Methane Emission and Carbon Sequestration Potential from Municipal Solid Waste Landfill, India

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Research Article

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Abstract

The quantities of waste generation are drastically increased every day, and most of the waste is disposed off through open dump and landfilling. Methane, carbon dioxide, and nitrous oxide are major greenhouse gases (GHG's) produced from landfill sites. However, the global warming potential of methane is 21 times higher than that of carbon dioxide. Hence, there is immense concern for utilization from landfill sites. In developing countries, the composition of municipal solid waste (MSW) has higher biodegradable waste (50–60%). This leads to emit higher GHG's from a per ton of MSW compared to the developed world. In this study, the attempt will be made to estimate the amount of carbon stored in MSW burial in landfills. Tests were conducted in two different locations at the Mavallipura landfill. MSW samples were collected for every meter interval (1-2m, 2-3m & so on) up to 6m. The result shows that carbon stored in organic matter increases with depth from approximately 2.2% at 1.0 m depth to 4.8% at 6m depth. Based on MSW's carbon storage factor and data on MSW generation, global carbon sequestration from MSW burial in the Mavallipura landfill is estimated to be at least 10 million metric tons per year. Also, the study aims to quantify methane gas production from the ward levels and the Mavallipura landfill site in India.

Introduction

A harmonious and balanced relationship between humans and nature on the earth is vital for the existence of life and sustainable development. As civilization advanced, humans directly or indirectly interfered with the natural environment for its comfort. Urbanization is a significant phenomenon that varies in social, economic, and environmental dimensions [1]. We have witnessed the dramatic shift of population from rural to urban areas and extensive expansion of the metropolitan regions [2]. At present, global climate change plays a vital role in environmental challenges facing society.

Consequently, more than 75 % of global anthropogenic carbon dioxide emissions have been produced from cities (Lester 2002). Meanwhile, large amounts of carbon have been identified in urban environments such as vegetation and soils and anthropogenic ones, including buildings and landfills [3]. Therefore, urban ecosystems' carbon cycle has received more considerable attention during the recent year [4]. The research focused majorly on carbon storage in natural pools [5] and rarely on carbon stored in landfills (anthropogenic pools). Due to the drastic growth in population and improved living standards, solid waste has escalated across the world [6]. In developing countries, the per capita MSW generated rate per year increased from 357.7–445.3 kg in the 1960s to 567-759.2 kg in the 2000s and for developing countries, 40.2 to 284.7 kg in the 1980s to 109.5 to 525.6 kg in 2000s [6]. A landfill is the cheapest disposal method of solid waste; currently, landfilling is the most common way to store MSW in most countries [7]. Besides, few research studies [8, 9] exist on investigating carbon storage in MSW landfills over large areas. These researches differ in how MSW landfill carbon dynamics may be represented. A combination of urban expansion and minimal studies on MSW landfill carbon dynamics has proven for more regional to global research to understand the importance of landfills in the carbon cycle.

In India, waste generation per capita increased from 0.44 kg/day in 2001 to 0.5 kg/day in 2011 due to lifestyles changing and drastic raise in procure power of Indians. Increased population growth and waste generation per capita have resulted in a 50 % increase in Indian cities' waste generation. As per the Census 2011, India generates approximately 110,000 metric tons of solid waste daily. Various research conducted by NEERI and other experts has shown that the waste generation rates are relatively high in cities over 2 million. A metropolis like Bangalore, located in India's southern part, generates about 3500 MT of waste per day [10]. Mumbai and Pune, located in India's western region, generates about 7000 and 3000 MT waste per day [11, 12]. Mumbai's population increased from 8.2 million in 1981 to 12.3 million in 1991 (i.e., 49%). The solid waste generated rose from 3.2 to 5.35 Gg per day during the same period, recording 67% growth. Chennai, a coastal city located in south India, witnessed a population growth of 21% from 1991 to 2001, while waste generation increased by 61% from 1996 to 2002. In Bangalore, the population increased by 53% from 1991 to 2012, while waste generation grew from 650 MTPD (in 2000) to 3500 MTPD (in 2015).

This shows the drastic increase in the production of waste in Indian cities concerning the population's growth. Therefore, a thorough estimation of carbon stocks and dynamics in India's landfills may greatly help understand urban areas' role in the carbon cycle at regional to global scales.

Presently, there is a lack of understanding in the global carbon cycle, and closing a global carbon balance requires a terrestrial sink of 1-2Gt C yr-1 [13, 14, and 15]. Several terrestrial carbon storage models have been developed [16]. However, the global uptake of anthropogenic carbon by the terrestrial system has been mainly deduced by differences in the global carbon budget. In this study, the attempt will be made to estimate the amount of carbon stored in the MSW burial in the Mavallipura landfill site. Also, the study aims to quantify methane gas production from the ward levels and Mavallipura landfill site in India.

Materials And Methods

Site description

The study area is situated in Bangalore north at Latitude 13°50' North, Longitude 77°36' East in Karnataka. Mavallipura landfill site has processed units for the waste generated from Bangalore cities. The annual average rainfall is 978mm. June to September is the primary rain seasons and secondary rainy seasons from November to December. The landfill site is located 20Km away from Bangalore city. Since 2005, villagers are used to dumping the waste by the local authority in 100 acres of land in and around. The landfill site was operated by M/s Ramky Environmental Engineers; it can sustain 600 tons of waste per day. But, BBMP forcefully transmits approximately 1000 tons of waste per day from Bangalore cities. In 2007, villagers complained that the landfill site is unregulated and didn't follow the waste management rules. As per the villager's views, the company collects the unsegregated wastes and piles the untreated waste at the landfill site. Hence, the villagers demanded to stop landfill site activities instantaneously as illegal and unscientifically managed. Finally, landfill locations are closed [17]. Mavallipura landfill site is about 40.48 hectares located in Mavallipura village, of which approximately 35 acres is used for landfill. The geographical representation of the Mavallipura landfill site is shown in Fig. 1.

Bangalore does not have scientific treatment method facilities for solid waste generated by municipal and industries around Bangalore. This has led to the development of several illegal and unauthorized dumpsites in Bangalore. The trash produced by the bulk generators such as hotels, restaurants, Kalyana mandapas, markets, etc., is being directly collected and transported to the treatment/disposal facilities. Figure 2 shows the location of these dumpsites along with wards and their boundary in Bangalore city.

Bangalore is the principal administrative, cultural, and commercial and knowledge capital of the Indian state of Karnataka. It covers an area of 1258 km^2 and has a population of about 10 million. Presently, the Bruhat Bangalore Mahanagara Palike (BBMP), the agency vested with responsibility for the disposal of solid waste, is engaged in the various activity to provide effective solid waste management (SWM) system for the Bangalore city, incorporating a series of approaches such as involvement of citizen, investment in infrastructure and technology, and also monitoring the various systems that are time managing the present mix of actions and techniques. For a more efficient and effective approach, the Bangalore city has been divided into different administrative units. There are 294 Health wards within the Bruhat Bangalore Mahanagara Palike (BBMP). The BBMP has a city council that consists of 123 elected members, or councilors, each representing a ward. For administrative purposes, the city of Bangalore is divided into eight zones namely: East(44-wards); West(44-wards); South(44-wards); Bommanahalli (16-wards); Mahadevapura (17-wards); R.R.Nagara (14-wards); Yelahanka (11-wards); Dasarahalli (8-wards), which are further subdivided into a total of 198 wards administered by the BBMP as shown in Fig. 3. Average MSW generated data about all zones are collected from BBMP and estimated methane emission using the IPCC default method and mass balance method.

