Recycling and Sustainable Development

www.rsd.tfbor.bg.ac.rs

RSD

Online ISSN 2560-3132
Print ISSN 1820-7480

Modelling landfill methane distribution into the ambient air: Case study of Novi Sad

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A R T I C L E I N F O

Received 05 October 2017
Accepted 30 November 2017

Research Article

Keywords:
Emissions
Greenhouse gas
Landfill gas
Methane
Modeling
Ambiental air

A B S T R A C T

Waste disposal is a common practice in Serbia. Landfills are largely unregulated and most commonly, waste is disposed without pre-selection so it represents an uncontrolled methane source of emission. Methane is a greenhouse gas which is estimated to have 20 times higher potential for global warming than carbon dioxide. In this paper, based on the available data on the level of emissions from the landfill, the modeling of methane dispersion after emission was performed for the periods of the dominant meteorological conditions whereby the quantification and characterization of the methane behaviour and its dispersion into the ambient air was carried out. Analysis of the modelled methane concentrations showed that maximum concentration of 7478.9 μg/m^3 was reached at the distance of 466.6 m from the landfill itself, with no significant influence on the nearest settlements.

1. Introduction

Disposal of municipal solid waste which does not follow principles of environmental protection represents a serious risk to the environment and human health. Waste dumps can become dominant sources of deterioration of the air quality due to the emission of the methane, caused by anaerobic decomposition of the organic waste parts. Methane, which emission derives from anthropogenic sources, is one of the most important gases with a greenhouse effect. One of the first studies on the greenhouse gas (GHG) emissions shows that landfills contribute with 5-10 % to the global methane emissions (Global Warming Potential Values, 2014) and up to 10 % to an anthropogenic carbon dioxide fraction, which implies that waste dumps are significant pollution sources (Bingemer et al., 1987).

According to the national inventory of the greenhouse gases, for the period 2010-2013, methane emission takes a share of 13.9 % of the total GHG emissions. GHG emission from the waste sector is 5.1 %, and within the waste management sector it is estimated that 62 % of GHG emissions occur due to the waste disposal. According to the first biennial updated report of the Republic of Serbia under the United Nations Framework Convention on Climate Change, the further trend of the GHG emission within this sector depends solely on the improvement of the waste management. Based on this report, the most favorable scenario of the system improvement (increasing the amount of the municipal waste managed with biological treatment, using anaerobic digestion and a smaller degree of composting, thermal waste treatment using the heat in larger cities) would reduce the amount of the emissions by 15 % due to the reduction in the amount of the waste in the dumps (up to 50 %) and the existence of solely sanitary landfills and absolute utilization of methane found (Ministry of Agriculture and Environmental Protection, 2016).

Disposal to landfills is one of the most common ways of the municipal waste disposal in developing

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doi:10.5937/ror1701009V

countries. In Serbia, there are 160 controlled and 3,500 uncontrolled waste dumps with undefined emission of landfill gas (Stanisavljević et al., 2014; Environmental Protection Agency, 2017). The estimation of methane emission from the landfills is extremely complex because landfills cover large areas. Besides, emission may depend on the topography, on the type of waste landfilled, on the type of materials used as a covering etc. Therefore, the methods for estimating the methane emissions from the waste dumps are different. Although the long-term methane emissions measurement is the most reliable and at the same time the most expensive, the application of the software packages for estimating the emissions are frequently used. One of the most commonly used software is "LandGem" of the US Environmental Protection Agency (USEPA). LandGem is often used to estimate the production of methane and carbon dioxide from cumulatively disposed municipal waste (USEPA, 2005). Methods defined by the Intergovernmental Panel on Climate Change - IPCC are also used to estimate the methane emissions from the solid waste dumps (IPCC, 2006). Different approaches for methane emission estimation are constantly developing (Karanjekar, 2015; Svensson, 2001).

The effects of landfills on air quality is not negligible. The reduction of the GHG emission from landfills is very important and may provide benefits to the environment, sustainable development and may decrease adverse impacts on human health.

