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A Comprehensive Review of Atmospheric Air Pollutants Assessment Around Landfill Sites

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ABSTRACT: Air pollutants generated as a result of operations of landfill sites pose a threat not only the environment but also to human life. This work focuses on comprehensive review of atmospheric air pollutants around landfill sites with a view of identifying areas where future studies can be conducted. Environmental and health effects of air pollutants within the vicinity of landfill sites and the ways of minimizing the level of the air pollutants were presented. Previous works carried out by scholars for the past two decades were critically examined. Mathematical models for prediction of gaseous pollutants for landfill sites and assessment of human health risk due of inhalation of poisonous gases from landfill sites were discussed. Amongst conclusions made were: (1) Further studies on health impacts of particulate matters (PMs) within the vicinity of landfill sites should focus on low-income countries (LIC) especially in Nigeria which has been perceived as the capital poverty of the world. (2) Developing countries have not been practicing Circular Municipal Solid Waste Management System (CMSW) due to some militating factors hence further works should look into how the militating factors can be surmounted and provide way forward for the implementation of CMSW in developing countries. (3) More works still need to be conducted especially in temperate region to mechanistically explain the positive correlation between PMs and Coronavirus disease. (4) Future works should dive into the cost and economic implications of assessing atmospheric air pollutants within the vicinity of landfill sites for policy making decisions.

KEYWORDS: Landfill, air pollutants, kinetics, atmospheric, assessment

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Introduction

Human activities lead to generation of solid wastes that are usually solids and discarded as unwanted or useless (Salami, Odunlami et al., 2018). According to International Solid Waste Association (ISWA), 2.6 million tons per day of municipal solid waste is generated globally which may escalate to 4.5 million tons per day by 2050 (ISWA, 2021). The management of solid wastes involves minimization of waste generation, proper onsite handling and storage, adequate collection and transfer, and waste processing and recovery. Proper management of solid waste in developing countries is a big challenge which has been attributed to lack of financial resources and inadequate administration, lack of comprehensive and effective legislative framework, lack of awareness, inadequate data and information on solid waste (Imad, 2011; Khatib & Al-Khateeb, 2009; Ramachandra et al., 2018).

Disposal of wastes to open dumpsites is a common practice in developing (Ferronato & Torretta, 2019; Ferronato et al., 2017; Gupta et al., 2015; Imam et al., 2008; Salami et al., 2011; Salami & Susu, 2019). The operation of open dumpsite results to air pollution which is the contamination of air which makes it unfit for living. Air pollutants especially from dumpsites have very serious negative impacts on human health and environment. The solid wastes undergo microbial anaerobic digestion and release biogenic hydrocarbon gases such as polychlorinated dibenzo-p-dioxins (PCDD), vinyl chloride monomers, non-methanic volatile organic compounds, dibenzofurans, polycyclic aromatics hydrocarbons, odor, dioxin—like polychlorobiphenyls (PCB) and benzene (Palmiotto et al., 2014; Powell et al., 2016; Soile et al., 2018). These gases enter the atmosphere and ultraviolet radiation act as a catalyst and they are converted to gaseous pollutants including hydrogen sulfide (H_2S), ozone (O_3), carbon monoxide (CO), oxides of nitrogen, carbon dioxide (CO_2), and sulfur dioxide (SO_2) (Kumar et al., 2004). Figure 1 shows gas emission from a landfill site.

PMs which are also air pollutants are known as atmospheric aerosol particles or suspended particulate matters (SPMs). They are tiny particles of liquid or solid matter suspended in the air (Seinfeld & Pandis, 1998) which sources can be anthropogenic or natural (Plainiotis et al., 2010). PMs can be divided into three groups based on size: the coarse fraction having an aerodynamic diameter of less than 10 μm (PM_{10}) which are formed when larger solid particles are broken mechanically, fine fraction with aerodynamic diameters between 2.5 and 10 μm ($PM_{2.5}$) which are predominantly formed from gases and ultrafine fraction with aerodynamic diameters in the range of less than 2.5 μm and less than 0.1 μm (UFP or $PM_{0.1}$) which are formed as a result of nucleation (Agarwal & Shiva Nagendra, 2016; Araújo et al., 2014; Christian et al., 2008; Dianna, 2020).

PMs are mixtures of particles which can be grouped based on origin, into two: primary particles which are directly emitted into the atmosphere by human activities, combustion processes or wind, and secondary particles which are formed in the atmosphere by gaseous pollutants transformation (Parvez et al., 2017; Popoola et al., 2018). PMs are generated in dumpsites as a result of human actions by mechanical processes which include sorting, tipping and waste compaction by bulldozers, stock piling of soil, movement of vehicles and dustcarts over

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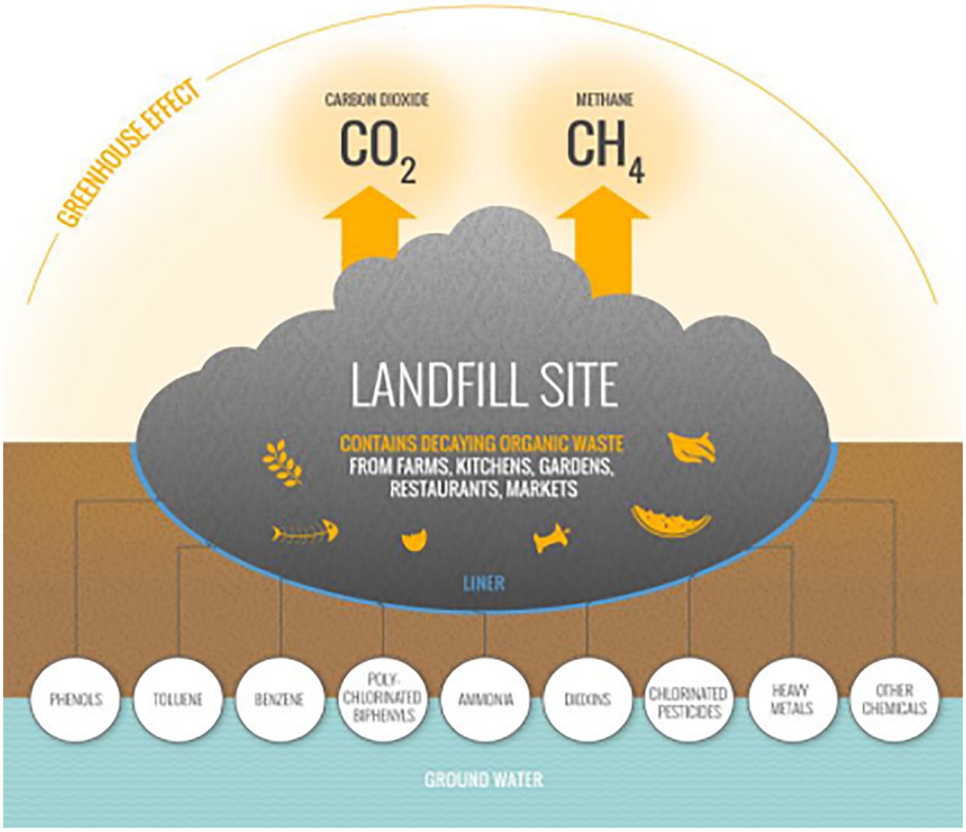

Figure 1. Gas emission from a landfill site.

past deposited waste. PMs are also generated when materials of altered and decomposed wastes are dispersed by wind (Chalvatzaki et al., 2010).