Methodology

Theoretical estimation methods

Stoichiometric mass balance approach

The mass balance approach is the most superficial level of emission estimation. Its use is generally discouraged because it gives a high estimate of emissions. This method does not include any factors and does not distinguish between various types of disposal sites. Theoretical emissions are calculated using stoichiometric equations as per Tchobanoglous et al [18]. Comparisons for aerobic and anaerobic degradations considering complete degradation of waste are given by Eqs. 1 and 2.

$$C_{2.98}H_{0.462}\ O_{1.02}\ N0.099 + 2.659\ O_2 \rightarrow 2.98\ CO_2 + 0.0825\ H_2O + 0.099\ NH_3 \quad (1)$$

$$C_{2.98}\ H_{0.462}\ O_{1.02}N0.099 + 2.4287\ H_2\ O \rightarrow 1.1978\ CH_4 + 1.2143\ CO_2 + 0.099\ NH_3 \quad (2)$$

IPCC Default Methodology

According to this default method (IPCC method), the methane generation capacity was calculated based on the decomposable degradable organic and does not include changes in carbon conversion to methane emissions with time (IPCC, 1996).

$$\mathrm{CH_4} = \mathrm{MSW_T x MSW_F x MCF x DOC x DOC_F x F x} \left(\frac{16}{12} - \mathrm{R}\right) \mathrm{x(1 - OX)}$$

3

Where, MSW_T = Total municipal solid waste generated, MSW_F = Fraction of MSW disposed of at the disposal sites (0.6), MCF = Methane correction factor (0.6), DOC = Degradable organic carbon (0.200), DOC_F = Fraction of DOC dissimilated (0.77), F = Fraction of methane in LFG (0.5), R = Recovery of LFG (0), and OX = Oxidation factor (0).

Landfill Gas Emissions Model (LandGEM)

LandGEM model was developed by the Control Technology Center (CTC) of the United States Environmental Protection Agency (USEPA). LandGEM is a simple tool for assessment of rate for landfill gas, methane, carbon dioxide. Default parameters can be incorporated in LandGEM when no site-specific data are available [19]. LandGEM is based on the first-order decomposition rate equation to estimate annual emissions over time in a specific landfill. The respective formula used in LandGEM (version 3.02) is presented in Eq. 4.

$$Q_{CH4} = \overset{n}{\underset{i=1}{?}} \overset{1}{\underset{j=0.1}{?}} kL_o \left(\frac{M_I}{10}\right) e^{-kt_{ij}}$$

4

Where, QCH4 = annual methane generation in the year of the calculation (m3/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 (m3/Mg); Mi = mass of waste accepted in the ith year (Mg); tij = age of the jth section of waste mass Mi accepted in the ith year (decimal years, e.g.,3.2 years).

Total Organic Carbon (TOC) Analyzer

Photocatalytic Oxidation estimates TOC in the presence of UV Light and Oxygen. Titanium dioxide catalyzes the oxidation of Organic Compounds in an aqueous medium. This reaction yields Carbon dioxide, water, acid, base, or salt of any organically bound elements. The liberated Carbon Dioxide is detected by non-dispersive infra-Red (NDIR) Detector. TOC is measured by injecting a portion, tens, or hundreds microliter, of the sample into a heated TOC (to 680°C in an oxygen-rich environment inside) combustion tube packed with an oxidation catalyst. Water is vaporized and total carbon, organic carbon, and inorganic carbon is converted to carbon dioxide. The carrier gas flow stream carries this CO_2 from the combustion tube to a non–dispersive infrared gas (NDIR) analyzer; finally, Carbon Dioxide (CO_2) is measured. Based on the standard solutions, the calibration curve is prepared, and TC concentration is obtained and expressed in percentage. For estimation of the TOC schematic diagram is shown in Fig. 4.

Results And Discussion

Waste generated pertaining to all zones

Bangalore generates around 3500 tonnes of municipal solid waste, with per capita generation of 0.4 kg/day of domestic waste. We provide an overview of zone-wise data of February 2013 on MSW per day at the Bangalore city, as shown in Fig. 5. Zone wise analysis indicates the variability of waste generated in each zone shown in Fig. 6. A quantum of waste generation in three zones (East, West, and South) is high compared to others. Also, the much lower waste generation in Yelahanka could be attributed to low economic activities.

Average MSW generated data about all zones are collected from BBMP and estimated methane emission using the IPCC default method and stoichiometric mass balance method, are discussed. Total ward-wise waste generated is 100792.10 MT per day. The calculation of methane emitting from zones during February 2013 at Bangalore was established on the amount of waste disposal and use of three independent methodologies, namely the Intergovernmental Panel on Climate Change (IPCC), experimental and the Stoichiometric method showing a massive difference in the total amount of estimated emissions. Table 1 indicated that stoichiometric estimation of emissions from waste is much higher than the Intergovernmental Panel on Climate Change determined value. Meantime, mismanagement of waste, either due to lack of adequate workforce of a vital functional element in waste management, creates serious health and environmental implications. Table 2 indicated that Intergovernmental Panel on Climate Change estimation of emissions from waste is much higher than the stoichiometric determined value. Reduction of waste generation is possible through reduced waste generation, segregation at source level, reuse, and recovery of waste. Generally, organic waste constitute (60–70%), composting and anaerobic digestion are treatment options, whereas inorganic waste (20–25%) is used for recycling. Remaining wastes that cannot be recycled are ultimately dumped in landfill sites. However, source segregation with treatment at ward levels (local levels) plays a significant role in minimizing organic fractions getting into dump site.

Table 1
Statistical analysis of Methane Emissions from solid waste generated per month across the zone

Zones Greater Bangalore Municipality BBMP	Total SW/month (tons)	Mean SW generated (tons/day)	Std deviation	Ward wise SW generated (tons/day)	CH_4 Emissions (tons/day)	
					IPCC	Stoichiometric
East (44-wards)	25317.36	904.19	33.66	20.55	32.55	320.99
West (44-wards)	24385.64	870.92	48.90	19.79	31.35	309.18
South (44-wards)	20142.81	719.39	41.13	16.35	25.90	255.38
Bommanahalli (16-wards)	9075.55	324.13	52.56	20.26	11.67	115.07
Mahadevapura (17-wards)	11238.56	401.38	29.75	23.61	14.45	142.49
R.R.Nagara (14-wards)	4351.71	155.42	18.36	11.10	5.60	55.17
Yelahanka (11-wards)	2594.03	92.64	12.66	8.42	3.34	32.89
Dasarahalli (8-wards)	3686.43	131.66	9.69	16.46	4.74	46.74
Total	100792.10	3599.72	246.71	136.54	129.59	1277.90

Table 2
Methane emission from solid waste generated per day across the zone

No. of Days	Total MSW Generated in Tons per day (198 wards)	CH_4 Emissions (tons/day)	
		Default Methodology, IPCC	Stoichiometric mass balance approach
1	3321.23	119.56	1179.04
2	3578.44	128.82	1270.35
3	3544.48	127.60	1258.29
4	3730.72	134.31	1324.41
5	3674.68	132.29	1304.51
6	3604.77	129.77	1279.69
7	3684.87	132.66	1308.13
8	3639.01	131.00	1291.85
9	3643.06	131.15	1293.29
10	3571.99	128.59	1268.06
11	3708.40	133.50	1316.48
12	3610.59	129.98	1281.76
13	3597.66	129.52	1277.17
14	3666.78	132.00	1301.71
15	3694.97	133.02	1311.72
16	3584.03	129.03	1272.33
17	3445.72	124.05	1223.23
18	3719.34	133.90	1320.36
19	3718.83	133.88	1320.19
20	3612.93	130.07	1282.59
21	3720.65	133.94	1320.83
22	3607.94	129.89	1280.82
23	3650.82	131.43	1296.04
24	3471.45	124.97	1232.37
25	3493.83	125.78	1240.31

No. of Days	Total MSW Generated in Tons per day (198 wards)	CH_4 Emissions (tons/day)	
		Default Methodology, IPCC	Stoichiometric mass balance approach
26	3540.13	127.44	1256.75
27	3478.88	125.24	1235.00
28	3475.91	125.13	1233.95
Total	100792.10	3628.52	35781.20

ESTIMATION OF CARBON STORED IN MAVALLIPURA LANDFILL

Insitu waste sample collection

Estimating the carbon stored in the buried organic matter in the Mavallipura landfill site has been carried out. Using hand auger, the solid waste samples were collected at two different locations in the Mavallipura landfill, as shown in Fig. 7. Auger drilling operation using a 150mm diameter is carried out in a landfill site. The purpose of the auger drilling operation was to characterize the municipal solid waste visually, retrieve bulk samples of debris from different depths, and varying degrees of degradation and age.