This paper focuses on the quantification and characterization of the methane behavior and its distribution into the ambient air. For this purpose, based on the available data on the amount of methane emission from the municipal landfill in Novi Sad, simulation of the spatial distribution of methane, as well as the impact on the air quality using the ADMS Urban software has been performed.

2. Methods

Mathematical models are very useful tools for calculating the concentration of pollutants in atmosphere when the data on the specific measurements is not available. The spread of pollutants depends on several factors. For example, a set of parameters related to the source (emission sources and emission levels), dominant meteorological conditions (wind speed and direction, atmospheric stability, precipitation, cloudiness, etc.), then the parameters which refer to the environment itself in which the pollutant is released (the configuration of the area) are crucial for establishing a good basis for obtaining reliable results of the modelling of pollutant diffusion. According to the given statement, the simulation was carried out using The Atmospheric Dispersion Modelling System software (ADMS) which is developed by the consulting company "Cambridge Environmental Experts Consultants" (CERC). ADMS is one of the widely used dispersion models which simulate a wide range of pollution from various sources (CERC, 2017).

2.1 Input data

<u>Source of emission</u>

At the landfill in Novi Sad, municipal waste from the territory of the City and the surrounding (341,953 people are covered) is disposed of. A waste separation plant is located nearby the landfill. The landfill site covers an area of 56 ha, where the landfill itself covers 22 ha. The landfill height on various parts of the site varies in the range of 2.5 m to 14 m. The landfill contains c. 2,000,000 m^3 of the waste. The average quantity of the waste which is disposed of is 629.7 tons per day. The landfill has a passive degassing system which is aimed to prevent the accumulation of methane in the landfill body and cause explosion later (Regional waste management plan, 2011).

Since there are no data on the number nor the position of gas wells on the landfill, the source of methane emission is defined as the surface (Jeremy et al., 2014). The landfill surface as a source of the methane emission is graphically presented using ADMS Mapper program. The graphical segment of the landfill presents a real environment of the simulation (Figure 1).

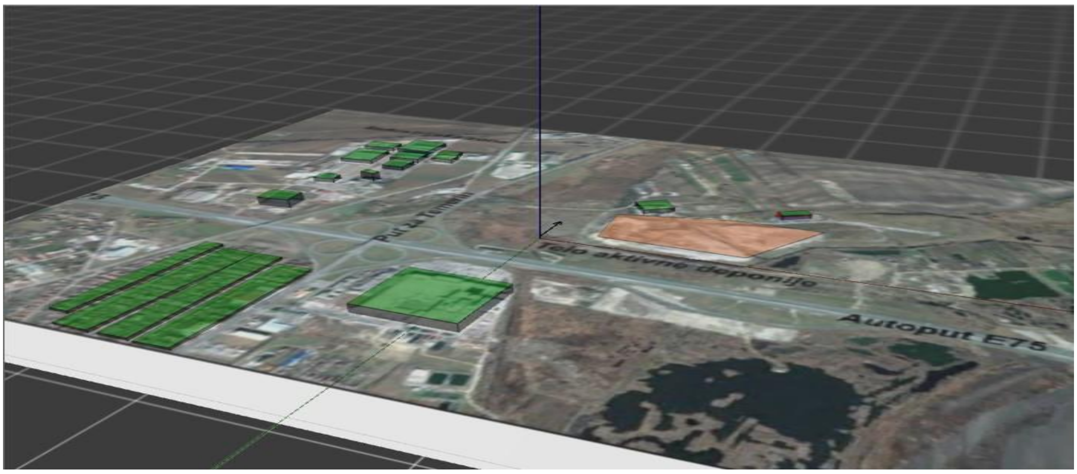

Figure 1. Defined area of the research - a landfill in Novi Sad as a surface source with the closest marked facilities

Emission

An IPCC methodology based on the First Order Decay (FOD) method is used to calculate methane emissions from the landfills (IPCC, 2006):

$$CH_4 emission = \left[\sum_{x}^{i} CH_4\ generated_{x,t} - R_t\right] \cdot (1 - OX_t)$$

Where:

CH_4 Emissions = CH_4 emitted in year T (Gg)
T = inventory year
x = waste category or type/material
R_T = recovered CH_4 in year T (Gg)
OX_T = oxidation factor in year T, (fraction)
CH_4 generated (x,t)

The amount of generated methane (CH_4) depends on the composition and age of waste but also on the conditions found on the landfill (temperature, moisture and oxygen content). The potential to generate methane from the waste that has been disposed in a certain year gradually decreases with time because the amount of degradable carbon is being reduced.

