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RESEARCH ARTICLE

Landfill air and odour emissions from an integrated waste management facility

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Abstract
A mixture of gases and obnoxious odours are major components of landfill emission. A dispersion modelling on air pollutants and odour emissions anticipated from a proposed Integrated Waste Management Facility was conducted considering five operating scenarios. Impacts of the predicted ground level concentrations of air pollutants (including carbon monoxide, CO; oxides of nitrogen, NO_X; sulphur dioxide, SO_2; particulate matter, PM and hydrocarbons, HC) and odour on ambient air quality were investigated using the 10-min 1 OU/m^3 odour limit, CH_4 Lower Explosive Limit (LEL) and the daily limits of CO, NOx, SO_2, PM and HC. The anticipated maximum ground level concentration of emitted odour and CH_4 are 0.0040 OU/m^3 and 0.0349 ppm, respectively. Simultaneous operations of all the major components of the facility will generate the daily maximum concentrations of 7.34, 2.60, 7.31, 29.72 and 0.42 μg/m^3, for CO, NO_X, SO_2, PM and HC, respectively. Generally, the facility impacts on ambient air quality will be within the acceptable limit.

Keywords Dispersion modeling · Emission · Gaseous pollutants · Landfill · Waste management

Introduction

Accelerated urbanization and industrialization has brought about an increase in the quantity of waste generated vis-à-vis increase in the number of waste management facilities required to manage the generated waste. Landfilling is one of the most popular methods of disposing of municipal and industrial wastes in the world. Apart from the potential threats landfill sites pose to soil and groundwater, gases and odour are also emitted [1–5]. A mixture of gases and odour are generated from the wastes deposited in landfills are due to the anaerobic decomposition of solid matter [6–8]. The emitted gases and odour are majorly generated from the biodegradation of organic matter contained in the waste [9, 10]. Air pollutants emitted from waste management facilities include carbon monoxide, CO; oxides of nitrogen, NO_X; sulphur dioxide, SO_2; particulate matter, PM; and hydrocarbons, HC; which are majorly volatile organic compounds (VOCs).

Emitted gases and odour from the landfill have associated environmental and health negative consequences. The proximity of landfill sites to the residential environments has reduced in recent decades due to rapid urbanization and urban sprawl. Dincer, Odabasi [11] posited that most of the emitted pollutants from the landfill are odorous and have significant impacts on the nearby communities. Elevation in odour thresholds from landfills are associated with an increase in landfill gases emission, and low wind speed which may hinder pollutants dispersion especially in complex terrains [10, 12]. Methane (CH_4) and carbon dioxide (CO_2) are among the major Greenhouse Gases (GHGs) emitted from landfills [13–16]. Anaerobic decomposition of wastes in landfills promotes the production of CH_4 which has a global warming potential of about 21 multiples of that of CO_2. Epidemiological studies have established that there is a high correlation between the concentration level of air contaminants and human health [2, 17, 18]. Correlation between air pollution and high morbidity and mortality rates due to high blood pressure and cardiovascular problems have been reported [19]. Aside the olfactory nuisance, the landfill generated malodorous gases. Previous studies have suggested that they portend respiratory,

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neurotoxic, carcinogenic, and teratogenic risk to people, especially those who stay around the host communities [20–24].

Studies have attempted to identify the air quality and health impact associated with landfill sites on the receptor environment via forecasting and dispersion modelling tools [25–33]. The most common dispersion tool used for the dispersion of air pollutants and odour from point and area sources include the US EPA ISC-AERMOD and the CALPUFF [34–37]. Çetin Doğruparmak, Pekey [26] used the CALPUFF multi-layer, multi-species non-steady-state puff dispersion model to identify the impact of odour emanating from a waste treatment facility on the receptor environment in Turkey. Seangkiatiyuth, Surapipith [38] posited that AERMOD dispersion tool is a good environmental impact assessment tool that predicts pollutants concentrations accurately. LandGEM 2.0.1 was combined with the atmospheric long-term dispersion model ISC3-LT in a previous study to estimate landfill emission impact on the receptor environment in greater Athens area, Greece [32]. In addition, Matacchiera, Manes [39] have successfully applied ISC-AERMOD view model to investigate and plan methane dispersion campaign for a landfill. Information about the impact of generated gases and odour on receptor environments of landfill sites in Nigeria is scarce.

Concerns over the possible air pollutants and odour impact on the receptor environments of the proposed facility in Nigeria is the main impetus for this assessment. The main goal of this study is to identify the environmental impacts associated with air and odour emissions from the proposed Integrated Waste Management project in its area of influence. This is with a view to identifying sources of air emissions and odour from the proposed project; quantify air and odour emissions from the identified sources in the project; estimate air pollutants and odour ground level concentrations at receptor of interest, and predict air quality and odour changes associated with the project in its site.

Methodology

Description of the study location and facility

The location of the proposed Integrated Waste Management Facility (IWMF) for the treatment of solid wastes is as presented in Fig. 1. This facility was designed to handle drill cuttings and sewage for oil producing and servicing companies in the Niger Delta area of Nigeria. It will facilitate regional solid waste management with collection, treatment and disposal of industrial waste from several States and E&P facilities such that economies of scale can be realized together with efficient and effective management. The proposed facility will increase the environmental performance of waste treatment and disposal facilities within the waste catchment area, replacing facilities of inferior design and operating standards.

The project was designed to comprise of an engineered landfill, four incinerators, a thermal desorption unit (TDU), a compost plant, a sewage treatment plant, shredders, balers, a steam boiler, a laboratory and a mini-clinic. The proposed site is about 25 km west of Benin City, the Edo State capital, Nigeria.

For ground-level concentrations determination of both the odour and air pollutants, ISC-AERMOD View air dispersion modelling tool was employed. The ISC-AERMOD is a complete and powerful air dispersion modelling package which seamlessly incorporates the popular U.S. EPA models into one interface: AERMOD, ISCST3, and ISC-PRIME. For impacts investigation, the obtained ground level concentrations of air pollutants were compared with the standards of ambient air quality (Table 1) derived from the World Bank Environmental Guidelines and the Nigerian Ambient Air Quality Standards of the Federal Ministry of Environment (FMEnv). Though, there are no published F for odour. 1 odour unit (OU) over a 10-min averaging period that represents the concentration at which 50% of the normal population say 'they can detect the odour', is typically used as a measure of acceptable odour levels and this was adopted in the study.

Emission sources

In this study, all the sources of air pollutants and odour in the proposed integrated waste management project were considered. Air pollutants modelled for the ground level concentrations determination included: carbon monoxide (CO), oxides of nitrogen (NO_X), sulphur dioxide (SO_2), volatile organic compounds (VOCs) and particulate matter (PM). Methane and odour which are essential emission from landfill operation were also considered. Emission rates and exhaust vent stack parameters (height, diameter, exhaust temperature, and exit velocity) used as model input parameters were obtained from project details. The identified sources of air emissions and odour from the proposed project during its operation are the engineered landfill, the four incinerators, a thermal desorption unit (TDU), a compost plant, a sewage treatment plant, and a steam boiler.