The changes in the composition of MSW should form essential criteria for any waste management system. Hence, the data available on the MSW composition of the from different borehole A & B has been collected and analyzed. MSW composition mainly depends on several factors such as cultural traditions, food habits, socio-economic and climatic conditions. It also varies from place to place. Studies are carried in the Mavallipura landfill site with a 100kg MSW sample. The collected MSW sample is sorted physically in various ingredients, such as paper, fiber, metals, soils, glass, and miscellaneous waste on a sorting platform. The individual components are separated and weighed. From Fig. 8, the observed Municipal solid waste comprises 8 to 10% yard waste (garden waste), 20 to 21.9% of paper, cardboard waste in landfill, indicating recycling activities of paper and cardboard at the source itself. 35 to 39% of plastic might be due to the urbanization, and increased use of plastic carry bags, 9 to 9.7% miscellaneous wastes (includes textile, rubber, leather, and other) and 16 to 16.8% metals and glass products are effectively recycled by segregation at sources itself.

Solid waste samples were collected at two different locations in the Mavallipura landfill. Samples were collected for every half meter interval (0-0.5m, 0.5-1m, and so on) until 6m depth. The solid waste sample's first half-meter was discarded as it contained the soil cover mixed with the upper layer of waste. Samples were collected in the plastic bags, sealed and labeled, then brought back to the laboratory, and determined all the samples' moisture content. The rest of the samples were spread out for air drying in the room, as shown in Fig. 9. They were further dried at 65°C in an oven, and then the various components were manually separated and weighed. The soil component was separated using sieves of different sizes into three fractions, namely < 2.36 mm but > 1.18 mm, < 1.18 mm but > 600 µm, and < 600 µm. The slightest bit (< 600 µm) was used to determine the TOC analyzer's carbon content.

In-situ testing’s

Temperature Test

Temperature of the MSW material is recorded as soon as the waste is brought to the surface and attempt made to evaluate the age of MSW material, newspaper, magazines, or other documents can provide general information on the age of the MSW in the landfill at the location of the bore

From the Fig. 10 shows the temperature tended to increase with depth. Due to the heterogeneity of material. The highest temperatures for landfills were generally reported at mid-waste elevations with temperatures decreasing near the top. The temperatures near the top undergo variations similar to seasonal temperature fluctuations, whereas the temperatures at greater depth generally follow stable trends. Initial decomposition of wastes in a landfill occurs under aerobic conditions. Anaerobic conditions prevail upon depletion of oxygen at the bottom of the landfill. However, the trend shows some variations due to the heterogeneity of the waste.

Moisture content Test

At each depth, the moisture content of the MSW material is estimated by dry gravimetric moisture content: ratio of the mass of water in a waste sample to the mass of solids in the waste sample, expressed as a percentage. During the moisture content determinations, the temperature was maintained at 60° C to avoid combustion of volatile materials. From the Fig. 11 shows the moisture content tended to increase with depth. The moisture content increase with depth due to the degradation. The increase in moisture content may be also contributed to increasing in moisture content withholding capacity of MSW due to the disintegration of particles after degradation.

Unit Weight Test

In Mavallipura landfill, using the in-situ method of measuring the unit weight by replacing the waste with calibrated gravel. The weight of waste removed from a 0.5-1.0m length of the borehole was measured and the volume of the material was evaluated by backfilling the 0.5-1.0 m interval with gravel of known unit weight. The unit weight of MSW is expressed as a kN/m^3. Figure 12 shows the unit weight profile with depth ranging from a low unit weight of 3.8 kN/m^3 near the surface and the highest value of approximately 8.4 kN/m^3 at a depth of 6 m. The unit weight tended to increase with depth.

pH Test

The acidity or alkalinity of an MSW sample can be expressed on the pH scale. The unit of the scale is called pH value. This scale runs from 0 to 14 pH values. The neutral point in this scale is at pH 7.0. All values above pH 7.0 represent alkalinity and all values below 7.0 denote acidity. The degree of alkalinity increases as values go above pH 7.0 and the degree of acidity increases as the pH decreases below 8.0.

Figure 13 shows a pH variation of 8.3 to 8.9. pH is controlled principally by a series of chemical reactions. The important reaction is the degradation of organic materials to produce carbon dioxide and a small amount of ammonia. These dissolve in the leachate to form ammonium ions and carbonic acid. The carbonic acid dissociates with ease to produce hydrogen cations and bicarbonate anions which influence the level of pH of the system. Additionally, pH is also influenced by the partial pressure of the generated carbon dioxide gas that is contact with the leachate.

TOC Test

The typical height of solid waste dumping is 6m from the above ground level and the deposit consisted of uncompacted waste. By using Total organic carbon (TOC) analyzer, total organic carbon expressed in percentage was evaluated with respect to depth. From Fig. 14 shows that carbon stored in organic matter is increasing with depth from approximately 2% at 1.0 m depth to 23% at 6m depth. Similarly, the total carbon content of MSW in other countries has been reported to be the same range of 15.74 to 29.67 % being identified for Taiwan [20]. These ranges are considered to be more representative of a heterogeneous material obtained from an MSW In-situ testing.

Volume of Mavallipura landfill

The total volume of municipal solid waste in the Mavallipura landfill was determined by measuring the landfill area and average depth. A GPS tracker (Garmin) with an altitude display was used to measure the dumpsite's perimeter. The perimeter of the dumpsite is 867 m, and it encloses an area of 59,828 m^2 (Fig. 15(a)). Based on the contour map, the landfill's average vertical depth is 17m—typical Mavallipura landfill site sketch (Fig. 15(b)). The uncompacted waste dump area at the top level is about 875m^2; the volume is estimated for each respective depth till 6m, and the carbon stored in each layer is determined. Mass of the MSW in landfills above the ground level is calculated based on the density and volume with respective each layer. Carbon stored in the uncompacted waste is calculated based on the carbon content obtained from the TOC analyzer and mass of MSW stored in a landfill with respective layers. The carbon stored in the uncompacted waste, as shown in Table 3.

Table 3
Carbon stored in solid waste dump above the ground level

Above GL Depth, m	In-situ density, kN/m^3	Mass of MSW Stored in landfill, metric tons	Carbon content obtained from TOC analyzer, %	Carbon stored in landfill, metric tons
1	4.02	1157	2	23.14
2	4.5	1245	5	62.25
3	5.8	1552	7.5	116.4
4	7.0	2168	12	260.16
5	7.45	2327	16	372.32
6	8.0	2562	23	589.26
Total Estimated MSW carbon stored above the ground level				1423.53

Due to the physical nature of solid waste present in the landfill, it is tough to conduct the boring and sampling below the ground level. Hence, the total volume is calculated based on the contour map. The total volume of landfill below the ground level is 52714 m^3, assuming the bulk unit weight is $8kN/m^3$, the carbon content is 23%. The total Mass of MSW stored is 42171 metric tons, and the total carbon stored in MSW is 9699metric tons below the Mavallipura landfill is estimated. Finally, the sum of the net amount of standing stock carbon deposited above and below dump is 11122.53 metric tons.

Global Carbon Sequestration from Mavallipura landfill

Carbon sequestration from MSW buried in the Mavallipura landfill on a global scale was estimated by using Eq. 5.

Cseqi = Gi x LFfri x CSFm (5)

Gi is the mass of MSW generated in the Mavallipura landfill is 600metric tons per day; LFfri is the fraction of waste generated in Bangalore buried in landfills; CSFm is the carbon stored factor is 0.302 based on the EPA's guidelines.

Global carbon sequestration due to MSW burial in the Mavallipura landfill is estimated to be $10x10^6$ tons per year. Only stored carbon associated with paper, plastic, wood, and yard. etc., was considered.

Barlaz [21] reported the global carbon sequestration of MSW burial in the US landfill is estimated to be 118.7x106 per year. Bogner [22] determined the carbon sequestration of MSW burial in the US landfill was found to be $31.6x10^6$ tons per year.

Carbon sequestration is one of the significant factors that should be considered in comparing the environmental benefits and liabilities associated with the MSW landfills in specific and MSW management strategies in general. Other factors include gaseous emissions from MSW decomposition and the equipment used for MSW landfill operation, energy consumed during MSW landfill construction and maintenance, and methane's potential recovery for energy. Hence, appropriate treatment options are necessary to treat the municipal solid waste's organic fractions to reduce Greenhouse Gas Emissions. Decentralized treatment options of converting to energy or composting would provide a better solution by converting the waste to wealth.