Therefore, in order to achieve a more precise calculation of the methane emission in a certain year, it is recommended to use the data on waste disposal for the period of 50 years at least (IPCC, 2006).

Additionally, due to the complex degradation process that occurs at the landfill, the amount of methane can vary in time and space within a certain waste dump. Research in this area confirm variability of the methane emissions, so Lando et al. (2017) reported that the average values of all values of estimated flux by point and scanning method were 38.3 and 71.2 g $CH_4/m^2/d$, respectively. Based on Scheutz (2009), the standard rate of methane emission ranged from 77 to 155 g $CH_4/m^2/d$, and by Boeckx et al. (2009), methane emission from a small covered landfill site showed, seasonally varying fluxes, ranging from 5.9 to 914.3 g $CH_4/m^2/d$. Field measurement of landfill methane in emissions indicated variability from 0.0004 to more than 4000 g $CH_4/m^2/d$ (Bogner et al., 1997).

Methane emission rate from landfills in Serbia are in the range of 0.3 g $CH_4/m^2/d$ (for shallow landfills) to 60 g $CH_4/m^2/d$ (for landfills with a waste volume of more than 100,000 m^3), which is relatively low and can be explained by the fact that these landfills are generally not managed and show less waste compaction and are therefore not fully anaerobic, which results in lower CH_4 generation (Stanisavljević et al., 2012).

Meteorological conditions

Data for air dispersion modelling include two sets of meteorological data:

1. Required parameters:

   - Wind speed (m/s) and wind direction (°)
   - Parameters related to the sensitive surface flux:
     - year/day/time/cloud cover (oktas) or surface flux (W/m^2)

2. Additional meteorological data:

   - Boundary layer height (m)
   - Surface temperature (°C)
   - Lateral spread (°)
   - Relative humidity (%)

The meteorological parameters used in this paper are: wind speed and direction, cloudiness and temperature in 2016.

These parameters were taken from the automatic air quality measuring station located in the surrounding that is not far from the landfill and are presented in this paper.

Terrain configuration

For the modeling of propagation of methane from landfills, surface roughness of 1 m which is typical for cities and woodlands is used in this paper.

3. Results and discussion

The simulations of the methane dispersion from the landfill is conducted within two scenarios: (I) the winter period (February-March) which is characterized by dominant winds with sometimes extreme windblasts and (II) the summer period (June-September) when temperatures are relatively high and wind speed is low.

The dominant weather conditions for the period January-March 2016 are characterized by a dominant northeast wind direction (NE), which is typical for this area. The NE wind reached a speed of 5.3 m/s in 2.4 % of cases (Figure 2). Wind calms were presented in 4 % of measurement cases. The average cloud cover during this period was 6 oktas, the temperature ranged from -9.7 to -16.7 °C (average temperature – 7 °C) while the average relative humidity was 80.4 % (Table 1).

During the period of the II scenario (June-September 2016.), north (N) wind directions (14 % of the measurement) and west (W) wind directions (15 %) were dominant. The northern direction of the wind has significantly higher speed. The maximal windblast of 5.4 m/s was recorded (Figure 3).

The northwest wind (NW) had a slightly lower frequency (11.7 %) but with significantly higher number of wind blasts within the range of wind class of 3.6-5.7 m/s in relation to the E and N direction. However, dominant winds during the summer period have lower frequency of higher wind speed compared to the winter winds. The wind calms were noted in 10 % of the measurements.