The engineered landfill

The proposed landfill is an engineered pit, in which layers of solid waste will be filled, compacted and covered for final disposal. At its bottom, it will be lined to prevent groundwater pollution. After a few years, the degradation of the biodegradable part in the waste will landfill gas. This gas will be captured by a network of wells installed all over the site and is burned or converted into energy. Once their final capacity is attained, the closure of the cells shall be closed by installing a cover that will favour the growth of vegetation. All non-recyclables but biodegradables at the site shall be handled by

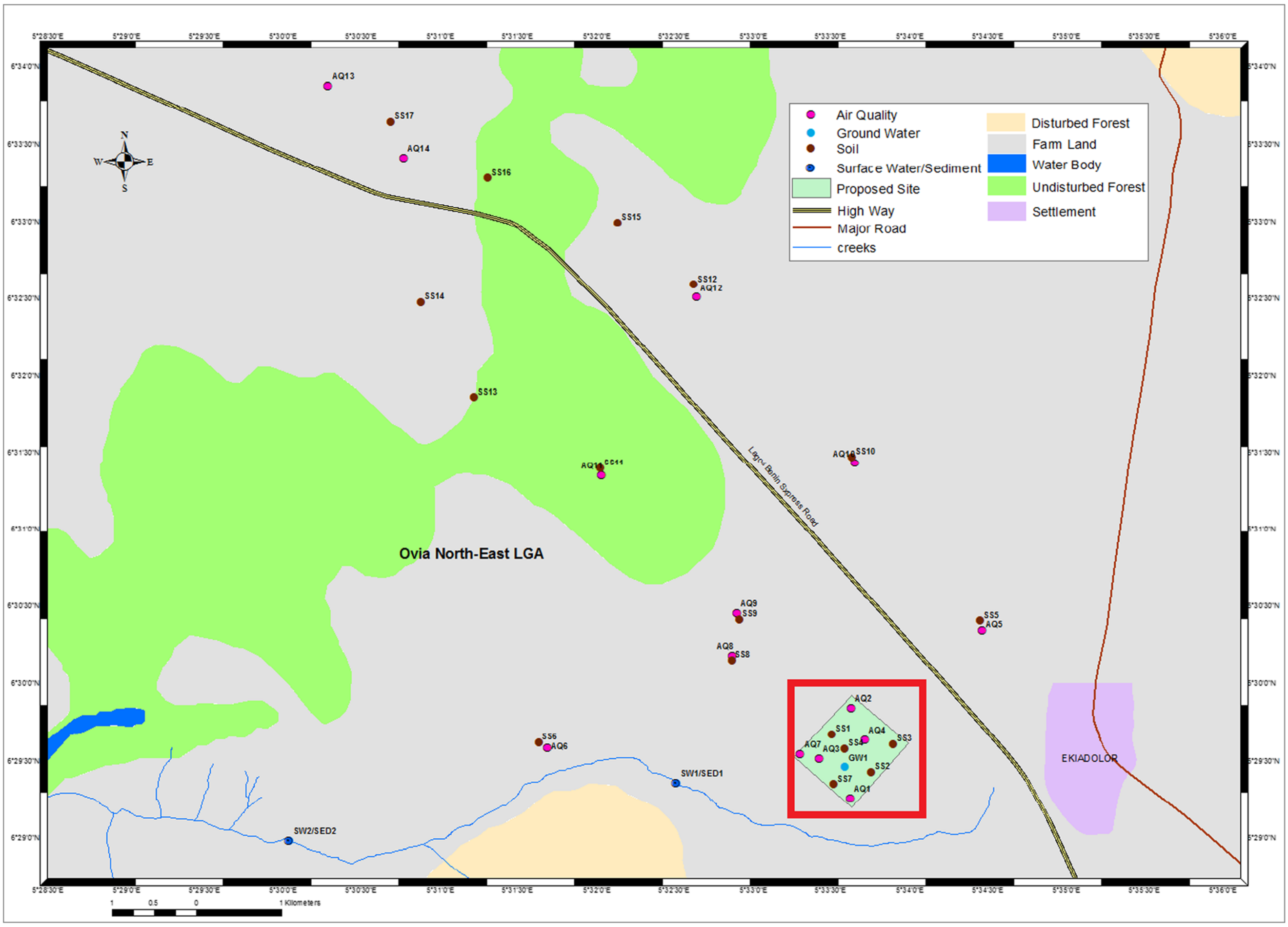


Fig. 1 The Proposed waste management facility site and area of influence

the engineered landfill. However, no liquid shall be disposed of in the landfill.

Though, the proposed project site is about 530 m × 460 m (243,800 m^2). The landfill surface area on the land was chosen to be about 212 m × 184 m (39,008 m^2) handling about 51.43 tons/day biodegradable solid wastes. These wastes were assumed increasing at about 3% per annum. The landfill has a release height of 5 m chosen to represent the elevation of its mound. The worst case scenario assumed is that none of the methane is captured thus allowed into the atmosphere on the site without destruction.

Table 1 Standards of ambient air quality and odour level

S/No	Contaminant	Averaging Period	Maximum Concentration ($\mu g/m^3$)	
			FMENV[a]	World Bank[b]
1.	CO	1 – hr	–	30,000
		8 – hr	22,800	10,000
		24 – hr	11,400	–
2.	NO_X	24 – hr	75–113	150
3	SO_2	1 – hr	260	–
		24 – hr	26	–
4.	TSP	1 – hr	600	–
		24 – hr	250	80
5.	HC	24-h	6000	
6.	Odour	10 – minute	1 OU	

[a] Source: FEPA (1991); [b] Source: WHO (2006)

The incinerators

There are four units incinerator made of 3 × 4 × 3 m primary chambers and 2 × 4 × 3 m secondary chamber equipped with a venturi scrubber, droplet separator, and a re-circulation tank proposed for the project. Generally, the incinerators are 4 × 3 × 2 m dimensions having stack height of 30 m with solid and liquid handling capacities of 500 kg/h and 300 kg/h respectively. Each consumes 42 l/h of Automotive Gas Oil (AGO) for operation and operates at about 32–1500 °C temperature. It also has a scrubber unit with water diffusion system, which has a water scrubbing unit of 1500 l flowing at 20 l/s, and water storage capacity of 5000 l. The incinerator has manual waste charging system with manual ash removal system. During operation, each of these incinerators will handle 5 metric tons/day of solid/liquid wastes from the oilfield.

Summarized in Table 2 are the landfill characteristics considered, while Table 3 are the parameters used in the modelling and Table 4 contains their emission characteristics. Sewage sludge incinerators can emit significant quantities of pollutants including particulate matter (PM), carbon monoxide (CO), oxides of nitrogen (NO_X), sulphur dioxide (SO_2), and unburned hydrocarbons (VOCs).

The thermal desorption unit (TDU)

The proposed Thermal Desorption Unit (TDU) in the project is an indirect fired low-temperature system with a maximum operating temperature of 325 °C inside the dryer chamber. The entire dryer chamber of the TDU is heat insulated while its generated hot air will be used for heating the chamber. The outlet of the flue gas will pass through a wet scrubber to filter and cool down to air temperature or atmospheric temperature. The proposed total amount of drill cuttings to be treated is 3 tons/batch, anticipating four batches per day. Emissions to air from thermal desorption systems are influenced by the waste characteristics, the process applied, and the emissions control equipment used. The principal emissions released from the TDU are likely combustion gases from the heating system including carbon monoxide (CO), Volatile Organic Compounds (VOCs) and particulates (PM).

Table 2 Landfill emission characteristics considered in the dispersion modelling

Source	Dimensions		Emission Flux	
	x (m)	y (m)	CH_4 (g/s m^2)	Odour (OU/s m^2)
×1, y1	4926.7	730.51	2.54×10^{-6}	7.95×10^{-5}

Emission modelling protocol

Emissions from the biodegradation of solid wastes in the engineered landfill of the proposed project were determined with the United States Environmental Protection Agency's (U.S. EPA) Landfill Gas Emissions Model (LandGEM). LandGEM is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in municipal solid waste (MSW) landfills. The software provides a relatively simple approach to estimating landfill gas emissions. Inventory defaults parameters were used in the model and the combustion products associated with air emissions from the combustion equipment in the proposed project were computed using emission factors from the AP-42 [40].