METHANE PRODUCTION FROM MAVALLIPURA LANDFILL

IPCC Default Method

The methodology was adapted from IPCC [23]. Methane emission for Bangalore waste was estimated as

Methane emission = 1227.5 x 0.80 x 0.6 x 0.200 x 0.77 x 0.5 x 16/12 = 63 Gg/yr

Obtained methane emission is used to calculate energy and power generation using a density of methane at standard conditions was taken as 0.7167 kg/m^3 and calorific value (lowest) as 9,000 kcal/m^3. Energy production for one-year adopting a gas collection of 80 % is 2,375 TJ, and the corresponding power generated is calculated as 75 MW.

LandGEM model

Mavallipura landfill methane emission is calculated based on the landfilled waste data for the period 2007 to 2013. The amount estimation of generated methane is the landfill site (1,022,000 Mg/year), annual acceptance rate, and concentration of total non-methane organic compounds (4,000 ppmv as hexane) and the years of waste acceptance. Figure 16 illustrates the drift of methane gas emissions in different years of Mavallipura landfill site projects. Results revealed that the amount of annual waste generation in the Mavallipura landfill, in the range of 1, 10,000 tons to 2,20,000 tons from the open landfill to closure landfill.

Over time, the landfill scenario has been changing. With a drastic increase in waste generation rates, scarcity of land availability, and GHGs issues, there is a unique need to modify the existing landfill design aiming at the energy and power generation from waste with less requirement of the area. The calculations of methane emitting from landfill during 2007–2013 at the Mavallipura landfill were establish on the amount of waste disposal and use of three independent methodologies, namely, Intergovernmental Panel on Climate Change (IPCC), and LandGEM showing a minor difference in the total amount of estimated emissions.

Conclusions

This study indicated that stoichiometric method estimation of methane emissions from waste is much higher than the Intergovernmental Panel on Climate Change determined values. Reduction of waste generation is possible through reduced waste generation, segregation at source level, reuse, and recovery of waste.

This study's objective illustrated that the carbon storage factor for MSW and data on MSW generation, global carbon sequestration from MSW burial in the Mavallipura landfill is estimated to be at least 10 $x10^6$ tons per year. Based on the landfill site's characterization, it can be said that the Mavallipura landfill site is still in a degradation process.

Over time, the Mavallipura landfill scenario has been changing. With a drastic increase in waste generation rates, scarcity of land availability, and GHGs issues, there is a unique need to modify the existing landfill design aiming at the energy and power generation from waste with less requirement of the area. The calculations of methane emitting from landfill during 2007–2013 at the Mavallipura landfill were establish on the amount of waste disposal and use of two independent methodologies, namely, Intergovernmental Panel on Climate Change (IPCC), and LandGEM showing a minor difference in the total amount of estimated emissions. The maximum methane production rate occurred in the year 2007–2013.

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Figures

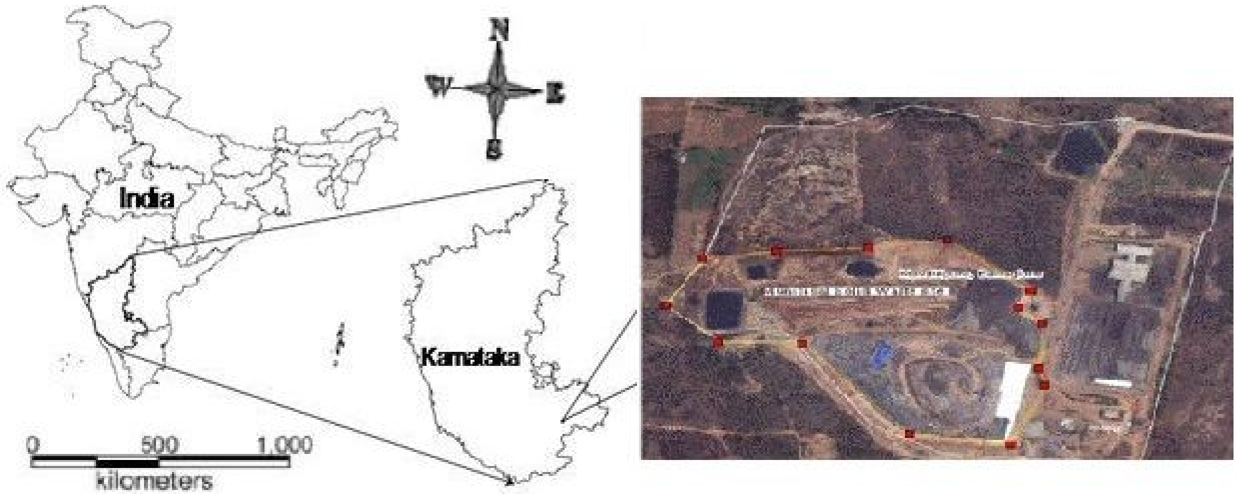


Figure 1

Location of Mavallipura Landfill. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