Several scholars have worked on assessment of air pollutants within the vicinity of landfill sites (Abaje et al., 2020; Angaye & Nestor Abowei, 2018; Koshy et al., 2009; Maisonet et al., 2004; Musa et al., 2021; Nixon et al., 2013; Richa et al., 2011; Saxena & Bhardwaji, 2003; Scheutz et al., 2017; Zmirou et al., 1994). Continuous assessment and critical review of previous works carried out by scholars on assessment of atmospheric air pollutants within the vicinity of landfill sites is important in order to X-ray what has been done and suggest works for future studies. The aim of this work is to carry out a comprehensive review of various works on assessment of atmospheric air pollutants within the vicinity of landfill sites with a view of providing what can be worked on in future studies which justifies this work.

Environmental and Health Effects of Air Pollutants Generated in Landfill Sites

Health effects of air pollution

Long term exposure to PMs can result different respiratory diseases such as respiratory tract inflammation, lung cancer and asthma (Guo et al., 2017; Jeon et al., 2011; Pan et al., 2010; Salami, 2022; Sun et al., 2020; Zhao et al., 2019; Zhu et al., 2021). Previous works of scholars had also shown exposure to PMs lead to cardiovascular problems (Brook et al., 2010; Cao et al., 2011; Li, Geng et al., 2017; Long et al., 2020; Radan et al., 2019; Tofler & Muller, 2006). The findings from the work of Guo et al. (2017) revealed that an increase of $10\,ug/m^3$ $PM_{2.5}$ and PM_{10} may result to a rise in circulatory disease mortality and cardiovascular problem, by 1.22% and 0.55% respectively. PMs have a high impact on the central nervous system of human (Feng et al., 2013; Mostafa et al., 2016; Wiedinmyer et al., 2014). In 2018, World Health Organization (WHO) report indicated that 93% of children were exposed to $PM_{2.5}$ at a concentration more than the guideline level, out of which 630 million were under the age of 5 years and 1.8 billion under 15 years.

The report of Douglas et al. (2017) and Zhao et al. (2019) showed there exit a correlation between exposure to PMs and immune function. Exposure to PMs impaired immune function (Douglas et al., 2017). Recent studies (Jiang et al., 2020; Li et al., 2020; Yao et al., 2020; Zhu et al., 2020, 2021) have equally established a positive correlation between PM and risk of COVID-19 infection especially in temperate region. However a mechanistic explanation was not provided hence further studies are required in this area in order to provide mechanistic explanation for the correlation between PM and risk of COVID-19 infection. It is evident

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from myriad of several epidemiology studies that residence within the vicinity of landfill sites, exposed to PMs have a high risk of having immune malfunction, central nervous disorder, respiratory, cardiovascular, and cerebrovascular problems. More studies are still needed to be conducted to establish if exposure to PMs could lead to risk of COVID-19 infection problems in temperate and non-temperate region.

It is pertinent that more works on health effects of PMs be carried out in low-income countries (LIC) as 69% of researches reported on health effects of PMs were done in high-income countries (HIC) (Sharma et al., 2020). The yearly mean exposure of $PM_{2.5}$ between 2011 and 2017 for LIC and HIC were 48.42 and 20.02 ug/m^3 respectively (Sharma et al., 2020). This is also a cogent reason why future studies on health impact of PMs particularly within the vicinity of landfill sites should focus more on LIC especially in Nigeria which is perceived as the capital poverty of the world.

Gaseous pollutants from landfill sites equally have tremendous impact on human health. Exposure to CH_4 from landfill sites may result to wheezing, shortness of breath, asphyxia or loss of consciousness, burning in the mouth or coughing (Byard & Wilson, 1992; Kumar & Gupta, 2021). Acute exposure to H_2S leads to acute respiratory failure, eye irritation, and even dearth (Doujaiji & Al-Tawfiq, 2010; Gabbay et al., 2001; Langford, 2005; Snyder et al., 1995). Lambert et al. (2006) and Lewis et al. (2003) reported long time exposure to H_2S causes ophthalmic lesions and malignant disorders respectively although it was pointed out that H_2S at ambient level plays a vital role in the cardiovascular and immune system as well as central nervous system. CO_2 is also one of the pollutants emanating from landfill sites. Jacobson et al. (2019) had shown that exposure to CO_2 at elevated concentrations above the natural concentration will result to inflammation, kidney calcification, bone demineralization, reduction in higher-level cognitive abilities and endothelial dysfunction.

The result of the work of Amaducci and Downs (2022) stated that the minimum adverse effect was 5 ppm of NO_2 for human short-term exposure. The health of effects of NO_2 includes asthma, inflammatory reaction and decrease in lung function (Lindall, 1985; Salami, Odunlami et al., 2018; Samoli et al., 2006). The health effects of SO_2 are also related to the health effects of other pollutants. Previous epidemiology studies revealed exposure to SO_2 causes respiratory problems, retardation in growth of fetuses of pregnant female gender and premature death (Altounyan & Cole, 1986; Chen et al., 2007; Cox & Penkett, 1971). CO is a poisonous gas. It combines with hemoglobin in the blood which in turn reduces the ability of blood to carry oxygen to the body organs. According to California Air Resources Board (CARB, 2022), the health effects of CO are not limited to headaches, fatigue and dizziness, difficulty in breathing and inadequate supply of oxygen to the brain which may result to stroke. It causes ischemia, hypoxia, and cardiovascular diseases (Manisalidis et al., 2020).

Ozone (O_3) which is also a pollutant generated in landfill sites is formed through a chemical reaction between nitrogen oxides and volatile organic compounds (VOCs). O_3 causes immunological, functional biochemical and morphologic disorder in human (Lippmann, 1989). It is undoubted from several epidemiology studies that residences within the vicinity of landfill sites exposed to air pollutants emanating from landfill sites have a huge risk of developing asphyxia, acute respiratory failure, ischemia, ophthalmic lesions, kidney calcification, and bone demineralization. Other health effects are endothelial dysfunction, decrease in lung function, pregnancy problem, and premature death.

Environmental effects of air pollutant

According to CARB (2022), presence of PMs impacts negatively on the environment by causing a decrease in visibility (haze). PMs are absorbed in atmosphere and scatter light. As the volume of PMs increases in the atmosphere especially $PM_{2.5}$, more light is scattered resulting in less clarity. This is an indication that people living within the vicinity of landfill sites are likely to be susceptible to visibility problem.

Gaseous air pollutants emanating from landfill sites such as SO_2, NO_2, CH_4, and H_2S react with water vapor in air and in the presence of ultraviolet ray, form acid rain (Sobodh, 2017; USEPA, 2022). The acid rain peels paints and corrode roof. This shows the residence within the vicinity of landfill sites will incur more expenditure for maintenance of their structures when compared to those who do not leave within the vicinity of landfill sites. The gaseous pollutants also undergo chemical reaction and result to global warming which is the general increase in the temperature of earth and water bodies. This implies the vicinity of landfill sites is likely to be hotter and residence will experience a hotter condition. Moreover, gaseous pollutants cause climate change which affect adaptive features of man and plants.