In this air emission and odour dispersion modelling, the ISC-AERMOD View was used. This is a user-friendly interface modelling tool for four U.S. EPA air dispersion models: ISCST3, ISC-PRIME, AERMOD and MET developed specially for Microsoft Windows. It uses pathways that compose the run-stream file as the basis for its functional organization. Its version 8.2.0 with serial number AER00005543 was used. This study adopted the point source emissions for methane from the landfill and the air pollutants from the incinerators and the thermal desorption units while odour emissions from the landfill were treated as an area source.

Table 1 was used to investigate their impacts on ambient air quality and odour levels in the immediate and distant environments of the project site. The area source parameter summarized in Table 2 were the area source information taken as input for the study while the point emission characteristics and sources parameters considered as input for point emission sources dispersion modelling are given in Tables 3 and 4. Zou, Zhan [41] established that concentrations simulated by AERMOD at the 8 h, daily, monthly, and annual intervals match their respective observed concentrations. The variation between the simulated concentration output and the measured concentration are mostly insignificant when AERMOD is used [42].

Emission sources input scenarios

This modelling exercise considered five emission scenarios from the identified sources in the proposed integrated waste management facility. The scenarios predicted the potential ground level CH_4 and odour levels from the engineered landfill. It also predicted ground level concentrations of air pollutants from the incinerators, and the TDU within the proposed site and its surroundings for the prevailing meteorological conditions. The operating scenarios investigated were:

Scenario 1: Assumes odour emission from the engineered landfill during its operations.

Table 3 Parameters used in the dispersion modelling

Source	Location		Gas temp (°C)	Stack diameter (m)	Exit velocity (m/s)	Release height (m)
	x (m)	y (m)				
Incinerator	5009.18	1060.42	1227	0.50	2.5	30
Incinerator	5019.18	1060.42	1227	0.50	2.5	30
Incinerator	5029.18	1060.42	1227	0.50	2.5	30
Incinerator	5039.18	1060.42	1227	0.50	2.5	30
TDU	5039.18	1090.42	500	0.325	13.36	12
	Area					
Landfill	39,008 m^2		32	–	0.10	5

Scenario 2: In this scenario, CH_4 was assumed emitted from the engineered landfill during its operations.

Scenario 3: This is the incinerator “worst case” scenario, where three of the four incinerators were simultaneously in operation handling the medical waste, the sewage sludge and the combustibles MSW during operations.

Scenario 4: Operation of the TDU was considered in the scenario and the proposed TDU was assumed to be in continuous operation.

Scenario 5: This is the air pollutants “worst case” scenario, in which all the sources of air pollutants (three of the four incinerators and the TDU) in the proposed project site is in simultaneous operations.

Receptors locations

Both the immediate and distant environments of the proposed project site were considered as receptors to air pollutants in this study. Specifically, about 10 km radius of the proposed project location in Edo State, Nigeria was given adequate attention.

Table 4 Proposed incinerator emissions characteristics used in the \`modelling

S/No	Waste type/Source	Emission (g/s)				
		CO	NO_X	SO_2	PM	HC
1	Medical*	0.0856	0.1030	0.0631	0.1348	0.0087
2	Sewage Sludge*	0.8970	0.1447	0.8102	3.0093	0.0486
3	Combustibles MSW*	0.0134	0.1059	0.1001	0.7292	0.0000
4	The proposed TDU**	0.0007	0.0251	0.0018	0.0115	0.0001

*Calculated from the daily 5 Metric tons wastes types proposed to be handled by the incinerators and the respective emission factors as provided by AP-42 (US EPA, 1996)

**Calculated from the daily 12 Metric tons of cuttings treated

Meteorological data

The hourly meteorological information is an essential input requirement for the ISCST air dispersion modelling tool [43]. One-year valid hourly data with good data-capture for a number of specific parameters such as windspeed, wind direction, height of the station, wind gust and so on, are required. The meteorological data used for the present son the project area was acquired from Lakes Environmental meteorological observations. The data are the real time data obtained on the proposed integrated waste facility location.

Land surface characteristics data

Parameters used to represent certain features that affect complex dispersion processes to accomplish its calculations are the required in the AERMOD View dispersion tool. This include information about the terrain of the study location, the roughness length and other features which may serve as obstructions to wind flow. The ISC-AERMOD View modelling results from the five operating conditions scenarios considered in the study are presented in this section. The maximum anticipated odour levels and CH_4 maximum ground levels concentrations associated with the landfill operations were considered. Also presented and discussed are the anticipated maximum air pollutants from both the proposed four units of incinerators and the Thermal Desorption Unit (TDU). The 1 OU/s odour limit, CH_4 50,000 ppm Lower Explosive Limit (LEL), its 5000 ppm Continuous Exposure Limit (CEL) of ACGIH [44] and the Federal Ministry of Environment ambient air quality standards for air pollutants were considered in impact assessment.

Results and discussion

The surface and upper air observations were compiled. The generated windrose for the study area is presented in Fig. 2. The wind of the area has a prevalence for a south-westerly direction. Using the LandGem, summarized in Table 5 is the