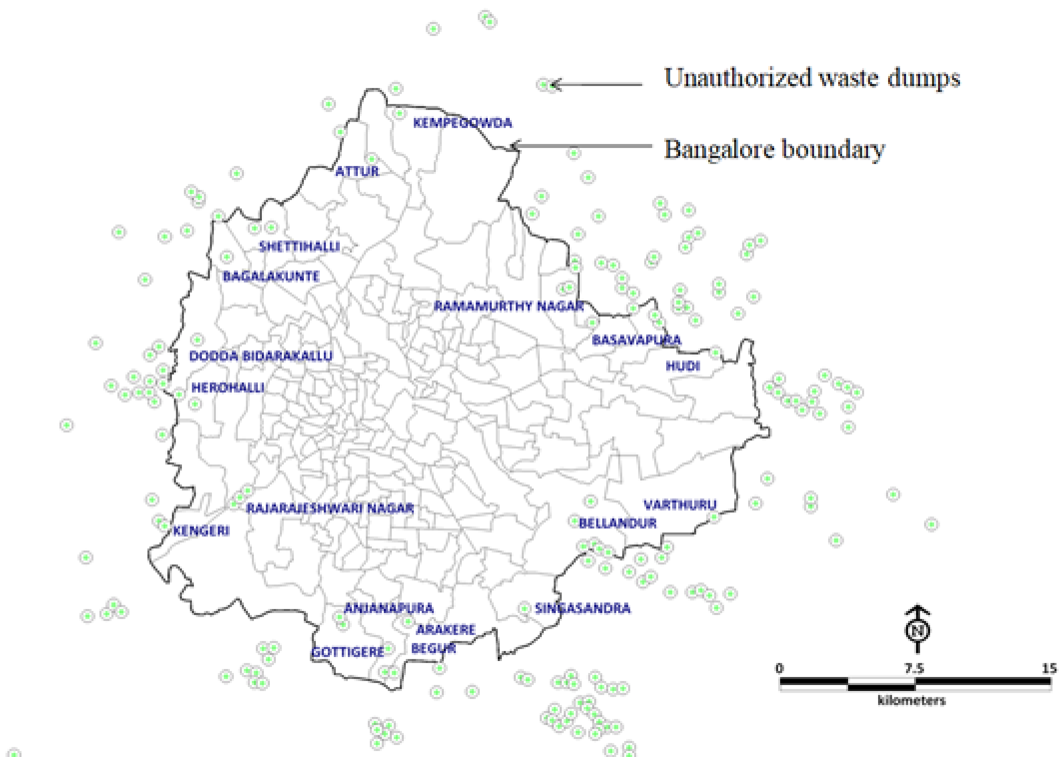


Figure 2

Unauthorized dumping along with wards in and around Bangalore city

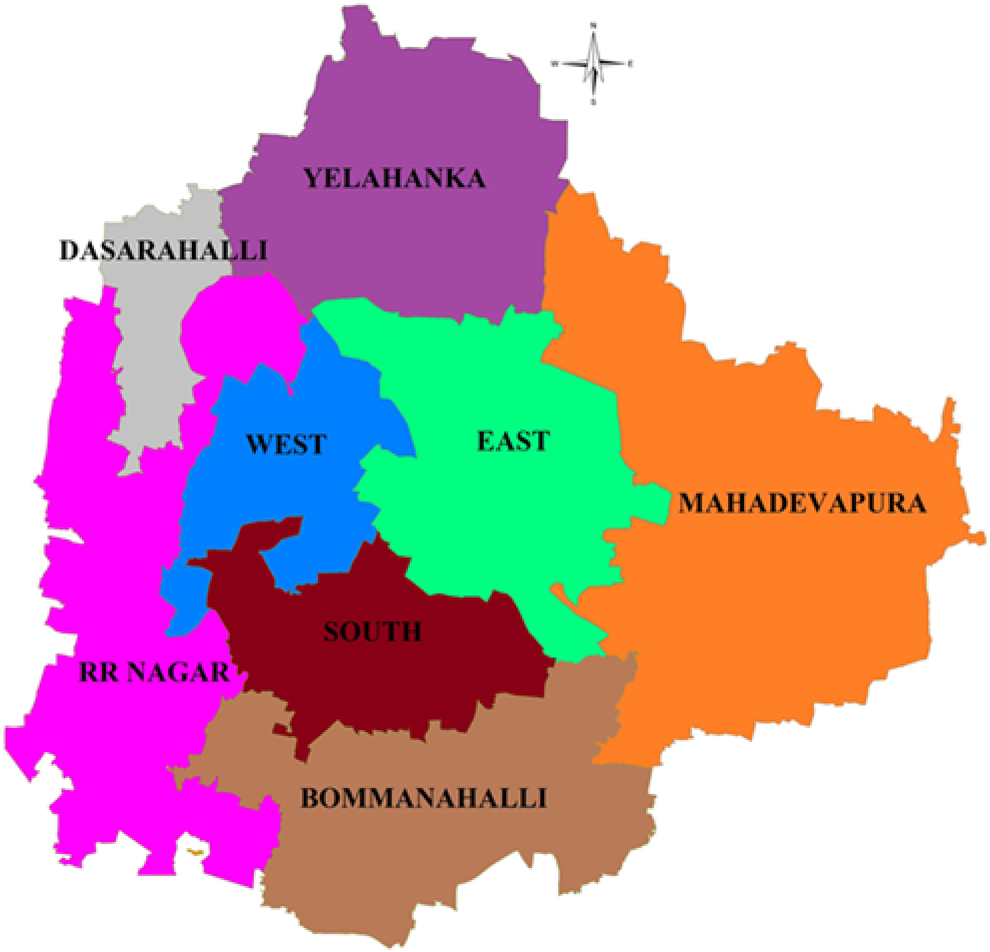


Figure 3

Unauthorized dumping along with wards in and around Bangalore city

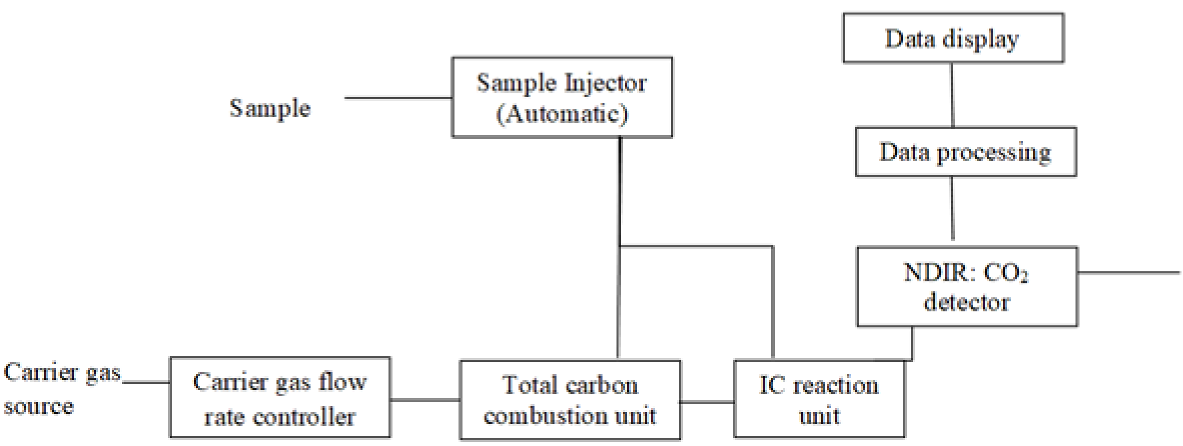


Figure 4

Schematic diagram of TOC analyzer

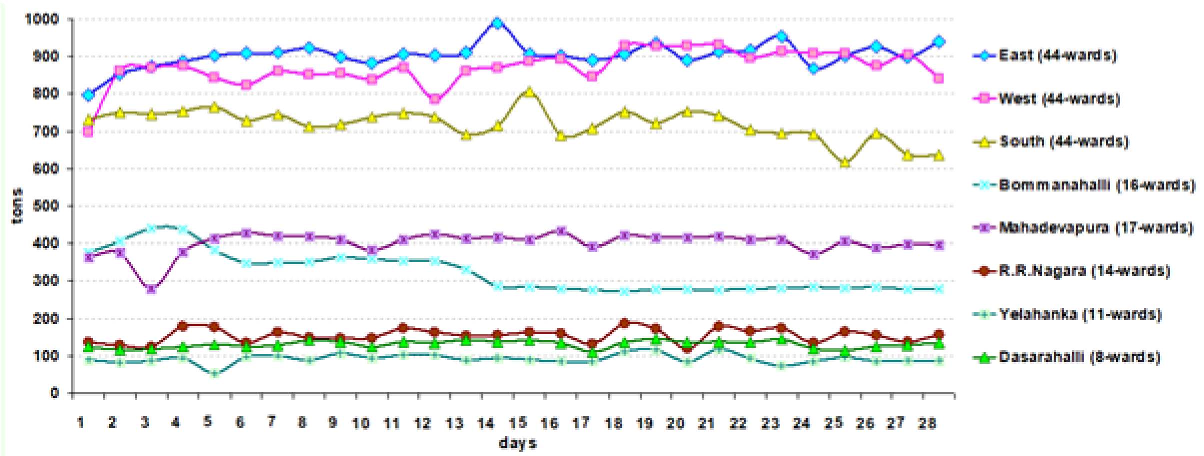