Ways of Minimizing Air Pollutants Generated in Landfill Sites

According to Himmel (2022), landfill gas can be stable for more than 20 years and comprises CH_4 (50 vol %), CO_2 (40 vol %), N_2 (0–4 vol %), H_2O (5–7 vol %), H_2S (20 ppm), and merkaptene (30 ppm). These components of landfill gas constitute gaseous air pollutants. Gómez-Sanabria et al. (2022) reported that to minimize air pollutants generated in landfill sites, Circular Municipal Solid Waste Management (CMSW) system must be employed. The CMSW for reduction of air pollutants in landfill sites involves the following steps (GAIA, 2022):

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- Food loss and wastage account for 6% of the entire greenhouse gas emission (Poore & Nemecek, 2018). Therefore food loss and wastages should be minimized which translates to reduction in landfill gas (Dorward, 2012; Salemdeeb et al., 2017; Venkat, 2011).
- Source segregation must be practiced. Putrescible (organic waste) must be separated from the source as this eradicates CH4 and other gaseous pollutants from landfill sites, enhances the utilization of the putrescible materials and prevents cross contamination with other disposed wastes which increases the rate of recycling (Morris et al., 2013).
- Disposed organics should be reused as the organics composed of valuable nutrient and carbon. They can be used for composting (at landfill sites or home) for agricultural fertilizer (Abu Qdais et al., 2019; Pezzolla et al., 2012). Moreover organic as a stock feed for biogas and animal feeds
- The organic residue must be stabilized or treated using biological or mechanical process before disposing to landfill sites. This process minimizes generation of CH4 by 80%–90% (Gioannis et al., 2009; Scaglia et al., 2010).
- Installation of landfill gas capturing facilities at landfill sites is paramount as some organic which find their ways to landfill sites will continue to produce CH4 for several years (Powell et al., 2016).
- The landfill sites should be covered preferably with selected soil organisms which degrade fugitive CH4 emission (Barlaz et al., 2004; Mønster et al., 2015).

Burning of municipal solid wastes (MSW) releases air pollutants such as CO_2, SO_2, NO_x, and NH_3 to the atmosphere (Ipeaiyeda & Falusi, 2018). The study of Gómez-Sanabria et al. (2022) revealed that burning of MSW resulted in 2.5 Tg/annum of $PM_{2.5}$ in 2015 out of which black carbon was 7% while organic carbon was 60%. The study further indicated that $PM_{2.5}$ emitted from burning of MSW contributed 8% of the world anthropogenic emission of $PM_{2.5.}$ To reduce air particulate pollutant generated in landfill sites, mechanical activities should be minimized in landfill sites while CMSW, which steps have been enumerated must be implemented to reduce the generation of gaseous pollutants in landfill sites. In addition, burning of waste must be averted as this result to generation of air pollutants. Land use management which involves implementing any measures to control and regulate the use of land to achieve certain objectives should also be practiced with a view to minimize the volume of air pollutants emanating from landfill sites. Reduction of emission from landfill sites can be achieved through zoning ordinances in order to have acceptable air quality standards (Dajani et al., 1977; Mostafa et al., 2016).

It is clear from previous works of researchers that CMSW has not been implemented in developing countries which have been attributed to poverty, high population and urbanization, lack of fund and infrastructure and low level of education. However, studies on how these militating factors can be surmounted for the implementation of CMSW are limited in the literature. Hence future studies should focus on how these impediments for implementation of CMSW can be overcome in developing countries.

Previous Works on Assessment of Air Pollutants

Raza et al. (2021) reported that the mean level of assessed $PM_{2.5}$ ranged between 127.1 and 286 $6 ug/m^3$ and between 172.3 and $343.4 ug/m^3$ at the source site and downwind respectively in wet season around the solid waste facility in Lahore Pakistan. Lawrencia et al. (2022) indicated the $PM_{2.5}$ and PM_{10} concentrations were found to be 99 ± 56 and 218 ± 158 ug/m^3 (median ± interquartile range) respectively in the waste recycling site in Ghana. The polyaromatic hydrocarbons cancer risk ranged between 10^{-4} and 10^{-6} which is a pointer for the need to reduce emission at the site. Douglas et al. (2017) estimated the PM_{10} concentrations within 1 km radius from modern municipal waste incinerator in Britain to range between 1×10^{-5} and $5.53 \times 10^{-2} ug/cm^3$. This contributed a small amount to United Kingdom PM_{10} ground level which varied between 6.59 and $2.68 \times 10^1 ug/m^3$ yearly. Imad (2011) pointed out that developing and least developed countries need to plan for sustainable development process and implement integrated waste management scheme. This is necessary as it will upgrade the open dumping practices in developing countries particularly in Africa countries.

The components of odor emitted from landfill sites composed of dimethyl disulfide, toluene, styrene, acetone, xylene, and ammonia. Others are n-butyl aldehyde. n-butanone, dimethyl sulfide, and acetic acid (Chemel et al., 2012; Fang et al., 2012). Dincer et al. (2006) showed that odorous gases in Turkey comprises VOCs which composed sulfur/nitrogen containing compounds (0.00–5.05 ug/m^3), monoaromatics (0.09–47.42 ug/m^3), esters (0.01–7.54 ug/m^3), aldehydes (0.01–38.55 ug/m^3), halogenated compounds (0.001–62.91 ug/m^3), ketone (0.03–67.60), and volatile fatty acids (VFAs) (0.05–43.71 ug/m^3). It further stated that the concentrations of esters, aldehyde, and ketones explained the variability in the odor concentrations up to 96%.

In the work of Rafiq et al. (2018), it was estimated that the total volume of CH_4 and CO_2 were 2.257×10^8 and $9.026 \times 10^7 m^3$/year respectively from Muhammad Wala site of Faisalabad, Pakistan. Chalvatzaki et al. (2010) reported the maximum emission rate of CO_2, H_2S, C_6H_6, and vinylchloride were 2.14×10^{-1}, 6.68×10^{-2}, 4.68×10^{-1}, and 4.11×10^{-2} mg/annum respectively from Akrotiri landfill site in Greece. In the results obtained by Chen et al. (2008), the concentrations of CO_2 and CH_4 of a non-active landfill site in Taiwan varied between 324 and 409 ppm and between 1.7 and 4.6 ppm respectively. The emission rates ranged between 495 and 1,531

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and between 8.8 and 163 mg/m²h for CH_4 and CO_2 respectively. It was also revealed that CH_4 and CO_2 measured within the vicinity of solid waste facility varied between 1.5 and 13.7 ppm and between 443.4 and 509.8 ppm respectively in the work of Raza et al. (2021). The work of Khademi et al. (2022) determined the concentrations of VOCs, C_6H_6, toluene, ethylbenzene and xylene to be 3.7, 0.68, 0.61, and 1.3 ppm respectively. The concentrations of C_6H_6 emitted was of great concern because it carcinogenic effect. Bogner et al. (1995) observed the rates from different controlled monitored experiments for emission of CH4 between 1998 and 1994 varied between 0.003and >1,000 g CH_4/m^2d from three various landfills in United State. They reported that landfill covers soil used as sinks was capable of minimizing the amount of CH_4 emission to the atmosphere.