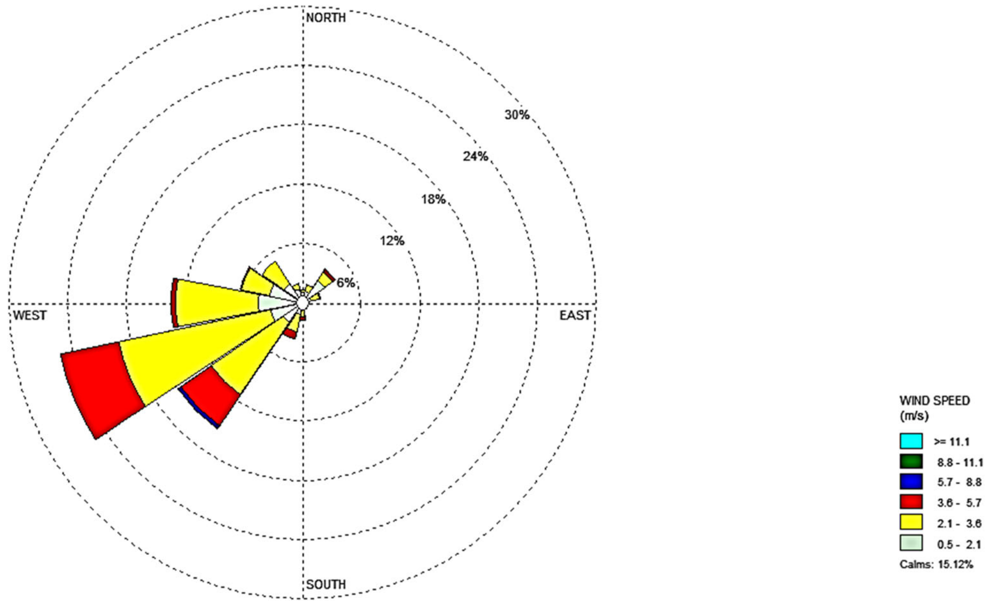
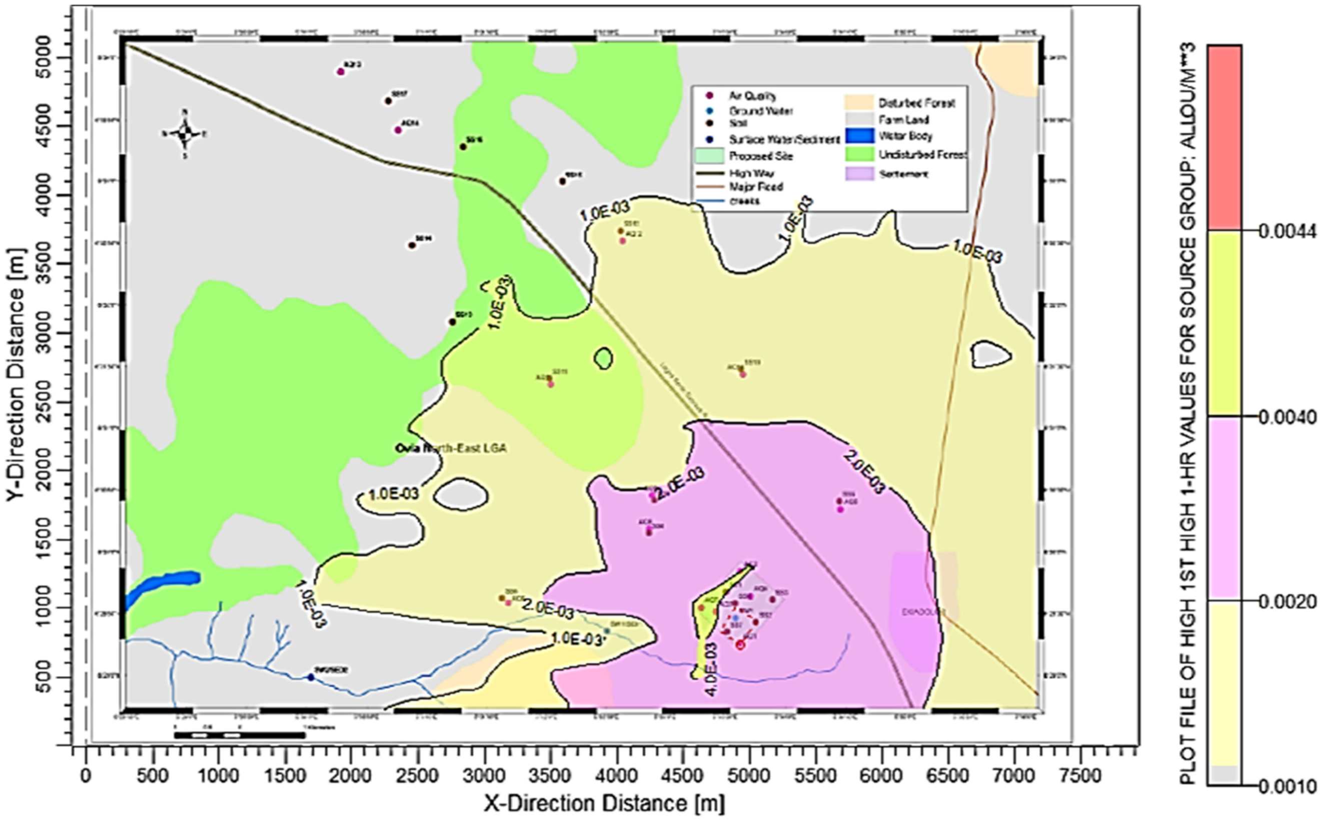


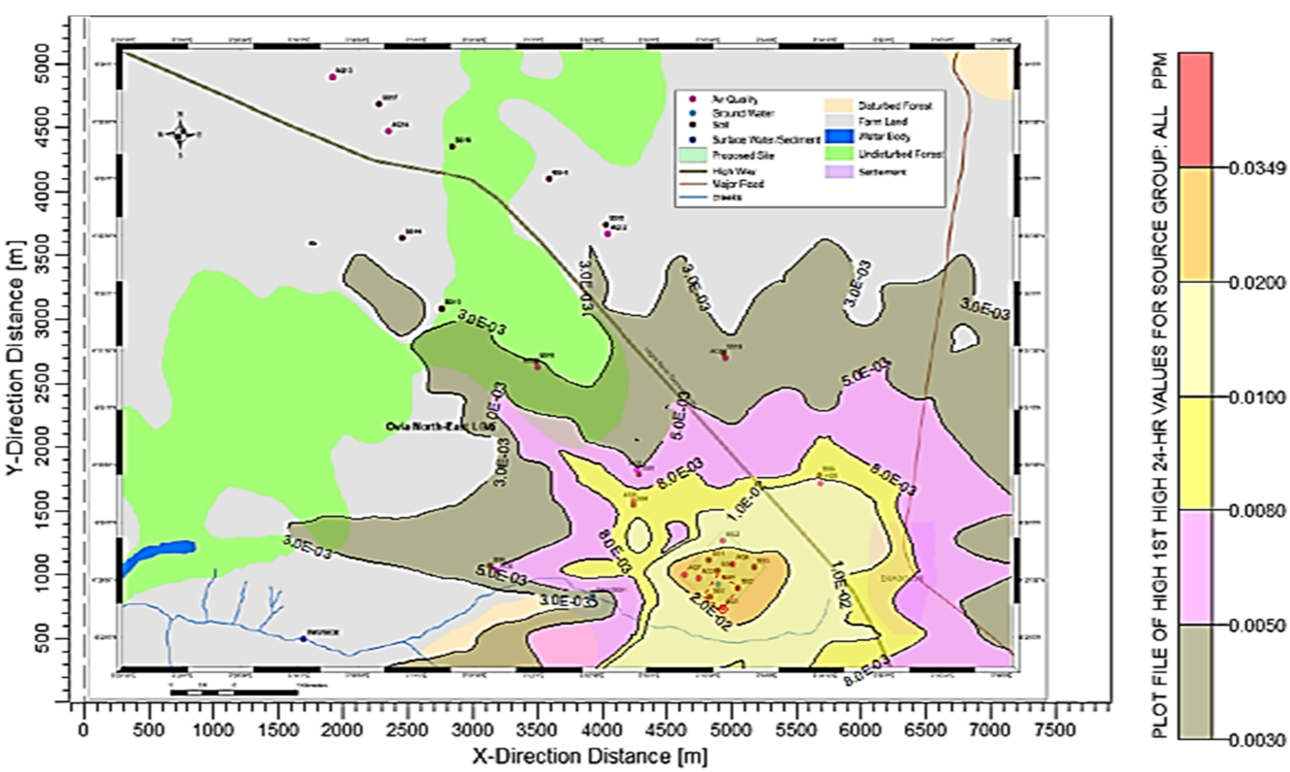
Fig. 2 Generated windrose from the wind data of the study