Figure 5

MSW generation per day in all wards

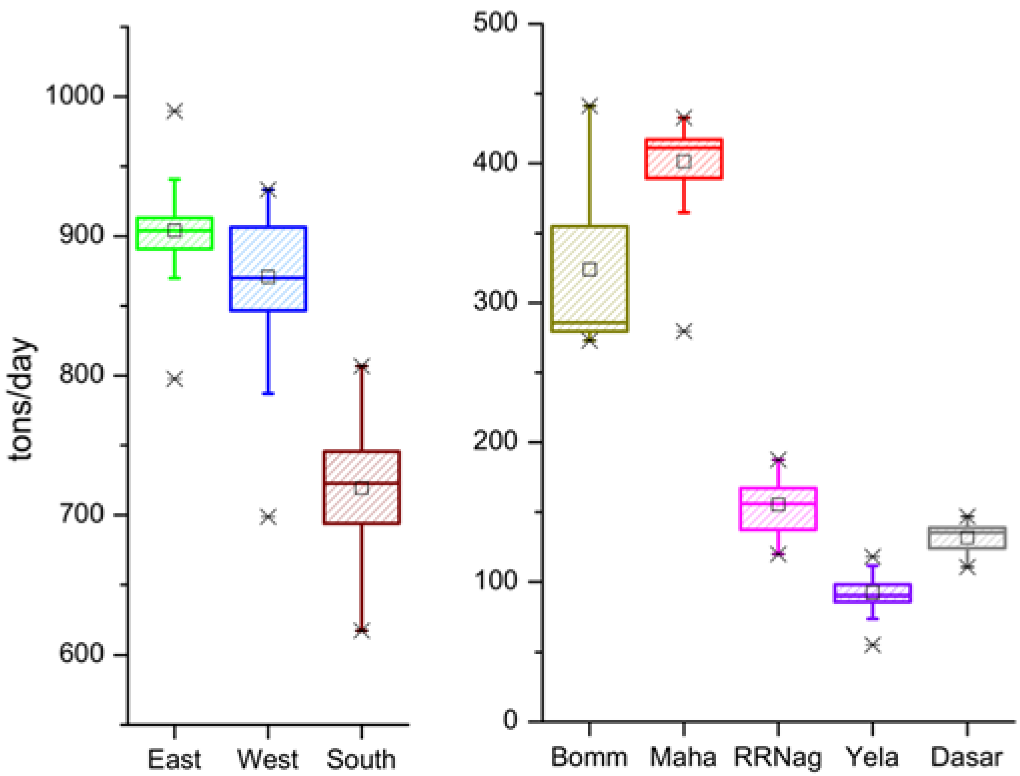


Figure 6

Zone-wise generation of waste per day

Figure 7

Sampling using a manual auger at every half-meter interval

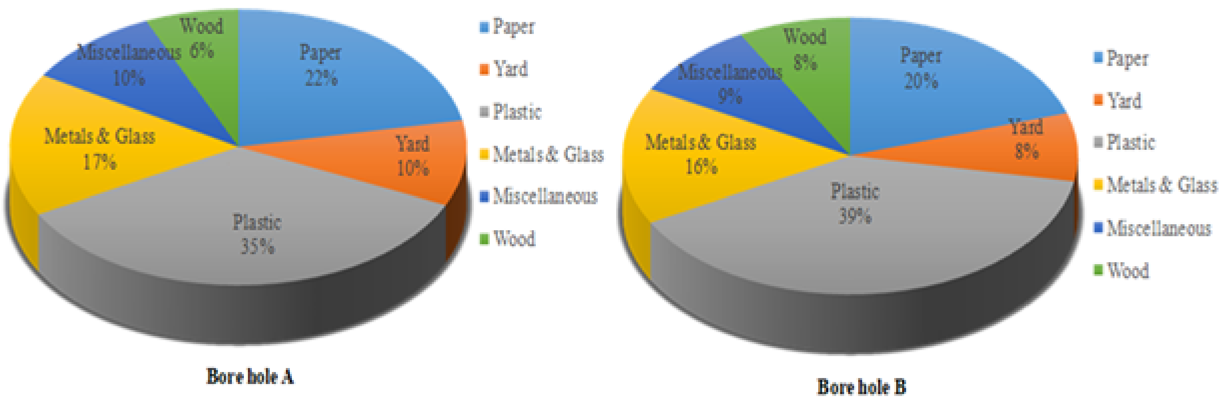


Figure 8

MSW composition at Mavallipura landfill

(a): Air dried (b): Oven dried (c): finest fraction (<600 μm)