Hossain et al. (2019) had shown that the measured concentrations of air pollutants: $PM_{2.5}$, PM_{10}, SO_2, NO_x, and CO were 39.2, 145.8, 18.39, 5.7 ug/m^3 and 2 ppm respectively. The concentrations of all these air pollutants were within the Bangladesh National Ambient Air Quality Standards (2005) of 65, 150, 365, 100 ug/m^3 and 9 ppm for $PM_{2.5}$, PM_{10}, SO_2, NO_x and CO respectively. The CH_4 generated or emitted from landfill can be used as a source of energy (Faour et al., 2007; Karanjekar et al., 2015; Kormi et al., 2017; Salami et al., 2020; Shin et al., 2005) but unfortunate most developing countries especially in Africa are tapping these benefits of waste to wealth and waste to energy principles. The amount of CH_4 emission from Sanandaj landfill has been estimated at 410, 549, and 671 m³/hr for 2023, 2028, and 2033 respectively (Shahmoradi et al., 2015). In another study, it was shown that 1.164 × 106 m³/annum of CH_4 was produced in Kachok dumpsite (Kenya) in the year 2018 (Kabok et al., 2021). The work of Pansuk et al. (2018) in Thailand revealed that open burning of solid waste emitted N_2O, CH_4, and CO_2 at the rate of 0.574, 22.29, and 418.73 killoton per year (kt/yr) respectively. Other air pollutants emitted by open burning include PM, NO, SO_2, and CO at the rate of 16.5, 6.2, 1.0, and 86.4 kt/yr respectively. The study of Jha et al. (2008) had shown that in India, the greenhouse gas emission flux range from Chennai landfill sites include CH_4 (1–23.5 mg/m²h), N_2O (6–460 ug/m²h), CO_2 (39–906 mg/m²h) at Kodungaiyur and CH_4 (0.9–433 mg/m²h), N_2O (2.7–1,200 ug/m²h), CO_2 (12.3–946.4 mg/m²h) at Perungudi. The summary of the previous works conducted by researchers are presented in Table 1.

Prediction of Gaseous Pollutants

Gaseous pollutants models show the mathematical representation of a system from which gaseous emission can be forecast or predicted. When the amount of gaseous emissions are known through prediction with the aid of the mathematical models, it helps the authorities and decision makers to put measures in place with a view to ensuring the emission do not have negative impacts on the society. Several mathematical models have been used to predict the emission of air pollutants from landfill sites. The models for prediction of gaseous air pollutants generated from landfill sites were based on Monod's equation which is a well-known kinetic model for biodegradation processes and depending on the concentration of substrate, if the concentration of substrate is large with constant concentration of microorganism, lead to zero order model and if the concentration of substrate is small with constant concentration of microorganism, yields first order models. Other models include complex models (second order kinetics), stoichiometric models, numerical models, and air dispersion models.

Zero order kinetics models

The gaseous pollutants generation from landfill site is not a function of age and type of wastes in landfill. However the generation of pollutants (biogas) is constant against time.

Intergovernmental Panel on Climate Change (IPCC) model is a function of population, methane correction factor and degradable component of the waste. It is depicted in equation (1) (IPCC, 1996).

$$Q = MSWT \times MSWF \times MCF \times DOC \times DOCF \times F \times \frac{16}{2} - R\left(1 - OX\right) \quad (1)$$

Where Q connotes methane emissions, $MSWT$ is the total generated MSW, $MSWF$ represents fraction of MSW discharged to solid waste landfill site, MCF is the correction factor for CH_4, DOC is degradable organic carbon, $DOCF$ is portion of DOC dissimilated, F denotes fraction of CH_4 present in in landfill gas (0.5 by default), R is CH_4 recovered, and OX means oxidation factor (zero by default).

German European Pollutant Emission register (German EPER) model worked on the assumption that the potential emission from a volume of waste will take place in the disposal year. This assumption can only work in a landfill with constant volume of waste and constant composition which in reality is difficult to achieve hence this model may yield inaccurate result. The German EPER model is presented in equation (2) (Scharff & Jacobs, 2006).

$$Me = M \times BDC \times BDCf \times f \times D \times C \quad (2)$$

Where Me is the quantity of diffused CH_4 emitted, M is the yearly quantity of waste in landfill, BDC is the fraction of biodegradable carbon (usually 0.15), $BDCf$ means converted fraction of biodegradable carbon (0.5), f denotes calculation factor of converted carbon into CH_4 (1.33). D is collection efficiency: active LFG recovery and cover (0.1), no recovery (0.9) and active degassing (0.4) and C is concentration of CH_4 (0.5). A constant quantity of waste discharge in a landfill with a constant composition changes this model to a degradable first order model (Kamalan et al., 2011).

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Table 1. Summary of Previous Works Carried Out by Researchers on Assessment of Air Pollutants.

REFERENCES	RESEARCH LOCATION	WHAT WAS DONE	METHODOLOGY	AIR POLLUTANTS ASSESSED	REMARKS
Loizidou and Kapetanios (1992)	U.S.A	Gaseous emissions from a landfill were studied	Gas chromatography (GC)	CH_4, H_2S, NO_2, VOCs	1. The concentrations of pollutants assessed in landfill were higher than ambient air quality. 2. The odor was created by H_2S
Reinhart (1993)	U.S.A	Recent studies on sources of hazardous compounds emitted from solid waste landfill were reviewed	n.a	n.a	1. For proper design and smooth operation of gas collection and treatment facilities, source identification which will facilitate characterization quantification of emission is essential
Bogner et al. (1995)	U.S.A	Atmospheric CH_4 sources and sink in landfills was studied	1. Closed chamber technique 2. In vitro—field incubation 3. Gradient depth	CH_4	1. Static closed chamber, in vitro field incubation and gradient depth functioned as sink 2. The strategies in (1) above are ways of mitigating emission of CH_4 to atmosphere 3. Mitigation of emission strategies for reduction of emission of CH_4 from landfill should be developed.
Nastev et al. (2001)	Canada	Gas production and mitigation in landfill was carried out	1. LGM model	CH_4, CO_2, H_2O, heat	1. The development of one and two dimensional illustrative simulations was accomplished.
De Visscher and Van Cleemput (2003)	Belgium	Simulation model for gas diffusion and methane oxidation in landfill cover soil was developed	1.Simulation model	CH_4	1. A development of simulation model which incorporated methane oxidation, Stefan–Maxwell diffusion and methanotrophic growth was accomplished 2. There bwas an excellent agreement between the developed model and previous laboratory data of researchers 3. The model needs to be validated with the field data
Kumar et al. (2004)	India	Qualitative assessment of methane emission inventory from MSW disposal sites was studied	1.Modified triangular method 2. Monte Carlo simulation technique	CH_4	1. The modified triangular method X-rayed the true pattern of degradation process by providing a time dependent emission profile
Paraskaki and Lazaridis (2005)	Athen	Quantification of landfill emission to air was carried out using Ano Liosia landfill site in Athen as a case study	1. Land GEM 2.01 Software 2. Dispersion model	Vinyl chloride, C_6H_6	1. The concentrations of pollutants assessed were higher than the WHO standards 2. The pollutants have the potentials to cause annoyance and health impacts in the surrounding residential areas 3. The pollutant concentrations validated the prediction model
Dincer et al. (2006)	Turkey	Odourous gases at a landfill site were chemically characterized	1. GC–Mass Spectrometry 2. Step–wise multiple regression analysis	VOCs	1. The VOCs detected included monoaromatics, halogenated compounds, aldehydes, ester, ketones, VFAs, sulfur/nitrogen containing compounds 2. The VOCs concentrations were low

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Table 1. (Continued)