Table 5 Predicted gaseous emissions from the proposed engineered landfill

Year	Waste accepted	Waste in place	Total landfill gas		Methane emission, m^3/ Annum	Odour contaminants (m^3/Annum)		
			Tons/ Annum	m^3/ Annum		Dimethyl sulphide	Hydrogen sulphide	Methyl mercaptan
2016	51	0	0	0	0	0	0	0
2017	53	51.00	1.06	847.80	423.90	0.01	0.03	0.00
2018	54	104.00	2.10	1680.00	839.80	0.01	0.06	0.00
2019	56	158.00	3.12	2497.00	1249.00	0.02	0.09	0.01
2020	57	213.00	4.12	3302.00	1651.00	0.03	0.12	0.01
2021	59	271.00	5.11	4095.00	2047.00	0.03	0.15	0.01
2022	61	330.00	6.09	4878.00	2439.00	0.04	0.18	0.01
2023	63	391.00	7.06	5653.00	2826.00	0.04	0.20	0.01
2024	65	454.00	8.02	6420.00	3210.00	0.05	0.23	0.02
2025	67	518.00	8.97	7180.00	3590.00	0.06	0.26	0.02
2026	69	585.00	9.91	7936.00	3968.00	0.06	0.29	0.02
2027	71	653.00	10.85	8689.00	4344.00	0.07	0.31	0.02
2028	73	724.00	11.79	9438.00	4719.00	0.07	0.34	0.02
2029	75	797.00	12.72	10,190.00	5093.00	0.08	0.37	0.03
2030	77	871.00	13.66	10,940.00	5468.00	0.09	0.39	0.03
2031	79	949.00	14.59	11,680.00	5842.00	0.09	0.42	0.03
2032	82	1028.00	15.53	12,440.00	6218.00	0.10	0.45	0.03
2033	84	1110.00	16.47	13,190.00	6595.00	0.10	0.47	0.03
2034	87	1194.00	17.42	13,950.00	6974.00	0.11	0.50	0.03
2035	89	1281.00	18.37	14,710.00	7355.00	0.11	0.53	0.04
2036	92	1370.00	19.33	15,480.00	7740.00	0.12	0.56	0.04
2037	95	1463.00	20.30	16,260.00	8128.00	0.13	0.59	0.04
2038	98	1557.00	21.28	17,040.00	8520.00	0.13	0.61	0.04
2039	101	1655.00	22.27	17,830.00	8917.00	0.14	0.64	0.04
2040	104	1756.00	23.27	18,640.00	9318.00	0.15	0.67	0.05



(a)



(b)

Fig. 3 **a** Predicted 1-Hour odour levels from the proposed landfill operations. **b** Predicted daily ground level ch_4 from the proposed landfill

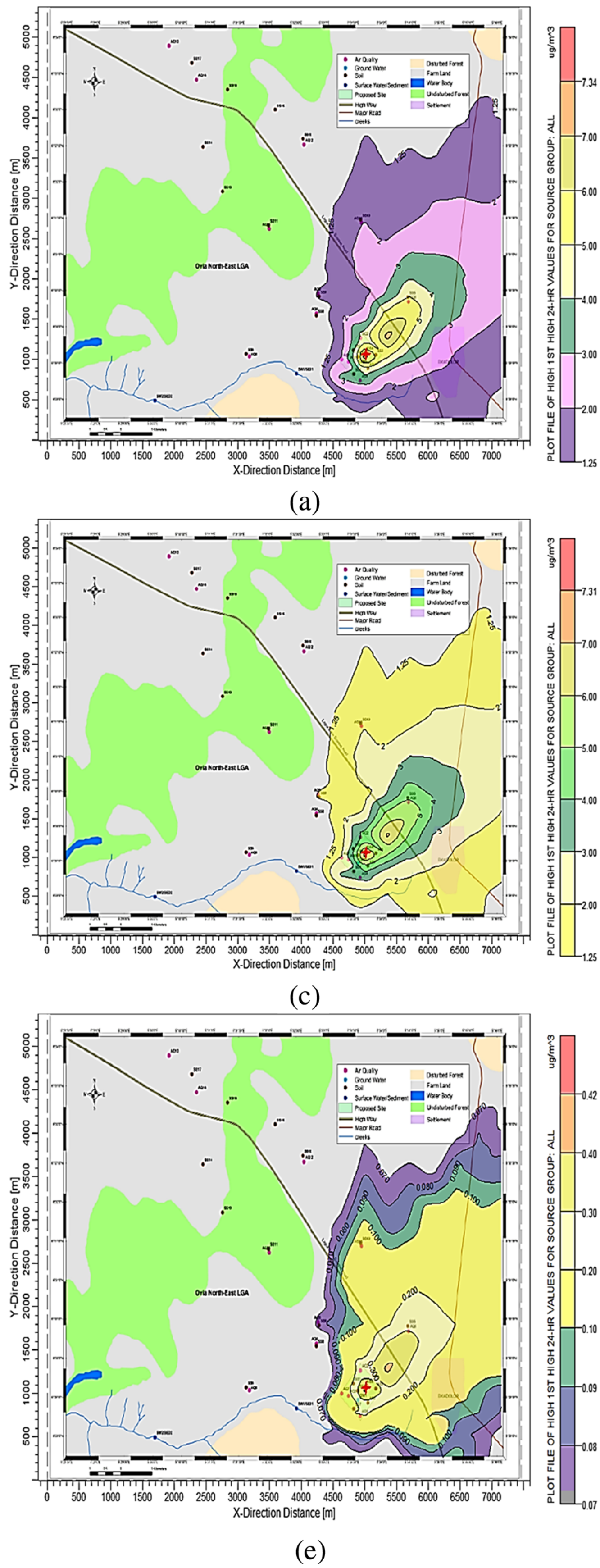


Fig. 4 Predicted daily air pollutants ground level concentrations from the incinerators. **a** CO. **b** NO_X. **c** SO_2. **d** PM. **e** HC

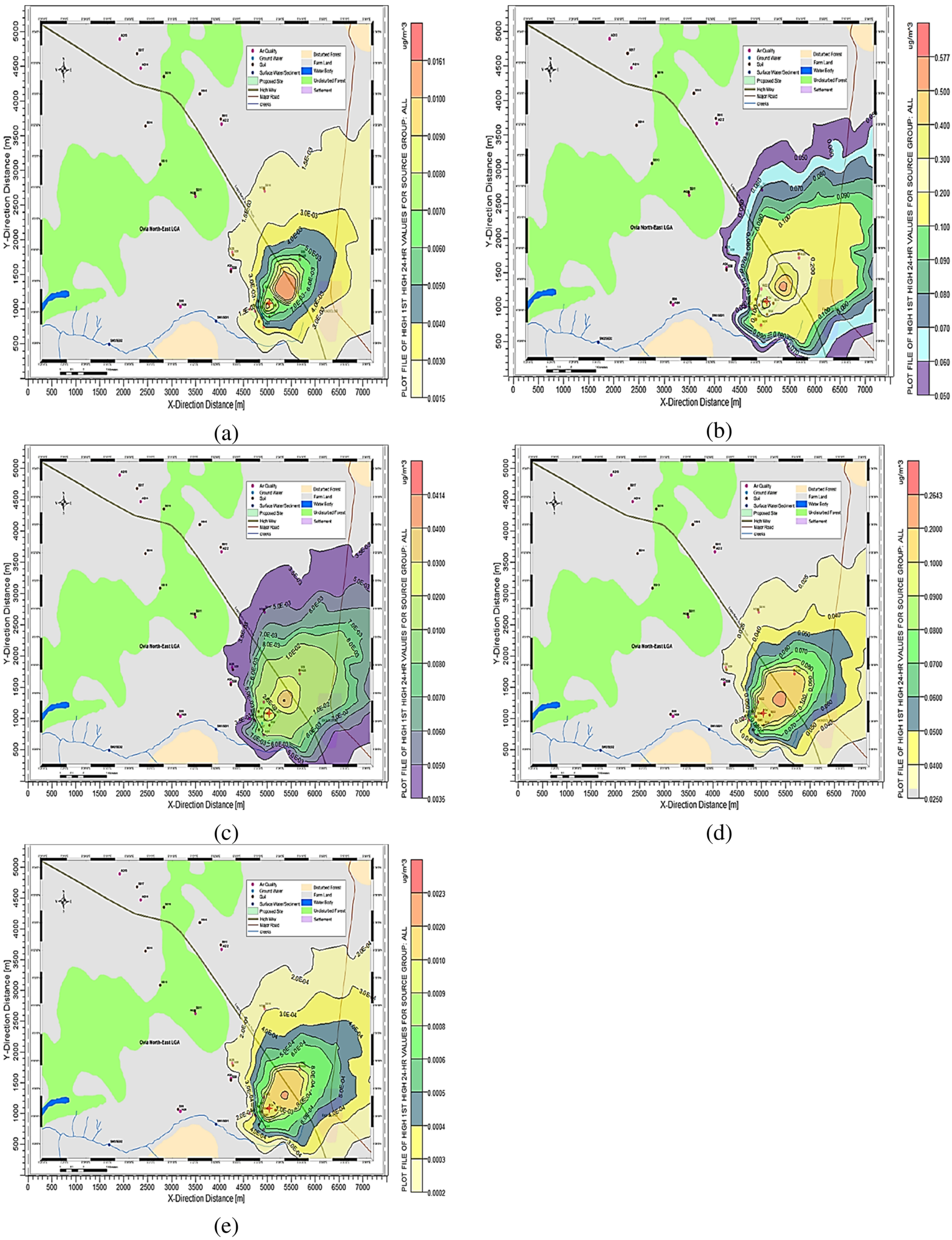


Fig. 5 Predicted daily pollutants ground concentrations from the thermal desorption unit. **a** CO. **b** NO_X. **c** SO_2. **d** PM. **e** HC

