Mercury (total) - HAP	0.000001
Benzene - Co-disposal - HAP/VOC	0.007635	Methyl ethyl ketone - HAP/VOC	0.004550
Bromodichloromethane – VOC	0.004513	Methyl isobutyl ketone - HAP/VOC	0.001691
Butane – VOC	0.002582	Methyl mercaptan – VOC	0.001069
Carbon disulfide - HAP/VOC	0.000392	Pentane - VOC	0.002116
Carbon monoxide	0.034850	Perchloroethylene (tetrachloroethylene) – HAP	0.005452
Carbon tetrachloride - HAP/VOC	0.000005	Propane - VOC	0.004310
Carbonyl sulfide - HAP/VOC	0.000262	t-1,2-Dichloroethene – VOC	0.002412
Chlorobenzene - HAP/VOC	0.000250	Toluene - No or Unknown Co-disposal - HAP/VOC	0.031930
Chlorodifluoromethane	0.000999	Toluene - Co-disposal - HAP/VOC	0.139200
Chloroethane (ethyl chloride) - HAP/VOC	0.000745	Trichloroethylene (trichloroethene) - HAP/VOC	0.003269
Chloroform - HAP/VOC	0.000032	Vinyl chloride - HAP/VOC	0.004054
Chloromethane – VOC	0.000538	Xylenes - HAP/VOC	0.011320

The LandGEM software is capable of calculating the emission rate of 48 chemical compounds in NMOCs collection. The calculation results are presented in Table 6. Based on this table, the emission rate of compounds such as vinyl chloride and benzene in the atmosphere are estimated to be 0.004 and 0.011 tons respectively in 2016. Aspiration of high concentrations of vinyl chloride in low intervals would result in negative effects on the central nervous system which is followed by symptoms such as vertigo, insomnia and headache. Low levels of vinyl chloride can dissolve in surface and underground water sources which could enter the human digestion system. Prolonged contact with low concentration of vinyl chloride by aspiration or digestion could damage the liver. The aspiration of vinyl chloride would increase the risk of liver cancer. Thus, the USEPA has classified vinyl chloride as carcinogenic compounds. Reports of the destructive effects of vinyl chlorides on the human reproduction system have also been provided (16). Although, various epidemiological studies have confirmed the relation of vinyl chloride with birth defects, however several other studies found no such connection (17). Several other studies have also confirmed that men who were in contact with vinyl chloride at works have faced abortion (16). However, various other studies have denied such connection. Studies report a reduction in fertility in mouse that was exposed to low quantities of vinyl chloride in the course of 12 months (16). The half-life of vinyl chloride in the atmosphere is only a few hours, however, in the case of wind blow; this harmful substance

can be transmitted across the nearby areas which could pose threat for the residents of those areas. The contact of vinyl chloride with the human body would demand a concentration of 1.3 mg/m³. Otherwise it could pose serious threat to human health as it was mentioned that the compounds such as vinyl chloride have serious consequences for human body. Thus the inhibition and control of this substance is highly significant in Rodan's landfill. Majority of the compounds in Table 6 are members of VOCs and hazardous air pollutants (PAH) which are indicated in the table.

The modeling of the pollutants emission in the atmosphere

In this section, the total biogas transmittance of carbon dioxide, methane and NMOCs in the atmosphere is modeled in the direction of the wind using Screen View software. Figure 6 presents the total concentration of biogases in the nearby atmosphere of the Rodan's landfill. As it is shown, the concentrations of both pollutants would reach their maximum within the distance of 200 m. The concentration of the total biogas and carbon dioxide within the distance of 200 m of the landfill is equal to 202580 and 10430 µg/m³. The total concentration of the biogas and carbon dioxide would decrease by taking the distance from the landfill in such a way in which it would reach 3507 and 2534 µg/m³ respectively within the distance of 100 m. Since the average concentration of carbon dioxide in the atmosphere is 7560 µg/m³ (14), the produced car-

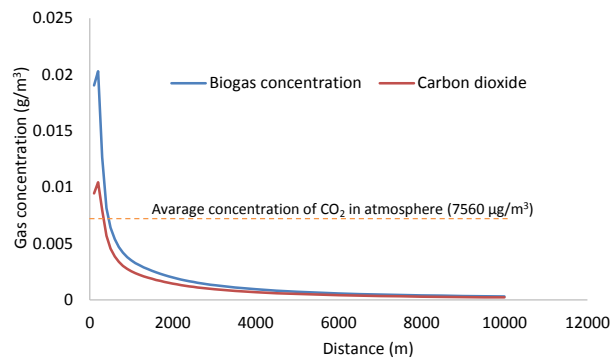


Figure 6. Total biogas emission and carbon dioxide in the vicinity of the landfill of Rodan in the direction of the wind.