REFERENCES	RESEARCH LOCATION	WHAT WAS DONE	METHODOLOGY	AIR POLLUTANTS ASSESSED	REMARKS
Chen et al. (2008)	Taiwan	Concentrations of CH_4 and CO_2 emissions from closed landfill were studied	1. GC 2. Fourier Transform Infrared (FTIR) 3. Linear regression model	CH_4, CO_2	1. CH_4 and CO_2 concentrations and emission rates were higher at night compared to daytime concentrations 2. Information about greenhouse gas emissions is useful for design of future landfill 3. Significant diurnal variations in atmosphere concentrations or emission were noticed
Chen et al. (2008)	China	Air pollution directional risk for siting a landfill was assessed	1. Dispersion model 2. GIS map 3. DRAXLER	n.a	1. Landfill should be sited in an area of a relative low air pollution directional risk (APDR) 2. APDR sitting factor enhances the quality of selection of landfill
Chalvatzaki and Lazaridis (2013)	Greece	Gas emissions from Akrotiri landfill site were estimated	1. Triangular model 2. Stoichiometric model 3. Land GEM model	CH_4, CO, H_2S, C_6H_6, vinyl chloride	1. The model differs in their scientific approach for quantification of gas emission 2. Land GEM was chosen as best model among the models used
Imad (2011)	Palestine	Future challenges and possible opportunities on municipal solid waste management in developing countries were looked into	-	-	1. It was concluded MSW service was not adequately managed which negatively affected all other developing sectors 2. Developing countries need to plan and implement sustainable, integrated and developed management process
Fang et al. (2012)	China	Odor compounds from different sources of landfill sites were characterized	n.a	Odor	1. It was concluded the odor substances released fromlandfill sites were toluene, xylene, styrene, acetone, n-butanone, n-butyl aldehyde, acetic acid, dimethyl sulfide
Jerez et al. (2013)	Cameroon	A mathematical model was developed to quantify the environmental impact of gaseous pollutants emitted from sanitary landfill site	1. Gaussian model 2. MATLAB computer program 3. Normal distribution function	n.a	1. The conditions of confinement have a greater influence on the rate of gaseous emission from sanitary landfill than the volume of waste disposed in the landfill 2. The concentrations of gaseous emission in a covered surface landfill was lower than uncovered surface landfill
Wiedinmyer et al. (2014)	U.S.A	PM and hazardous air pollutants from open burning of domestic waste were investigated	1. Air monitoring equipment	PM_{10}, CO_2	1. Emission model revealed that many air pollutants were under estimated because open burning were not included 2. Open burning account for 22% of anthropogenic PM_{10} emissions
Rim Rukeh (2014)	Nigeria	The effects of municipal solid waste dumpsites fired to atmospheric pollution was studied	1. Global Positioning System (GPS) 2. Aerosol mass monitor model 3. ITX Multi–Gas monitor	SPM_{10}, NO_2, CO_2, CH_4, CO, SO_2	1. Dumpsite fires occur frequency in the study area 2. Dumpsite fires in the study area threatened the health of people 3. The pollutants assessed were higher than the regulatory standards

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Table 1. (Continued)

REFERENCES	RESEARCH LOCATION	WHAT WAS DONE	METHODOLOGY	AIR POLLUTANTS ASSESSED	REMARKS
Salami and Odunlami (2015)	Nigeria	Air quality of Soluos dumpsite was assessed	1. GPS 2. Air quality monitoring equipment 3. Correlation matrix 4. Weather monitoring equipment	NO_2, CO_2, CH_4, CO, SO_2, H_2S	1. Assessment of air pollutants in the vicinity of dumpsite is a very vital tool for identifying the effects of emission from dumpsite 2. Soluos dumpsite has impacted negatively on the air quality within the vicinity of the dumpsite 3. Correlation matrix established there existed a relation between air pollutants and weather parameters
Douglas et al. (2017)	Britain	Particulate exposure from modern municipal waste incinerator was estimated	1. Data from natural resources Wales (NRW), Scottish Environment al Protection Agency (SEM) 2. Dispersion modeling 3. Correlation analysis	PM_{10}, NO_x, SO_2, PAH	1. PM_{10} concentrations varied between 1×10^{-5} and $5.53 \times 10^{-2}\ ug/m^3$ within 10 km radius 2. The estimated PM_{10} contributed a small fraction of UK PM_{10} background level which varied between 6.59 and $2.68 \times 10^1\ ug/m^3$ yearly 3. Correlation between PM_{10} and PAHs ($r = .2$, $p = .05$), between PM_{10} and PCB ($r = .19$, $p = .022$)
Premakumara et al. (2018)	Philippines	Reduction of greenhouse gases and short climate pollutants from municipal solid waste management in Phillipines were investigated	1. Emission quantification tool (EQT) 2. Usage of National data on waste	CH4, black carbon	1. Reduction in methane emission can be achieved by practicing good waste management 2. Black carbon can be minimized by avoiding open burning 3. There should be awareness on the effects of CH_4 and black carbon
Guo et al. (2017)	Cameroon	Air quality and human health risk in the residential areas at the proximity of Nkolfoulou landfill in Yaounde metropolis were assessed	1. GPS 2. Aeronautic Reconnaissance Coverage Geographic Information System (ArcGIS) Software 10 3. Aeroqual gas sensor model s – 500 L 4. Digital Aeroqual dust sentry with a laser 5. Health index	$PM_{2.5}$, PM_{10}, CO, NO_2, O_3, H_2S, SO_2, CH_2O, CH_4	1. 30% of $PM_{2.5}$ and PM_{10} measured were above the daily maximum safe limit 2. The concentrations of CO, NO_2, O_3, H_2S, and SO_2 were within the emission standards 3. The residence near the landfill sites have high risk of developing cancer due to their exposure to pollutants from the landfill sites
Hossain et al. (2019)	Bangladesh	Air quality measurement at the solid waste disposal of Mathail landfill site at Dhaka, Bangladesh was conducted	1. GPS 2. Envirotech APM with combined PMs sampler 3. LATA Envirotech LES 411 gas monitoring equipment	PM, NO_x, SO_x, CO	1. The air pollutants assessed were within the limit stipulated by National standards 2. The landfill has not impacted negatively on the residence within the vicinity of the landfill
Norsa'adah et al. (2020)	Malaysia	Community health survey of residents living near solid waste open dumpsite in Sabak, Kelantan was carried out	1. Interview 2. Questionnaire	n.a	1. The study revealed that the unsanitary solid waste disposal in Malaysia is hazardous to the health of people living within 1 km from the disposal site

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Table 1. (Continued)