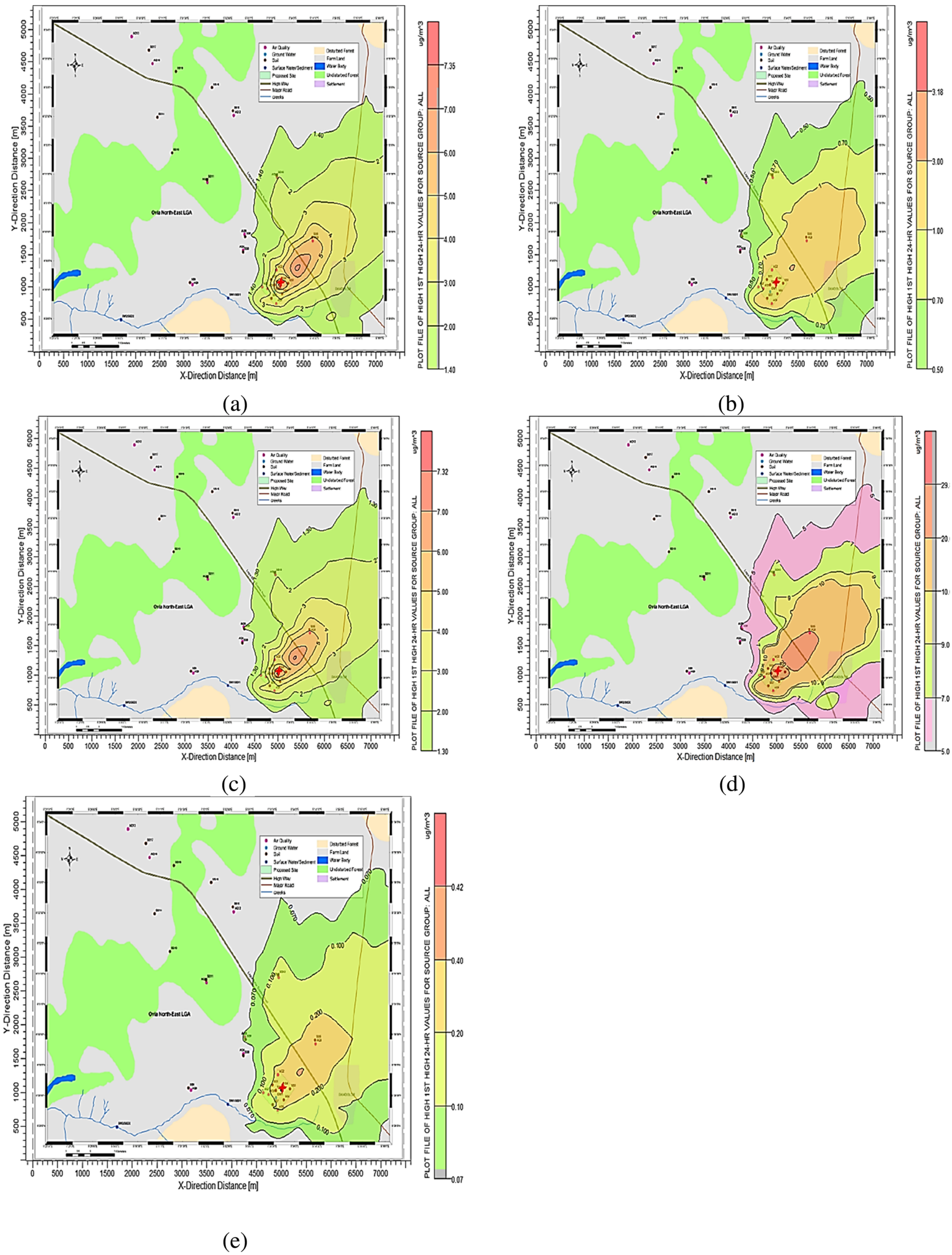


Fig. 6 Predicted daily pollutants ground concentrations from the TDU and the incinerators. **a** CO. **b** NO_X. **c** SO_2. **d** PM. **e** HC

anticipated landfill gas by composition from the proposed landfill over a 25-year period. However, the mean for the period was considered in this modelling exercise. Investigated along with the methane emission were the three landfill gases associated with 10-min averaging period odour including dimethyl sulphide, hydrogen sulphide and methyl mercaptan.

The mean annual total landfill gas over the 25-year period is 9.79×10^3 m^3 per year which is equivalent of 3.10×10^{-4} m^3/s (Table 5). Using the upper range odour concentration for landfill gas of 10,000 OU (odour units) per cubic meter of landfill gas, the mean anticipated odour emission rate from the proposed landfill project is 3.10×10^{-4} $m^3/s \times 10{,}000$ $OU/m^3 = 3.10$ OU/s. The odour emission flux rate from the proposed landfill project will be odour emission rate/Landfill Mound Area = 3.10 OU/s /39008 $m^2 = 7.95 \times 10^{-5}$ OU/m^2s. Also as reported in Table 5, the anticipated mean CH_4 emissions from the proposed facility are 4698.9 m^3/annum (3.13 tons/annum equivalent) which is about 0.0994 g/s. Thus the methane flux from the area will be 2.54×10^{-6} g/s. m^2.

Predicted odour levels from the landfill

As presented in Fig. 3, the anticipated ground level odour from the proposed landfill facility of the Integrated Waste Management during its operation is 0.0010–0.0040 OU/m^3 (a 10-min averaging period level of 0.0017–0.0066 OU/m^3) as investigated in scenario 1 of the study. The Landfill's odour concentration is insignificant to the complaint threshold of 5 OU/m^3 [45]. Also from the landfill, scenario 2 investigation of CH_4 emissions gave 0.0030–0.0349 ppm ground level concentration. Respiratory symptoms and other non-specific symptoms such as fatigue, sleepiness and headaches have been associated with exposure to odours from landfills and waste incineration facilities [22, 46].

Predicted air pollutants

Predicted daily ground level concentration of pollutant from the operation of the incinerators are presented in Fig. 4. The simultaneous operations of three incinerators handling medical wastes, sewage sludge and combustible MSW as investigated in scenario 3 will generate 1.25–7.34 $\mu g/m^3$ of daily CO with daily NO_X of 0.50–2.60 $\mu g/m^3$ and daily SO_2, ranging between 1.25 and 7.31 $\mu g/m^3$. Their anticipated daily PM and HC ground level concentrations are 5.0–29.72 $\mu g/m^3$ and 0.07–0.42 $\mu g/m^3$ respectively.