Table 1.
Meteorological data scenario I and scenario II

Period of the year	Temperature range (°C)	Average cloud cover (oktas)	RH (%)	Wind speed (m/s)
Scenario I January-March	-9.7 to 16.7	6	80.4	0.7-5.23
Scenario II June-September	15.5 to 27.5	4	81.4	0.19-5.45

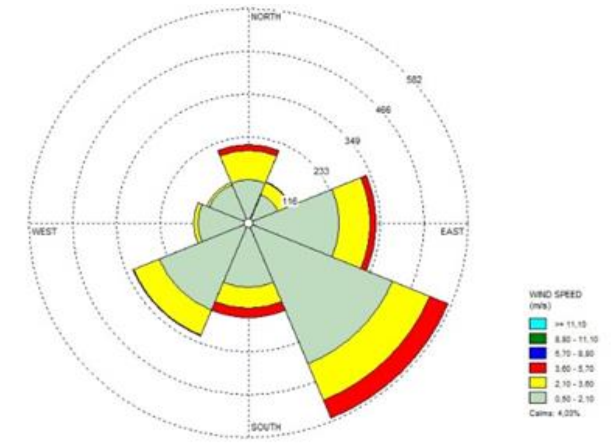

Figure 2. Wind rose (Scenario I)

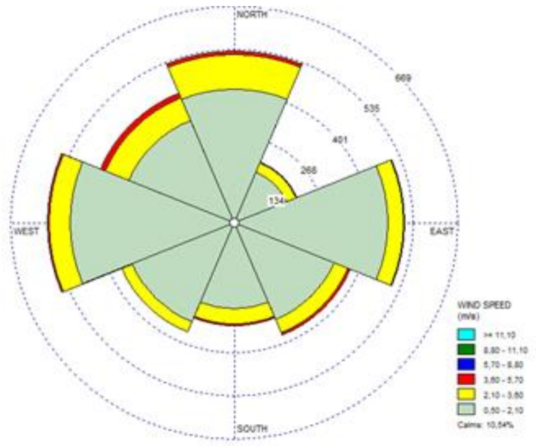

Figure 3. Wind rose (Scenario II)

After pre-processing of the meteorological data, a simulation of the methane dispersion was conducted for the both scenarios.

Software ADMS5 has the possibility to create short-term (daily and monthly) and long-term (annual) propagation scenarios, as well as pollutant concentration levels at different heights in relation to the surface of the soil and different distances from the pollution source.

Based on the contour maps of concentrations for the scenario I, modelled methane concentrations in the ambient air ranged from 1 μg/m^3 to 7478.9 μg/m^3. Numerical analysis of the data showed that the maximum modelled methane concentrations is reached 5 meters above the landfill and the distance of 466.6 m in the direction of the dominant wind (Figure 4).

In the case of Scenario II, the range of methane concentration in ambient air ranged from 3.07 μg/m^3 to 6371.26 μg/m^3, reaching its maximum to a height of 5m above the landfill lever and the distance of 380 m in the direction of the dominant wind blow.

In comparison to the summer period, the concentration levels of methane during the winter period are slightly higher and show a similar behavioral pattern (the distance and height of maximum concentrations).

The modelled methane concentration estimated within this paper are in the range of the modelled ambient concentration of the methane obtained in other studies (12-4259 ppm) (Lando, 2017).

Although methane is represented as one of the most important GHG, allowed concentrations of methane levels in ambient air are not standardized. However, studies suggest that 1,500 mg/m^3 of methane have an immediate toxic effect on people (Cotrău, 1991), while Dryahina (2010) discusses ambient methane levels of 30 ppm.

According to the Scenario I and II, the modeled concentrations of methane in ambient air are significantly below this level. Also, a methane dispersion during the dominant meteorological conditions is not spread in the right direction and does not reach settlements that are located c. 600 m from the landfill so it can be concluded that methane does not have a significant impact on the surrounding population.