Carbon dioxide in the landfill could reach 17990 and 10097 $\mu\text{g}/\text{m}^3$ respectively within the distance of 200 and 1000 m. This implies that within the distance of 200 m of the landfill, the concentration of the carbon dioxide which is 2.3 and is within its normal levels, would reach the concentration of 1.3 within the distance of 1000 m.

The emitted methane from the landfill has similar conditions to carbon dioxide. The maximum concentration of gas which is equal to 306 $\mu\text{g}/\text{m}^3$ is reached within the distance of 200 m. The concentration of methane would reach 94.41 $\mu\text{g}/\text{m}^3$ when the distance is increased over 1000 m and within the distance of 10000 m, it would be reduced to 7.92 $\mu\text{g}/\text{m}^3$. Methane is considered as a gas with greenhouse properties. The heating capacity of methane is 25 times stronger than carbon dioxide thus the inhibition of this gas is of significant importance. Generally, the effects of methane on human health are through the replacement of oxygen and lowering of its concentration (19,20). Headaches, vertigo and nausea are the symptoms of high concentration of methane in the breathing air. However based on the conducted calculations, the concentration of methane around the landfill of Rodan is not high enough to pose any threats for human health (Figure 7).

The NMOCs include dangerous substances such as vinyl chloride. Thus determining their concentrations in the vicinity of the landfill is of great importance. As it is presented in Figure 8, the highest level of concentration which is equal to 12.46 $\mu\text{g}/\text{m}^3$ is observed in the distance of 200 m from the landfill. By taking the distance from the landfill, the concentration of NMOCs would decrease, which would reach a concentration of 3.75 $\mu\text{g}/\text{m}^3$ in the distance of 1000 m. The concentration of NMOCs in the distance of 10000 m from the landfill would be equal to only 0.32 $\mu\text{g}/\text{m}^3$.

Conclusion

In this study, we investigated the production and emission of carbon dioxide, methane and 48 NMOCs in the landfill of Rodan by using the LandGEM software. We have also modeled the transmittance of the produced pollutants in the nearby areas of the landfill by using the Screen View software. The results suggested that the maximum gas production in the landfill would be achieved one year

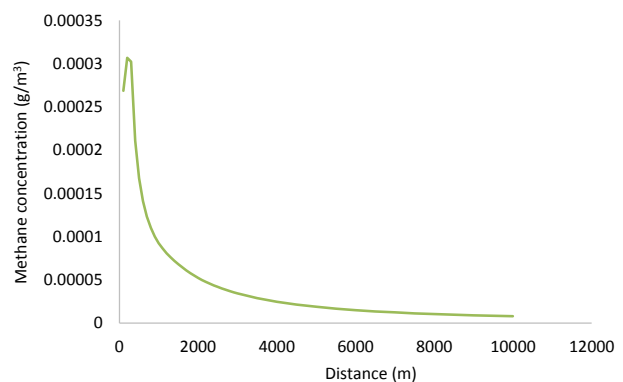


Figure 7. The transmittance of methane around the landfill of Rodan in the direction of the wind.

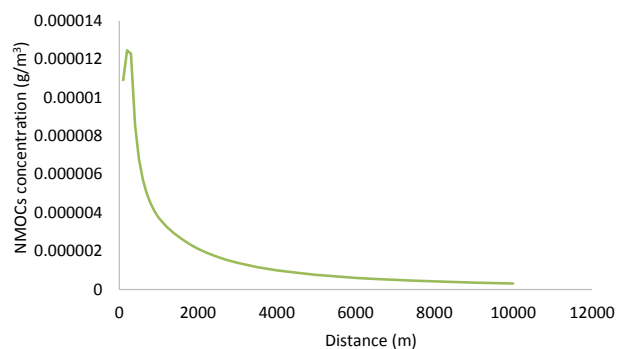


Figure 8. The concentration of NMOCs within various distances from the landfill in the direction of the wind.

after the operation shutdown which is in the year 1398. In this year, the production rate of carbon dioxide, methane and NMOCs would be equal to 308, 112 and 4.82 ton per year respectively. The results have also suggested that this landfill would only have the capacity for 1 MW of energy production due to the triviality of the methane production in the course of 11 years of operation. Thus it is suggested to incinerate the produced gas in order to protect the environment and inhibit the greenhouse property. Based on our calculations, the concentration of carbon dioxide, methane and NMOCs would be equal to 94.41, 10097 and 3.75 mg/m^3 respectively within the distance of 1000 m from the landfill. The concentration of carbon dioxide within the distance of 1000 m is 1.3 which is equal to the universal standard. The results obtained in this study could be used for the purpose of design and installation of extraction or incineration equipment in the landfill of Rodan.

Ethical issues

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

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