The isopleths of the predicted daily ground level concentration of pollutants from scenario 4 are presented in Fig. 5. Scenario 4 that investigated ground level concentrations of air

Table 6 Predicted maximum ground level concentrations from the landfill

Source	Contaminant	Predicted concentration	% of standard	Location		
				X (m)	Y (m)	Designation
Landfill	Odour (OU/m^3)*	0.01	1.00	4631.53	1034.41	South flank
	CH_4 (ppm)	0.03	0.00	4991.85	1034.41	Southeast
Incinerators	CO ($\mu g/m^3$)	7.34	0.06	4991.85	1034.41	Southeast
	NO_X ($\mu g/m^3$)	2.60	3.47	5352.17	1289.47	South flank
	SO_2 ($\mu g/m^3$)	7.31	2.81	4991.85	1034.41	Southeast
	PM ($\mu g/m^3$)	29.72	11.89	4991.85	1034.41	Southeast
	HC ($\mu g/m^3$)	0.42	0.01	5352.17	1289.47	South flank
Thermal desorption unit	CO ($\mu g/m^3$)	0.02	0.00	5352.17	1289.47	South flank
	NO_X ($\mu g/m^3$)	0.58	0.77	5352.17	1289.47	South flank
	SO_2 ($\mu g/m^3$)	0.04	0.02	5352.17	1289.47	South flank
	PM ($\mu g/m^3$)	0.26	0.10	5352.17	1289.47	South flank
	HC ($\mu g/m^3$)	0.002	0.00	5352.17	1289.47	South flank
Incinerators and thermal desorption unit	CO ($\mu g/m^3$)	7.35	0.06	5352.17	1289.47	South flank
	NO_X ($\mu g/m^3$)	3.18	4.24	5352.17	1289.47	South flank
	SO_2 ($\mu g/m^3$)	7.32	2.82	4991.85	1034.41	South flank
	PM ($\mu g/m^3$)	29.81	11.92	4991.85	1034.41	South flank
	HC ($\mu g/m^3$)	0.42	0.01	5352.17	1289.47	South flank

*The 1-h maximum concentration of 0.0043 OU/m^3 becomes 0.01 OU/m^3 on conversion to 10-min maximum concentrations for the purpose of comparison with the odour 10-min limiti of 1 OU/m^3 using the conversion rate of 10 min concentration (OU) = 1 h concentration (OU) x $(60 \text{ min}/10 \text{ min})^p$ with p, the representative exponent value taken as 0.28

Table 7 Cumulative impacts of the predicted co concentrations on air quality

Monitoring station		Concentrations (μg/m^3)			% of standard
Code	Designation	Measured*	Predicted	Total	
AQ-1	South flank	353.4 (0.31)	7.35	360.75	3.16
AQ-2	North flank	22.8 (0.02)	7.35	30.15	0.26
AQ-3	Mid point	0.0	7.35	7.35	0.06
AQ-4	East flank	0.0	7.35	7.35	0.06
AQ-5	0.84 km Northeast	0.0	2.00	2	0.02
AQ-6	1.5 km West of site	524.4 (0.46)	0.0	524.4	4.60
AQ-7	West flank	695.4 (0.61)	7.35	702.75	6.16
AQ-8	0.79 km Northwest	22.8 (0.02)	0.70	23.5	0.21
AQ-9	0.89 km Northwest	45.6 (0.04)	0.50	46.1	0.40
AQ-10	1.43 km North	22.8 (0.02)	1.40	24.2	0.21
AQ-11	1.96 km Northwest	11.4 (0.01)	0.00	11.4	0.10
AQ-12	2.68 km Northwest	205.2 (0.18)	0.00	205.2	1.80
AQ −13	2.86 km Northwest	91.2 (0.08)	0.00	91.2	0.80
AQ −14	3.57 km Northwest	250.8 (0.22)	0.00	250.8	2.20
	Lagos – Benin Expressway	–	7.00	7	0.06
	Ekiadolor, 0.8 km East		3.00	3	0.03

*Measured concentrations in ppm reported in the parenthesis

pollutants from the proposed Thermal Desorption Unit (TDU) shows that its daily CO will be 0.0015–0.0161 μg/m^3 with NO_X levels of 0.05–0.58 μg/m^3 and SO_2 of 0.0036–0.04 μg/m^3. It's PM and HC were predicted to be 0.03–0.26 μg/m^3 and 0.0002–0.0023 μg/m^3 respectively. Operations of all the incinerators and the TDU simultaneously as investigated in scenario 5 predicted their associated air pollutants to be 1.40–7.35 μg/m^3, 0.50–3.18 μg/m^3, 1.30–7.32 μg/m^3, 6.0–29.81 μg/m^3 and 0.07–0.42 μg/m^3 respectively (Fig. 6).

Maximum ground level concentrations

The anticipated maximum odour level associated with the landfill operation is 0.01 OU/m^3 with CH_4 level of 0.03 μg/

Table 8 Cumulative impacts of the predicted NO_X concentrations on air quality

Monitoring Station		Concentrations (μg/m^3)			% of standard
Code	Designation	Measured	Predicted	Total	
AQ-1	South flank	45.0 (0.024)	3.18	48.18	64.24
AQ-2	North flank	61.9(0.033)	3.18	65.055	86.74
AQ-3	Mid point	67.5 (0.036)	3.18	70.68	94.24
AQ-4	East flank	71.3(0.038)	3.18	74.43	99.24
AQ-5	0.84 km Northeast	95.6 (0.051)	1.00	96.625	128.83
AQ-6	1.5 km West of site	60.0 (0.032)	0.00	60	80.00
AQ-7	West flank	590.6(0.315)	3.18	593.805	791.74
AQ-8	0.79 km Northwest	88.1 (0.047)	0.70	88.825	118.43
AQ-9	0.89 km Northwest	82.5 (0.044)	0.50	83	110.67
AQ-10	1.43 km North	76.9 (0.041)	0.70	77.575	103.43
AQ-11	1.96 km Northwest	39.4 (0.021)	0.00	39.375	52.50
AQ-12	2.68 km Northwest	71.3 (0.038)	0.00	71.25	95.00
AQ −13	2.86 km Northwest	45.0 (0.024)	0.00	45	60.00
AQ −14	3.57 km Northwest	58.1 (0.031)	0.00	58.125	77.50
	Lagos – Benin Expressway	–	1.00	1	1.33
	Ekiadolor, 0.8 km East	–	0.70	0.7	0.93

*Measured concentrations in ppm reported in the parenthesis

Table 9 Cumulative impacts of the predicted SO_2 concentrations on air quality

Monitoring Station		Concentrations (μg/m^3)			% of Standard
Code	Designation	Measured	Predicted	Total	
AQ-1	South flank	3120.0 (0.12)	7.32	3127.32	1202.82
AQ-2	North flank	4160.0(0.16)	7.32	4167.32	1602.82
AQ-3	Mid point	520.0 (0.02)	7.32	527.32	202.82
AQ-4	East flank	520.0 (0.02)	7.32	527.32	202.82
AQ-5	0.84 km Northeast	0.0	5.00	5	1.92
AQ-6	1.5 km West of site	0.0	1.30	1.3	0.50
AQ-7	West flank	1040.0(0.04)	7.32	1047.32	402.82
AQ-8	0.79 km Northwest	0.0	2.00	2	0.77
AQ-9	0.89 km Northwest	0.0	1.30	1.3	0.50
AQ-10	1.43 km North	260.0 (0.01)	1.30	261.3	100.50
AQ-11	1.96 km Northwest	0.0	0.0	0	0.00
AQ-12	2.68 km Northwest	0.0	0.0	0	0.00
AQ −13	2.86 km Northwest	0.0	0.0	0	0.00
AQ −14	3.57 km Northwest	0.0	0.0	0	0.00
	Lagos – Benin Expressway	–	6.00	6	2.31
	Ekiadolor, 0.8 km East	–	2.00	2	0.77

*Measured concentrations in ppm reported in the parenthesis

m^3 (Table 6). The maximum CO from the incinerators worst case scenario is 7.34 μg/m^3 with NO_X, SO_2, PM and HC levels of 2.60 μg/m^3, 7.31 μg/m^3, 29.72 μg/m^3 and 0.42 μg/m^3 respectively. While the maximum ground level concentrations from the TDU are 0.02 μg/m^3, its NO_X and SO_2 are respectively 0.58 μg/m^3 and 0.04 μg/m^3 with PM level of 0.26 μg/m^3 and HC level of 0.002. The simultaneous operations of all the incinerators and TDU are anticipated to result in maximum ground-level concentrations of CO = 7.35 μg/m^3, NO_X = 3.18 μg/m^3, SO_2 = 7.32 μg/m^3, PM = 29.81 μg/m^3 and HC = 0.42 μg/m^3.