REFERENCES	RESEARCH LOCATION	WHAT WAS DONE	METHODOLOGY	AIR POLLUTANTS ASSESSED	REMARKS
Ogbemudia et al. (2020)	Nigeria	Air quality along landfill site in Uyo was investigated	1. Highly sensitive digital portable meters 2. Air quality index 3. Graph pad prism 6.0 4. Stratified sampling	CO, NO_2, Cl_2, H_2S, SO_2,HCN, $PM_{2.5}$, NH_3 PM_{10},	1. The concentrations of SO_2, NO_2, H_2S, Cl_2, and HCN were above the threshold limits of the regulatory bodies
Sarkawt et al. (2020)	India	Spatiotemporal characteristics of particulate and gaseous pollutants were examined for a period of 4 years	1. Ultraviolet fluorescence 2. Non-dispersive Infrared 3. UV Photometric 4. Thermo NO_x monitor 5. BAM 1,020	$PM_{2.5}$, PM_{10}, CO, NO_x, O_3, SO_2	1. The homogeneity was high for $PM_{2.5}$ concentrations 2. The concentrations of PM and gaseous pollutants (excluding O_3) were higher during winter than summer and monsoon period
Hoang Tran et al. (2020)	Vietnam	Impact of dour from a landfill site in the surrounding areas of Ho Chi Minh city was conducted	1. Odor level indicator XP-329 III 2. Questionnaire	1. Odor	1. Significant odor concentrations were detected in downwind areas of the landfill site 2. The study provided very important information for management of odor from disposal sites.
Raza et al. (2021)	Pakistan	Air quality within facilities of municipal solid waste management sites in Lahore, Pakistan was assessed	1. Aerosol monitor TSI's dusk track 2. Aeroqual 500 series monitor 3. Extech C0220	$PM_{2.5}$, CO_2, CH_4	1. An increase in $PM_{2.5}$ was noticed at downwind more than the source 2. Season variation revealed an increased level of $PM_{2.5}$ during dry season than wet season 3. There is need for implementation five of policies to manage the level of pollutants in air within the vicinity of the waste facilities
Lewrencia et al. (2022)	Ghana	Occupational exposure to PM associated PAH at Agbogboshie waste recycling site was conducted	1. Optical particle counter 2. Sampling pump 3. Mass Spectroscopy/ Chromatography	$PM_{2.5}$, PM_{10}, PAHs	1. PM and PAH concentrations exceeded the regulatory standard and risk-based guidelines. 2. There was need for emission reduction 3. Personal Protective Equipment should be provided for worker at the waste site
Khademi et al. (2022)	Iran	VOCs in the ambient air and biogas produced from landfill in Iran was investigated	1. GC	C_6H_6, toluene, ethyl benzene (BTEX)	1. BTEX concentrations exceeded the standards 2. BTEX have carcinogenic risk 3. Biological monitoring of metabolites of BTEX is recommended
Ramadan et al. (2022)	Japan	A comprehensive review of domestic-open waste burning was carried out	1. PRISMA 2020 2. Bibliometric approach 3. Qualitative content analysis	n.a	1. Environmental knowledge and awareness level influence open burning practice.

n.a = not available.

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Solid Waste Association of North America (SWANA) model worked on the principle of quantity of waste disposed, age and methane generation potential. It is shown in equation (3) (SWANA, 1998).

$$Q = \frac{M L_O}{t_o - t_f} \quad (3)$$

Where L_o is the generation potential of CH_4, t_o denotes lag time and t_f is the end time of generation.

First order kinetics models

It is assumed there exist a relationship between carbon portion of the waste and exponential function of rate of decay by time against methane generation. The models put into consideration the landfill conditions (temperature, precipitation, and climate) and quantity of waste which include carbon content, degradability of waste, moisture content, and waste age (Kamalan et al., 2011; Ozkaya et al., 2007).

Landfill Gas Emission Model (LandGEM) is used for determination of mass of CH4 which can be generated based on the mass of waste disposed. The LandGEM is presented in equation (4) (Scharff & Jacobs, 2006).

$$Q = \sum_{i=1}^{n} k L_o M_i \left(e^{-kt} \right) \quad (4)$$

Where k is methane generation constant and M_i waste in placed in specific time t. The waste composition used in this model was United State waste composition of MSW, inert material and other non-hazardous wastes (USEPA, 2004) and USEPA, 2005).

The Netherland Organization of applied Scientific Research (TNO) model determined generation of LFG as a function of organic carbon degradation in the waste. It is mathematical shown in equation (5) (Kamalan et al., 2011).

$$\alpha_t = 1.87 \zeta A C_o k_1 e^{k_1 t} \quad (5)$$

Where α_t is gas production in landfill at a given time, ζ is dissimilation factor (0.58), 1.87 represent conversion factor, A denotes quantity of waste in place, C_o is the quantity of organic carbon in waste and k_1 stands for constant rate of degradation (0.094). TNO model was developed with the assumptions of quantity of organic carbon presented in Table 2.

Gas SIM model uses two approaches for the estimation of emission of CH_4 (Gregory et al., 2003). It is a probabilistic model which uses multi-phase equation, mathematically described in equation (6).

$$\alpha_t = \zeta C \sum_{j=0}^{m} \sum_{i=1}^{n} A_j k_i C_{o,i,j} e^{-k_i (t-j)} \quad (6)$$

Table 2. Amount of Organic Carbon Used in TNO (Scharff & Jacobs, 2006).

WASTE CATEGORY	ORGANIC CARBON CONTENT (KG C/MG)
Household waste	130
Construction and demolition waste	11
Coarse household waste	130
Contaminated soil	11
Commercial waste	111
Sewage sludge and compost	90
Shredder waste	130
Street cleansing waste	90

Where C is the conversion factor, m is the number of landfilling, j is year of landfilling quantity A_j, n represents number of fraction i, i is waste fraction with degradable rate k_i, A_j represents quantity of waste in year j, C_o, i, j stands for quantity of organic matter in fraction i landfilled in year j, k_i is degradation rate constant of fraction i.

In this multi-phase model, the waste input is need to be in Mg and the specified degradation during the particular year is required. Moreover, each waste category is assigned a k value degradability class. The second approach uses LandGEM model to estimate formation of methane.

Complex models

Mathematical complex models like the Halvadakins model for landfill gas prediction is a function of growth of sequential biological process. The complex microbial ecosystem in landfill is represented by a system described by equations of the first order which are in terms of the following (Elfadel et al., 1989): carbon sources, pathways and sinks, description of hydrolysis of the hydrolyzable and biogasiflable waste components, utilization of aqueous carbon for acidogenic growth and methanogen biomass, acetate utilization and consequent methane generation and CO_2 and hydrogen representing 25%–30% of the total produced CH_4.

Stoichiometric models

Stoichiometric models put into consideration the chemical, physical and biological reactions which occur in landfill sites, changing complex compounds in the waste into simpler and more stable compounds (Rodrigo-Ilarri & Rodrigo-Clavero, 2020). The breaking down of organic portion of the wastes takes place because there exists a substrate with nutrients (carbon, hydrogen, oxygen, and nitrogen) that contributes to the growth of existing microorganisms which then convert the substrate into gases such as CH_4, NH_3, and CO_2 (Canale,

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1971). The stoichiometric equations which describe chemical reactions occurring inside landfill sites are influenced by the imposed environmental conditions (Levenspiel, 1999) and degradation of organic portion of the waste occurs under anaerobic condition.