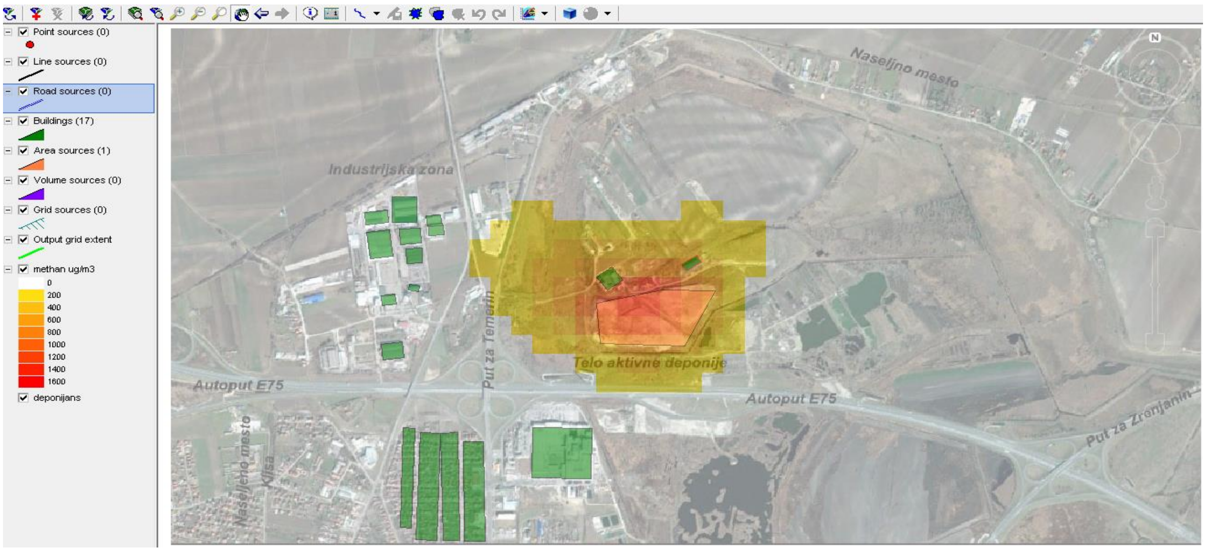

Figure 4. Example of contour maps of concentrations for scenario I

4. Conclusion

The paper shows the estimation of the distribution of methane from the landfill in Novi Sad during the winter and spring period using ADMS urban software tool.

The results demonstrated that the estimated quantities of the emitted methane during the dispersion simulation reach the values of the ambient concentration from 1µg/m^3 to 7478.9 µg/m^3 for the winter period and from 3.07 µg/m^3 to 6371.26 µg/m^3 for the summer period.

The estimated ambient concentrations of methane are relatively low which is a direct consequence of a low level of estimated emission i.e. poor waste management practice which often leads to the absence of entirely anaerobic conditions which are precondition for the methane generation.

By numerical analysis of the modeled concentrations, it was determined that the maximum methane concentrations were dispersed to a maximum half-diameter of 466 m from the landfill itself and did not arrived to the nearest settlements.

This paper also identifies the lack of adequate data on amount and type of landfilled waste during the previous period for a reliable estimation of the emission level from the landfill (data).

Further study requires a more precise methane emission estimation taking into account on site measurings at different temperature and precipitation regimes, while the modeled methane emissions need to be validated by monitoring ambient air at representative locations.

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Modelovanje distribucije metana u ambijentalnom vazduhu: studija slučaja deponija u Novom Sadu

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INFORMACIJE O RADU

Primljen 05 oktobar 2017
Prihvaćen 30 novembar 2017

Originalni rad

Ključne reči:
Emisija
Gas sa efektom staklene bašte
Deponijski gas
Metan
Modelovanje
Ambijentalni vazduh

I Z V O D

Deponovanje otpada je uobičajena praksa u Srbiji. Deponije su mahom neuređene i najčešće se odlaže otpad bez prethodne selekcije tako da predstavljaju nekontrolisan izvor metana, gasa sa efektom staklene bašte za koji se procenjuje da ima 20 puta veći potencijal globalnog zagrevanja od ugljen dioksida. U ovom radu je na osnovu raspoloživih podataka o stepenu emisije sa deponije izvršeno modelovanje rasprostiranja metana nakon emisije sa deponije, za periode dominantnih meteoroloških uslova. Takođe je izvršena kvantifikacija i karakterizacija modela ponašanja metana kao i njegova distribucija u ambijentalnom vazduhu. Analizom modelovanih koncentracionih nivoa metana utvrđeno je da su se koncentracije dostizale maksimalne vrednosti od 7478,9 $\mu g/m^3$ na udaljenosti od 455 m u pravcu dominantnog vetra ne utičući značajno na okolno stanovništvo.