Impacts of the anticipated maximum concentrations

Epidemiological studies have established a relationship between air pollution components and health of people

Table 10 Cumulative impacts of the predicted pm concentrations on air quality

Monitoring Station		Concentrations (μg/m^3)			% of Standard
Code	Designation	Measured	Predicted	Total	
AQ-1	South flank	109.0	29.8	138.8	55.52
AQ-2	North flank	140.0	29.8	169.8	67.92
AQ-3	Mid point	89.6	29.8	119.4	47.76
AQ-4	East flank	84.2	29.8	114	45.60
AQ-5	0.84 km Northeast	91.2	20.0	111.2	44.48
AQ-6	1.5 km West	98.4	0.0	98.4	39.36
AQ-7	West flank	62.2	29.8	92	36.80
AQ-8	0.79 km Northwest	106.4	5.0	111.4	44.56
AQ-9	0.89 km Northwest	104.2	0.0	104.2	41.68
AQ-10	1.43 km North	92.8	7.0	99.8	39.92
AQ-11	1.96 km Northwest	96.1	0.0	96.1	38.44
AQ-12	2.68 km Northwest	69.2	0.0	69.2	27.68
AQ −13	2.86 km Northwest	50.4	0.0	50.4	20.16
AQ −14	3.57 km Northwest	88.6	0.0	88.6	35.44
	Lagos – Benin Expressway	–	20.0	20	8.00
	Ekiadolor, 0.8 km East		7.0	7	2.80

[47–49]. Impacts assessment of the anticipated maximum concentrations of odour and air emissions from the proposed facility shows that, the anticipated maximum odour level from the landfill operation will be 1% of the 10-min 1 OU/m^3 limit while its maximum CH_4 emission will be 0.03% of its 50,000 LEL. The maximum CO ground level from the simultaneous operations of the incinerators will be 0.06% of its daily limit with the maximum concentrations of NO_X, SO_2, PM and HC being 3.47%, 2.81%, 11.89% and 0.01% of their respective daily limits. From the TDU, the maximum ground-level concentrations will be CO = 0%, NO_X = 0.77%, SO_2 = 0.02%, PM = 0.10%, and HC = 0% of their daily limits. Simultaneous operations of the incinerators and TDU will generate a maximum ground level concentration of CO that will be 0.06% of its daily limit while its maximum NO_X will be 4.24% of its daily limit. Their anticipated maximum SO_2 concentrations will be 2.82 of its daily limit with the maximum PM being 11.92% of its daily limit and the maximum HC level that will be 0.01 of its daily limit.

Cumulative impacts of the waste treatment facility emissions

Addition of the measured air pollutants during fieldwork to AERMOD predicted concentrations were used to investigate the cumulative impacts of the facility as earlier indicated. The anticipated CO will be 0.02–6.16% of the limit (Table 7). Its NO_X will be 0.93–99.24% of the daily limit but with the limit exceeded in five locations attributed to the present status of NO_X in the area (Table 8). Though SO_2 anticipated will breach its daily limit in six locations, it will be 0.00–2.31% of the limit in the other locations (Table 9). The anticipated PM will be 2.80–67.92% of its daily limit in all the investigated locations (Table 10). The minimum cumulative impacts are anticipated at the Ekiadolor, a community near the proposed site while the maximum cumulative impact is anticipated in the West flank of the site.

Acid gases such as nitrogen dioxide and sulphur dioxide emitted from integrated waste management facility can cause inflammation and bronchoconstriction [50–52]. They irritate airways, affect the immune cells in the lungs, and increase susceptibility to respiratory infections. While people suffering from Asthma are most susceptible, although a high level of NO_2 and SO_2 may also produce effects on the lung function of non-asthmatics [53]. Exposure to particles from landfill and waste incineration sites can enter the respiratory system and heart disease in children and the elderly [20, 54].

Odorous emissions are often associated with reports of ill-health from communities [55]. A wide range of non-specific health symptom attributed these to odour exposure, including nausea, headaches, drowsiness, fatigue, mucous membrane irritation and respiratory problems, and variation of complaints are reported among people [56]. Individual responses to odours are highly variable and are influenced by many factors including sensitivity, age and prior exposure to the odour. Psychological and social factors and an individual's level of concern about the potential harm to people's health play an important role in an individual's response [57, 58].

Conclusion

Landfill emission has an impact on the environment and health of people in the neighbouring environment. Utilization of air dispersion and modelling tools to investigate the impact of anthropogenic activities on the air quality of receptor environment is important. The present study modelled air pollutants and odour emissions anticipated from the operation of a proposed Integrated Waste Management Facility. The study was undertaken using an emission inventory and the ISC-AERMOD View dispersion modelling tool considering five operating conditions scenarios. Impacts of the predicted ground level concentrations of air pollutants (including carbon monoxide, CO; oxides of nitrogen, NO_X; sulphur dioxide, SO_2; particulate matter, PM and hydrocarbons, HC) and odour on ambient air quality were investigated using the 10-min 1 OU/m^3 odour limit, CH_4 Lower Explosive Limit (LEL) and the daily limits of air pollutants. The anticipated ground level odour is 0.0010–0.0040 OU/m^3 with the CH_4 ground level concentration of 0.0030–0.0349 ppm. Simultaneous operations of three incinerators handling medical wastes, sewage sludge and combustible MSW will generate 1.25–7.34 $\mu g/m^3$ daily CO, 0.50–2.60 $\mu g/m^3$ NO_X, 1.25–7.31 $\mu g/m^3$ SO_2, 5.0–29.72 $\mu g/m^3$ PM and 0.07–0.42 $\mu g/m^3$ HC respectively. The ground level concentrations of pollutants from the proposed Thermal Desorption Unit (TDU) are CO 0.0015–0.0161 $\mu g/m^3$ with NO_X of 0.05–0.58 $\mu g/m^3$ and SO_2 of 0.0036–0.04 $\mu g/m^3$. Its PM and HC were 0.03–0.26 and 0.0002–0.0023 $\mu g/m^3$ respectively. Operations of all the incinerators and the TDU simultaneously will result in 1.40–7.35, 0.50–3.18, 1.30–7.32, 6.0–29.81 and 0.07–0.42 $\mu g/m^3$ respectively. Generally, the facility impacts on ambient air quality will be within the acceptable limit. The obtained simulation results will serve as a guide for policy makers and relevant stakeholders in identifying areas of high exposure risks. Periodic monitoring of air quality and design parameters in the facility will assist in maintaining effective control.

Compliance with ethical standards

Ethics approval and consent to participate Not applicable.

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