Buswell and Neave (1930) proposed a stoichiometric model cited by Tchabanoglous et al. (1993) for the prediction of quantity of CH_4 once the chemical formular of the sample of waste has been established. The stoichiometric model presented in equation (7) which displaces the stoichiometric balance between organic portion of waste quantity and gaseous products which excluded sulfur. Buswell and Hatfield (1936) developed any stoichiometric model cited by Murphy and Thamsiririroj (2013) and Achinas and Euverink (2016) for the prediction of CH_4 as described in equation (8). The model did not consider nitrogen and sulfur as part of the chemical formular for the waste sample. Buswell and Mueller (1952) developed a model cited by Deublein and Steinhauser (2008) and Salami et al. (2020) which included nitrogen and sulfur in chemical formular of the waste sample. The products of reaction in the model were CH_4, CO_2, NH_3, and H_2S. The Buswell and Muller model is shown in equation (9).

$$C_aH_bO_cN_d + \left(a - \frac{b}{4} - \frac{c}{2} + \frac{3d}{4}\right)H_2O \rightarrow \left(\frac{4a + b - 2c - 3d}{8}\right) CH_4 + \left(\frac{4a - b + 2c + 3d}{8}\right)CO_2 + d\,NH_3 \tag{7}$$

$$C_aH_bO_c + \left(a - \frac{b}{4} - \frac{c}{2}\right)H_2O \rightarrow \left(\frac{a}{2} + \frac{b}{8} - \frac{c}{4}\right)CH_4 + \left(\frac{a}{2} - \frac{b}{8} + \frac{c}{4}\right)CO_2 \tag{8}$$

$$C_aH_bO_cN_dS_e + \left(a - \frac{b}{4} - \frac{c}{2} + \frac{3d}{4} + \frac{e}{2}\right)H_2O \rightarrow \left(\frac{4a + b - 2c - 3d - 2e}{8}\right)CH_4 + \left(\frac{4a - b + 2c + 3d + 2e}{8}\right) CO_2 + d\,NH_3 + e\,H_2S \tag{9}$$

Where *a, b, c, d*, and *e* are number of atoms of carbon, hydrogen, oxygen, nitrogen and sulfur respectively. Feng et al. (2013) had shown that the theoretical amount of CH_4 (M_{th}) from waste sample can be predicted using equation (10) with the following assumptions

- The product of reaction comprises only H_2S, CH_4, NH_3, and CO_2;
- No accumulation of ashes;
- Waste input consists only carbon, hydrogen, nitrogen and sulfur and
- Perfect mixing and constant temperature

$$M_{th} = \frac{22.4\left(\frac{4a - b + 2c + 3d + 2e}{8}\right)}{12a + b + 16c + 14d + 32e} \tag{10}$$

Numerical models

Numerical models use weighted residual method (WRM) which results to simpler models for easy application. Using the simplified numerical models assist landfill operators and those making decisions to have easier and better understanding about emission of methane (Shariatmad et al., 2007). Applying WRM to numerical models has shown a reliable and reasonable result with few data for real landfill (Kamalan et al., 2011) which makes the numerical model to be very effective. The numerical model, mathematically written in equation (11) can be applied for individual landfill with few methane data and the unknown parameters can be obtained with try and error (Shariatmad et al., 2007)

$$\int_{domain}\int w_{ip}\left(G - \psi\right)dt\,dw = \int_{domain}\int a_{mn}\left(w_{ip}\sum_{n,m=1} N_{mn}\right) \Leftrightarrow f_i = k_i \sum a_{mn} \tag{11}$$

Where ψ is a chosen function to satisfy boundary conditions, *a* is coefficient to be determined and *N* which is a trial function on the boundary should be zero. The target of WRM is to select a_{mn} in a way that residue (R) becomes small over a selected domain.

Air dispersion models

The American meteorological Society/ USEPA Regulatory model (AERMOD) is used for the assessment of concentrations of pollutants and deposition from various sources. It totally incorporates the Plume Rise Model Enhancement (PRIME) building downwash algorithms, advanced deposition parameters, urban heat island effects, location terrain, and advanced meteorological turbulence calculation. It is an advanced and sophisticated air dispersion modeling package which uses the USEPA preferred regulatory air dispersion model into a powerful and easy-to-use interface (Lakes Environmental Software, 2022). AERMOD can be used to estimate the emitted pollutants from landfills, disperse into the atmosphere. Table 3 presents the summary of mathematical prediction models for gaseous pollutants.

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Table 3. Summary of Mathematical Prediction Models of Gaseous Pollutants.

REFERENCES	TYPE OF MODEL	MODEL NAME	MODEL EQUATION
IPCC (1996)	Zero order kinetics models	Intergovernmental Panel on Climate Change (IPCC)	$Q = MSWT \times MSWF \times MCF \times DOC \times DOCF \times F \times \frac{16}{2} - R(1-OX)$
Scharff and Jacobs (2006)		German European Pollutant Emission register (German EPER) model	$Me = M \times BDC \times BDCf \times f \times D \times C$
SWANA (1998)		Solid Waste Association of North America (SWANA) model	$Q = \frac{M L_O}{t_o - t_f}$
Scharff and Jacobs (2006)	First order kinetics models	Landfill Gas Emission Model (LandGEM)	$Q = \sum_{i=1}^{n} k L_o M_i \left(e^{-kt}\right)$
Kamalan et al. (2011)		The Netherland Organization of applied Scientific Research (TNO) model	$\alpha_t = 1.87 \zeta A C_o k_1 e^{k_1 t}$
Gregory et al. (2003)		Gas SIM model	$\alpha_t = \zeta C \sum_{j=0}^{m} \sum_{i=1}^{n} A_j k_i C_{o,i,j} e^{-k_i(t-j)}$
Tchabanoglous et al. (1993)	Stoichiometric models	Buswell and Neave	$C_aH_bO_cN_d + \left(a - \frac{b}{4} - \frac{c}{2} + \frac{3d}{4}\right) H_2O \rightarrow \left(\frac{4a + b - 2c - 3d}{8}\right) CH_4 + \left(\frac{4a - b + 2c + 3d}{8}\right) CO_2 + d\,NH_3$
Murphy and Thamsiriroj (2013), Achinas and Euverink (2016)		Buswell and Hatfield	$C_aH_bO_c + \left(a - \frac{b}{4} - \frac{c}{2}\right) H_2O \rightarrow \left(\frac{a}{2} + \frac{b}{8} - \frac{c}{4}\right) CH_4 + \left(\frac{a}{2} - \frac{b}{8} + \frac{c}{4}\right) CO_2$
Deublein and Steinhauser (2008); Salami et al. (2020)		Buswell and Muller	$C_aH_bO_cN_dS_e + \left(a - \frac{b}{4} - \frac{c}{2} + \frac{3d}{4} + \frac{e}{2}\right) H_2O \rightarrow \left(\frac{4a + b - 2c - 3d - 2e}{8}\right) CH_4 + \left(\frac{4a - b + 2c + 3d + 2e}{8}\right) CO_2 + d\,NH_3 + e\,H_2S$
Feng et al. (2013)		n.a	$M_{th} = \frac{22.4\left(\frac{4a - b + 2c + 3d + 2e}{8}\right)}{12a + b + 16c + 14d + 32e}$
Shariatmad et al. (2007)	Numerical models		$\int_{domain} \int w_{ip} (G - \psi)\, dt\, dw = \int_{domain} \int a_{mn} \left(w_{ip} \sum_{n,m=1} N_{mn} \right) \Leftrightarrow f_i = k_i \sum a_{mn}$

n.a = not available.

Human Health Risk Assessment of Pollutants

Risk exposure assessment of gaseous pollutants

The exposure to pollutants from landfill sites can be acute or chronic (Giusti, 2009). The process of assessing the exposure to pollutants from landfill sites involves determination of frequency, duration of previous, present and future exposure, magnitude, and identification of pathway for potential exposure (Spinazzè et al., 2017). Guo et al. (2017) evaluated the non-cancer risks from inhalation of formaldehyde (CH_2O), H_2S,

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Table 4. Air Quality Index and Health Implications in India.