Figure 9

Sample preparation

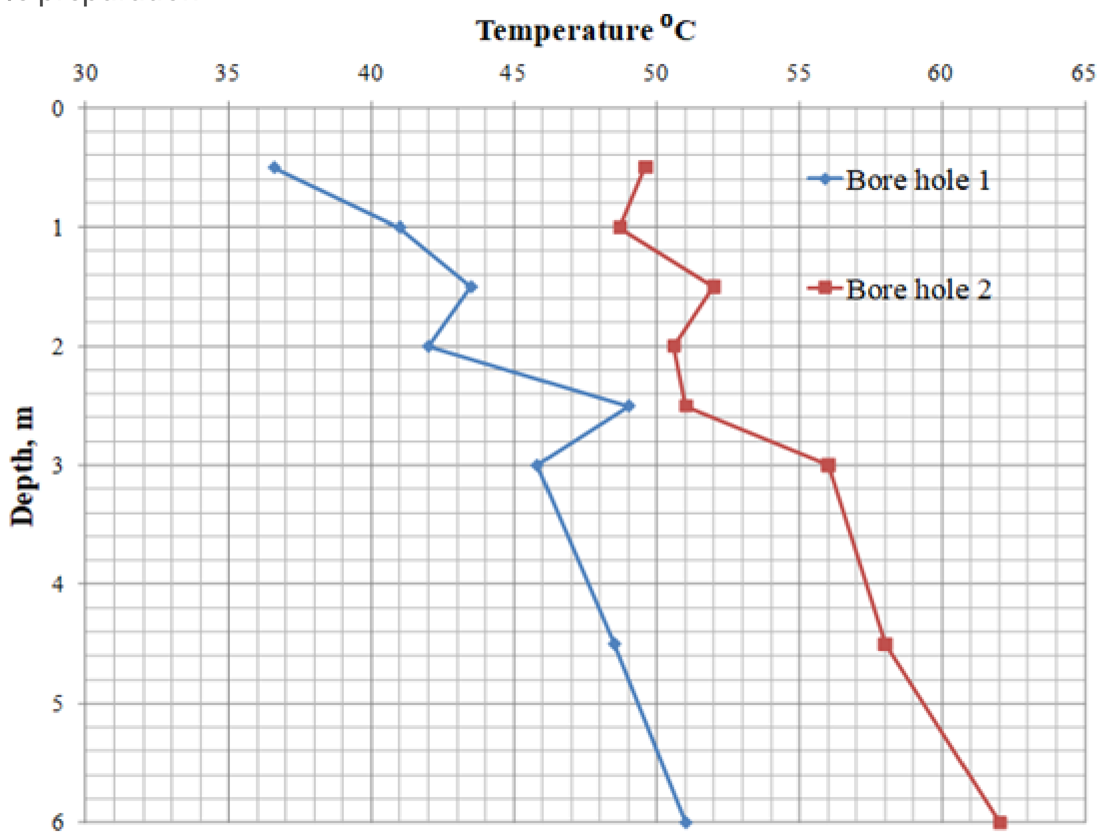


Figure 10

Variation in the temperature with depth

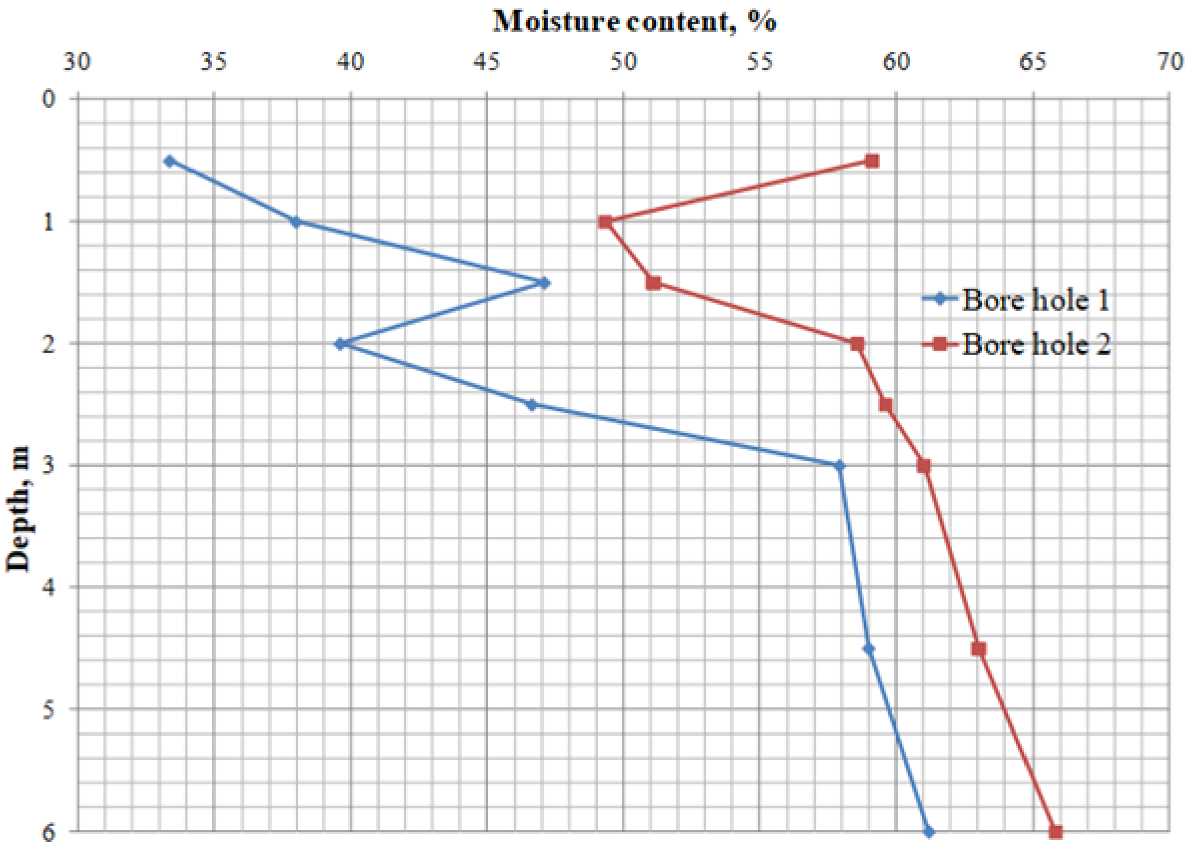


Figure 11

Variation in the moisture content with depth

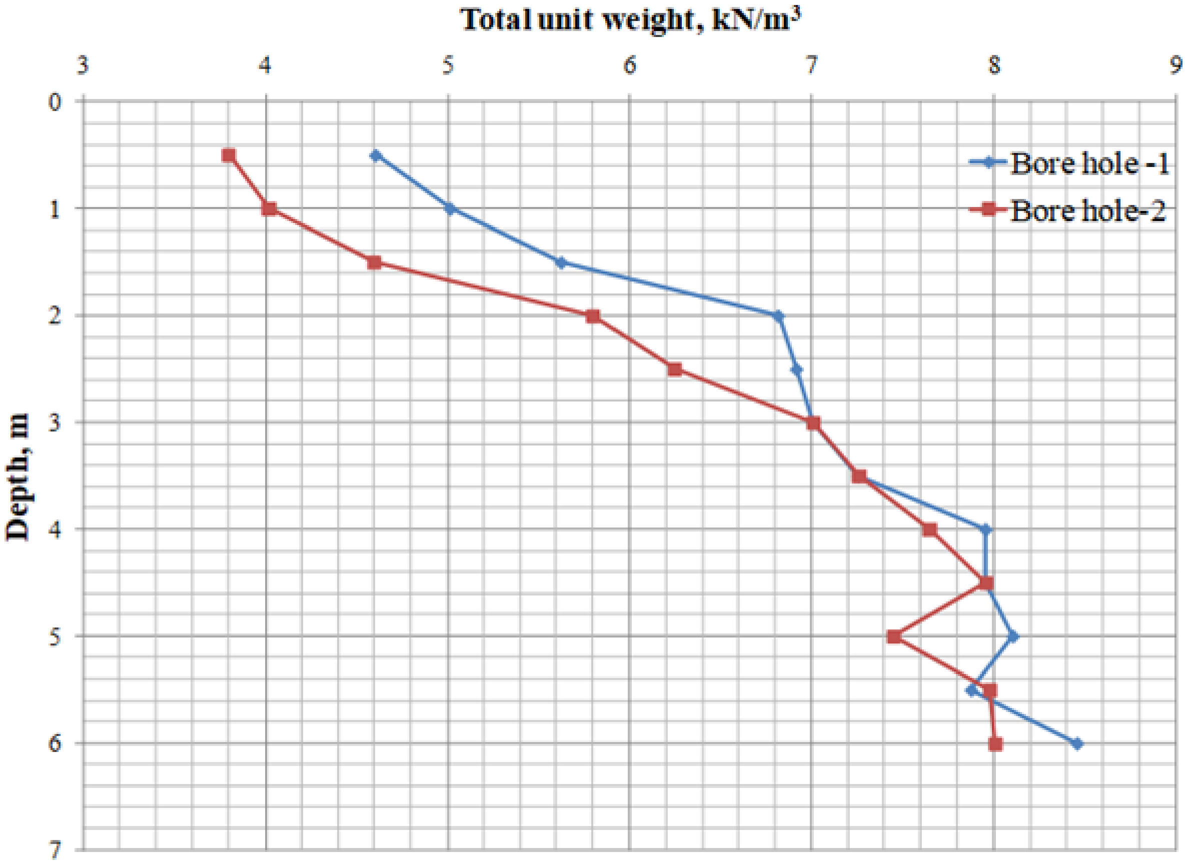


Figure 12

Variation in the total unit weight with depth

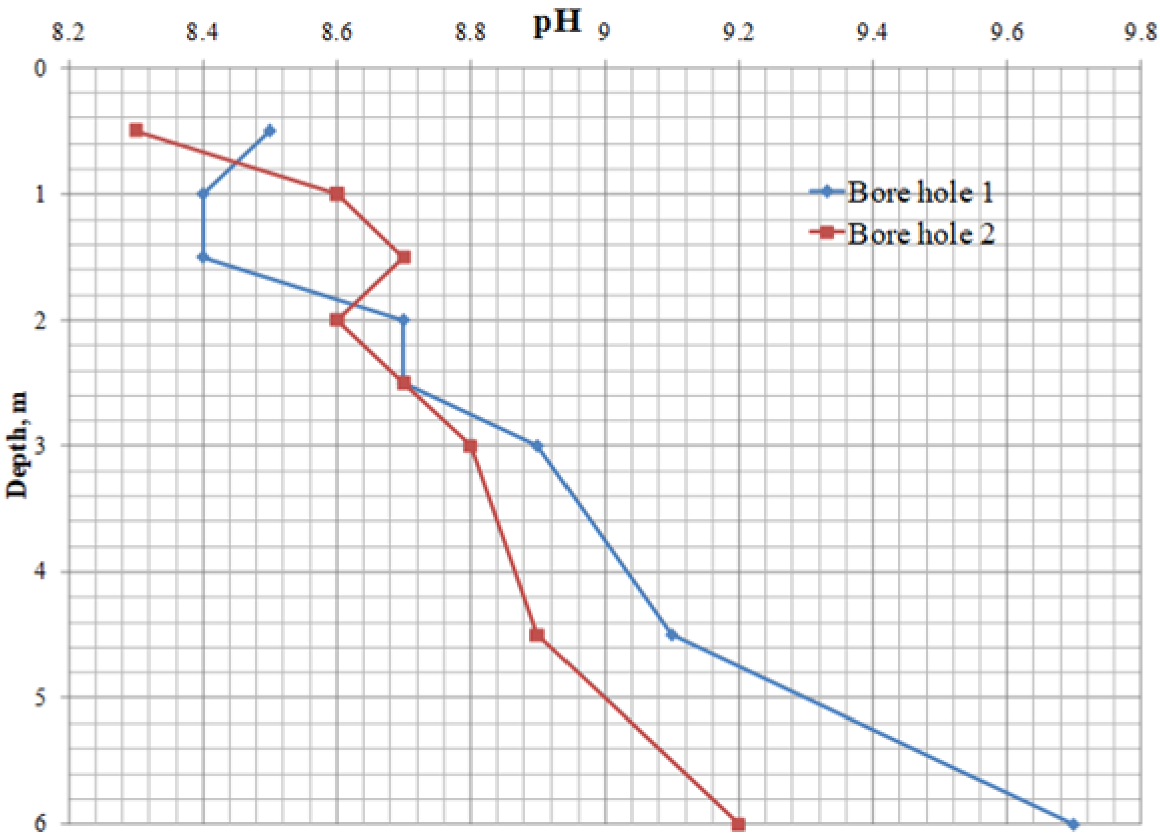


Figure 13

Variation in the pH with. Depth

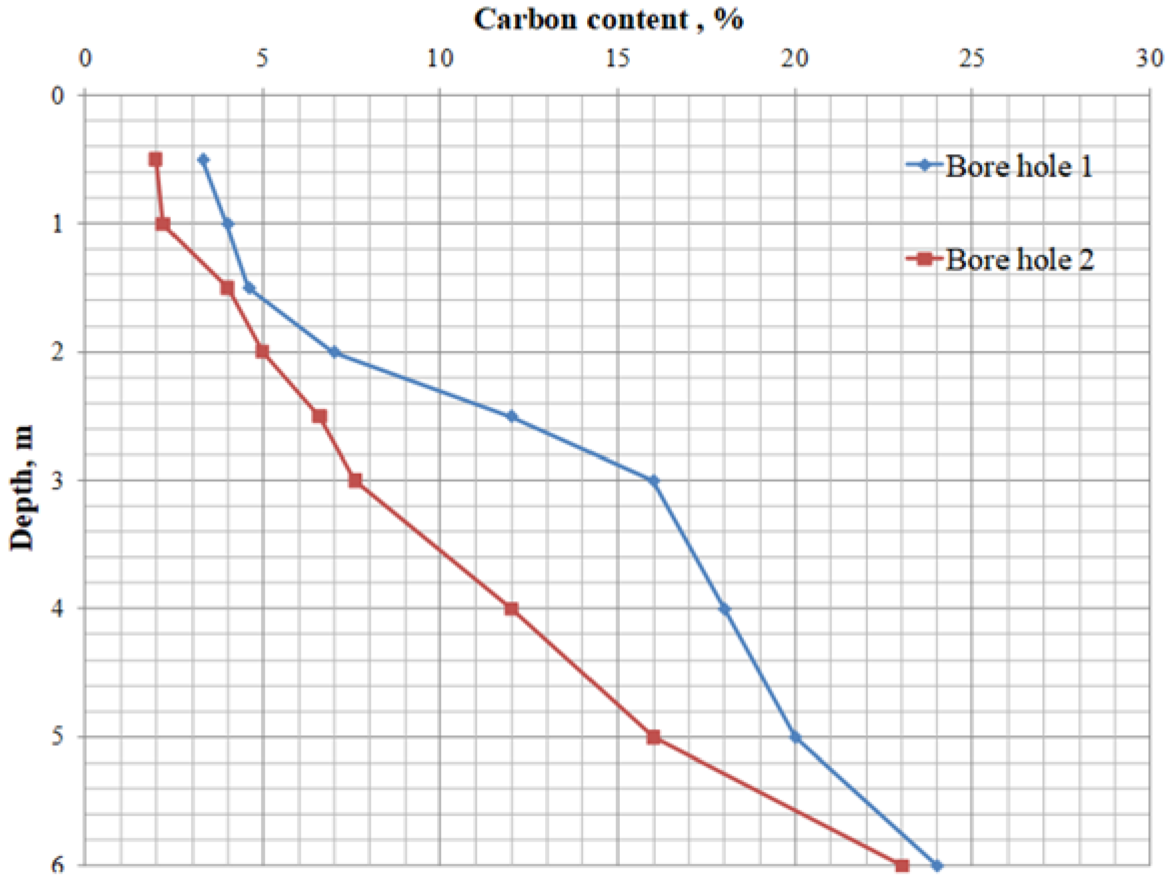
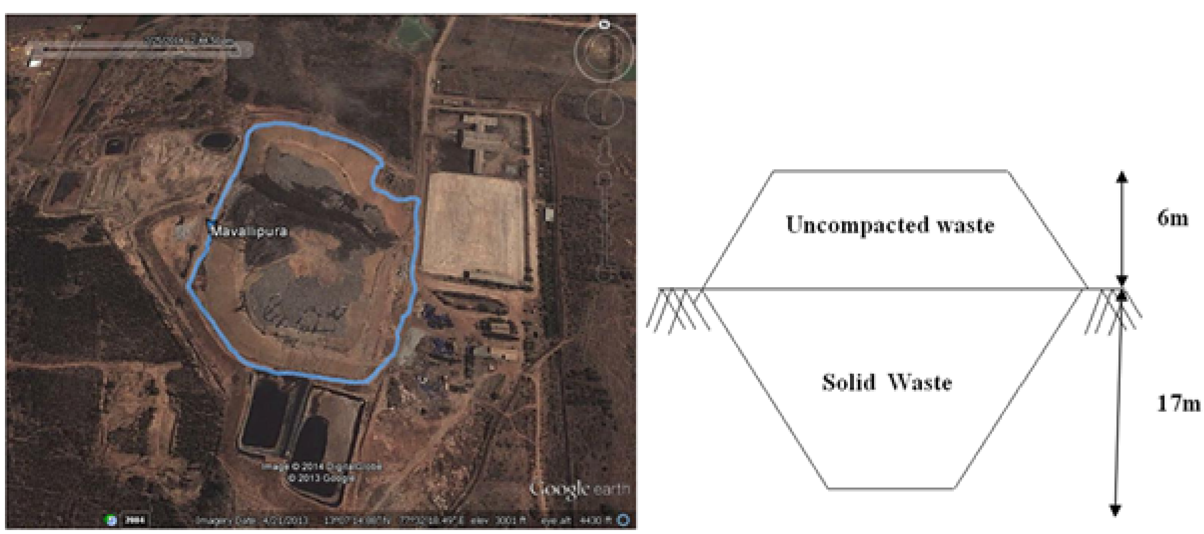


Figure 14

Variation in the Carbon content with depth



(a): perimeter of dumpsite (b): Typical landfill sketch

Figure 15

Variation in the Carbon content with depth

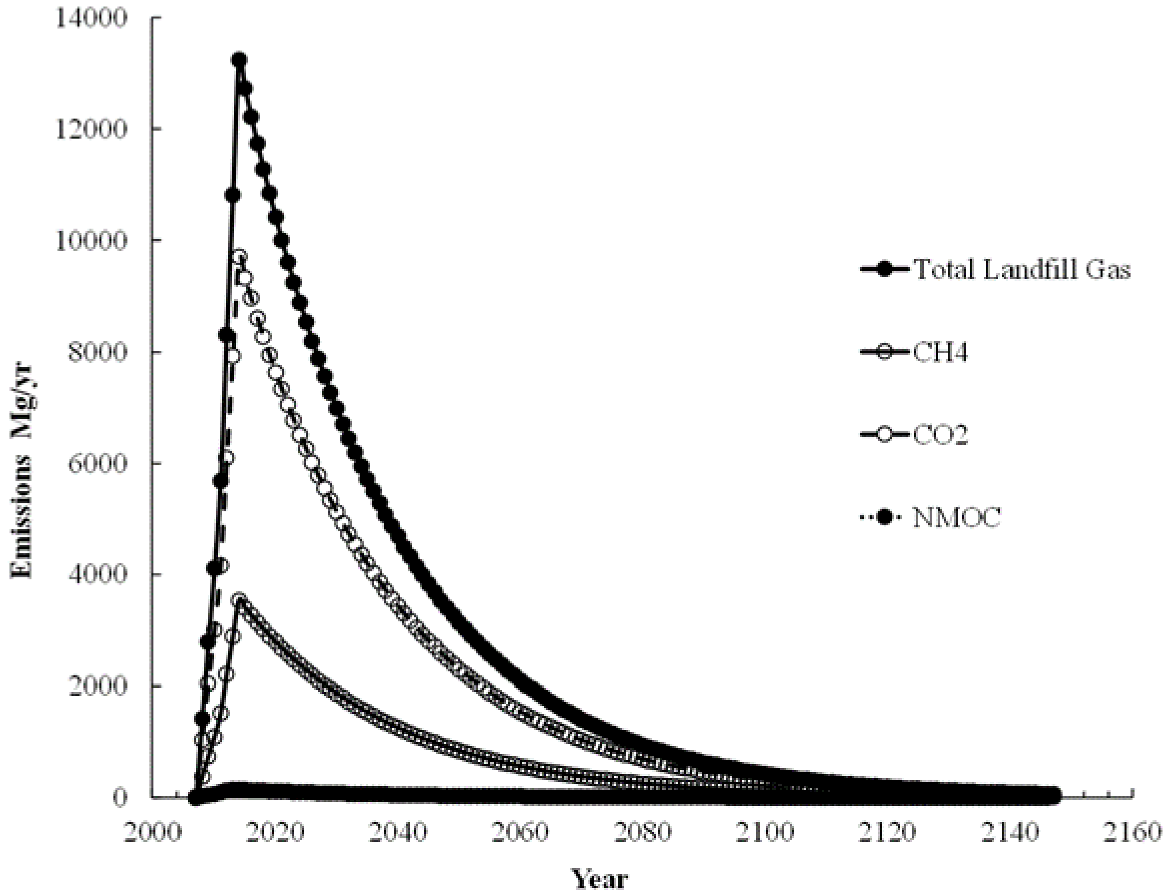


Figure 16

Estimated amount of gas emission with time from Mavallipura landfill site