AQI	DESCRIPTOR	ASSOCIATED HEALTH IMPACTS
51–100	Satisfactory	May result to minor breathing discomfort in sensitive people
101–200	Moderately polluted	May lead to discomfort in breathing discomfort in people with heart and lung disease
201–300	Poor	May cause discomfort in breathing to people exposed to air pollutants for a long period of time
301–400	Very poor	Can cause respiratory problem to people exposed to air pollutant for a long period of time
401–500	Severe	Can cause respiratory problem even on healthy people.
		May lead to serious health impact in people with heart and lung problem

Table 5. Air Quality Index and Health Implications Mainland China.

AQI	DESCRIPTOR	ASSOCIATED HEALTH IMPACTS
0–50	Excellent	No health impact
51–100	Good	May result to hypertension
101–150	Lightly polluted	May result in slight irritation. People with heart diseases should minimize outdoor exercise
150–200	Moderately polluted	Can cause slight irritation
201–300	Heavily polluted	Can cause fatigue even in healthy people
300+	Severely polluted	Can cause fatigue even in healthy people.
		May result to irritation and trigger other illnesses

and SO_2 using hazard quotient (HQ) shown in equation (12) while cancer risk (CR) as a result of inhalation of CH_2O was computed as presented in equation (13).

$$HQ = \frac{CA}{MRL} \tag{12}$$

Where *CA* is the concentration of contaminants in air and *MRL* is minimal risk level.

$$CR = IUR \times EC \tag{13}$$

Where *IUR* is the inhalation unit risk and *EC* is the exposure concentration.

Pawełczyk (2013) examined the effect of exposure to multiple non-carcinogenic contaminants using hazard index (HI) depicted in equation (14).

$$HI = \sum_{i}^{n} HQ_i \tag{14}$$

Salami et al. (2016) evaluated air status within the vicinity of Soluos dumpsite in Igando community of Lagos State using air quality index (AQI). The pollutants considered in the study include CO, CO_2, ozone, and NO_2. The AQI is presented in equation (15).

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}} \left(C - C_{low} \right) + I_{low} \tag{15}$$

Where *I* is air quality index, *C* is pollutant concentration, C_{low} is the concentration breakpoint less or equal to *C*, C high is the concentration breakpoint greater or equal to *C*, I_{low} means the index breakpoint corresponding to C_{low} and I_{high} is the index breakpoint corresponding to C_{high}. The AQI and health implications for India and Mainland China, adopted from the work of Salami et al. (2016) are shown in Tables 4 and 5 respectively.

Risk assessment of particulate pollutants

Human health risk assessment is a way through which possible negative effects of human to dangerous substances are characterized. For assessment of non-cancer risk of particulate matters from landfill sites, HQ, and HI can be used. The HQ is only applied for evaluation of exposure to one particulate matter while HI is applied for assessment of exposure to many particulate matters (Zmijkova et al., 2018). For evaluation of cancer risk, excess life time cancer risk (ELCR) can be applied in the case of one particulate matter and total excess life time cancer risk ($ELCR_{tol}$) in the case of many particulate matters. HQ, HI, ELCR, and $ELCR_{tol}$ for particulate matters can be quantified using equations (16)–(19), according to Zmijkova et al. (2018) and USEPA (2014).

$$HQ = \frac{ADD}{RFD} \tag{16}$$

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$$HI = HQ_1 + HQ_2 + HQ_3 + \ldots HQ_i \quad (17)$$

$$ELCR = \frac{LADD}{CSF} \quad (18)$$

$$ELCR_{tol} = ELCR_1 + ELCR_2 + ELCR_3 + \ldots ELCR_i \quad (19)$$

Where *ADD* is the average daily dose for inhalation of particulate matter i, *RFD* is the reference dose of particulate matter i via respiratory pathway, *LADD* stand s for life time cancer risk for particulate matter i through inhalation, and *CSF* represents cancer slope for particulate matter I, through inhalation.

Bodor et al. (2022) determined the short term effect of exposure to PM_{10} using the relative risk (RR) model as depicted in equation (20), on the basis that the measured concentration value of PM_{10} was higher than the background value. RR describes the adverse health effects associated among the population exposed to a higher pollutant concentrations relative to lower pollutant (Hassan Bhat et al., 2021).

$$RR = \exp[\beta\left(X_{PM10} - X_{B\,PM10}\right)] \quad (20)$$

Where X_{PM10} is the annual mean concentration of PM_{10}, $X_{B\,PM10}$ is the background concentration of PM_{10}, and β represents the risk function coefficient. RR associated with $PM_{2.5}$ was determined with the aid of equation (21).

$$RR = \left[\frac{\left(X_{PM2.5} + 1\right)}{\left(X_{BPM2.5} + 1\right)}\right]\beta \quad (21)$$

Where $X_{PM2.5}$ is the annual mean concentration of $PM_{2.5}$, $X_{B\,PM2.5}$ is the background concentration of $PM_{2.5}$, and β represents the risk function coefficient. The work of Ostro (2003) revealed that attributable fraction (AF) which indicates the ration of death from certain diseases and excess risk (ER) can be estimated using equations (22) and (23) respectively.

$$AF = \frac{\left(RR - 1\right)}{RR} \quad (22)$$

$$ER = RR - 1 \quad (23)$$

Conclusion and Recommendations

Conclusion

1. Most of the studies carried out on the health effects of $PM_{2.5}$ (approximately 69%) were done in high-income countries (HIC) (Sharma et al., 2020).
2. From available literature, it is obvious the developing countries have not been practicing CMSW due to some militating factors.
3. From previous studies (Jiang et al., 2020; Li et al., 2020; Yao et al., 2020), positive correlation between PMs and risk of COVID-19 infection has been reported.
4. Adequate attentions and considerations have not been given to the cost and economic implications of assessing air pollutants within the vicinity of landfill sites as these were very scarce in virtually all the literature reviewed.
5. There is lack of comprehensive data bank in the area of assessment of atmospheric air pollutants within the vicinity of landfill sites in developing countries hence funding should be made available especially by donors for researchers in developing countries for development of comprehensive data bank.
6. Several researchers have developed mathematical models for prediction of pollutants generated in the landfill sites. However there is still need for improvements especially in the number of assumptions made for the development of the models which in this present day reality, will be difficult to achieve. Some of the assumptions include:
   - German EPER model assumed the potential emission from a certain quantity of waste will occur in the disposal year which can only be achieved when there is constant volume of waste and composition in a landfill site.
   - For prediction of methane using stoichiometric model, it was assumed there will be no accumulation of ashes, the product gases include only CH_4, NH_3, CO_2, and H_2S and a constant temperature condition.

Recommendations for future studies

1. It is imperative that the future studies on the health impacts of PM within the vicinity of landfill sites should focus more on LIC especially in Nigeria which is perceived as capital poverty of the world.
2. The studies on how the militating factors can be surmounted are limited in the literature. Hence there is need for more studies to be conducted with a view of proffering solutions and ways forward for the implementation of CMSW in developing countries.
3. Further studies should be carried out to substantiate and establish the reported positive correlation between PMs and COVID-19 infection especially in non-temperate regions with a view to mechanistically explain the positive correlation between PMs and the risk of COVID-19 infection.
4. It is imperative the cost and economic implication of assessing atmospheric air pollutant are looked into as this will serve as a tool for policy makers in making decisions.

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