

Odour Monitoring & Management in Urban MSW Landfill sites



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(भारत सरकार)

CENTRAL POLLUTION CONTROL BOARD
Ministry of Environment, Forest & Climate Change
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FOREWORD

Though there are several odour generating activities (ex industries like paints, pharmaceuticals ,tanneries, etc.) however MSW landfill was identified by CPCB for conducting the first pilot study on Odour monitoring, as the activities associated with MSW management are familiar to both - urban local bodies (ULBs) and the public. The Solid Waste Management Rules 2016, recognises 'odour' as a public nuisance, unlike air pollutants ex. PM, CO, CO₂, SO₂, where there are specified standards for compliance. However, 'odour regulation' is still in nascent stage in the country.

In view of the above, CPCB identified MSW landfill site at Ghazipur, located in east Delhi for several reasons that include its unique locational features having odour generating sources at its periphery ex. slaughter house, poultry house, fish market, vegetable & fruits market, leachate flow, two waste to energy projects - RDF (by ILFS) and power generation of installed capacity 5 MW (by GAIL). Besides, it is the oldest landfill in the Union Territory.

The above project was closely co-ordinated by CPCB's Project monitoring team comprising Ms. Mita Sharma, Sh. Abhijit Pathak & Sh. Sharandeep Singh. The support & guidance provided by East Delhi Municipal Corporation (EDMC), CDAC-Kolkata, CSIR - National Physical Laboratory, Delhi, CSIR - NEERI Nagpur and IIT Delhi to CPCB and the Project Consultant - M/s JM EnviroNet (P) Ltd. (JMEPL) is highly appreciated. For simplification, the entire study has been divided into FOUR parts in order of their development viz. 'Sampling & Analysis Protocols for determining Odour emission from MSW Landfill site', 'Case study - Odour monitoring in Ghazipur MSW Landfill site in East Delhi, 'Dispersion Modeling (AERMOD) & Mapping of Odour in Ghazipur MSW Landfill site in East Delhi' and finally 'Guidelines on Odour Monitoring in Urban MSW Landfills'. Odour dispersion from MSW landfill is influenced by several factors including meteorological parameters. Hence it is hoped that ULBs & academic institutions will be encouraged by findings of this to undertake studies to create a database that can be utilised for further research and development in this important area of work.


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JULY 2017



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To the READER

Central Pollution Control Board (CPCB) awarded the project “*Development of National Guidelines on Odour Monitoring & Management of Urban Municipal Solid Waste (MSW) Landfill Site*” to M/s. J.M. EnviroNet Pvt. Ltd. (henceforth Project Consultant), Gurugram, Haryana, India in September 2015. The sampling & analysis protocols for determining odour emission from MSW Landfill site is the core of this study around which the pilot study on Odour monitoring was conducted at the identified MSW landfill site at Ghazipur located in East Delhi. Dynamic Olfactometry is the internationally accepted & recommended method which facilitates field sampling cum laboratory analyses by expert panelists – both, the expertise & instrumentation is cost prohibitive for a pilot study. In India ODOUR is a NEW area which needs to be familiarized, hence literature survey on various aspects and also to explore economically feasible and adaptable methods to create a database that can assist in generating mass awareness. For CPCB’s pilot study on Odour monitoring the use of Field Olfactometry was accepted. Odour Dispersion modeling & mapping was done by IIT Delhi. The above exercise assisted in preparing the **Guidelines on Odour Monitoring in MSW Landfills** which recognizes the diverse climatic zones of our vast country, hence odour surveys at MSW landfill sites cannot be generalized but to be assessed on a case to case basis taking into consideration the unique temporal & spatial influences of each MSW landfill site. This report is in compliance of the project’s ToR conditions. For simplification, the entire study is being presented in following **FOUR PARTS** in order of their development.

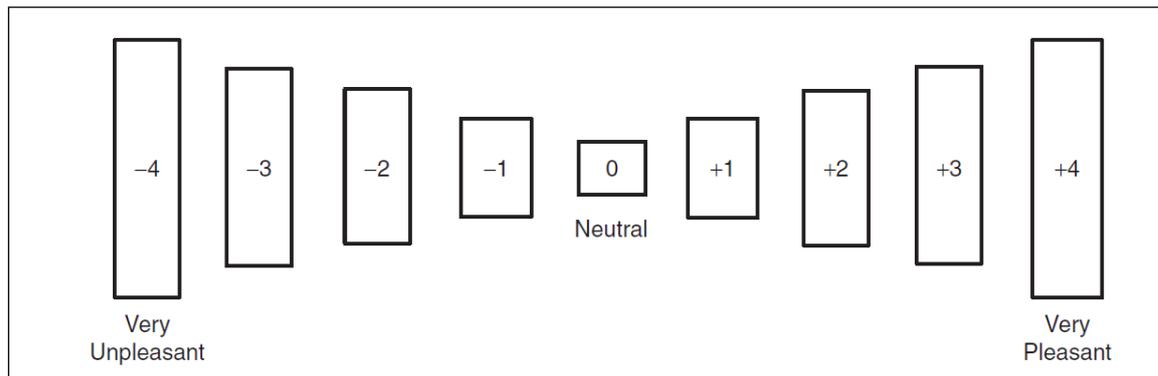
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GLOSSARY

1. **ODOUR** Odour is defined as perception of smell. The property of certain substances, in very small concentrations, to stimulate chemical sense receptors (sense of olfaction) that sample the surrounding air.
2. **ODOUR DETECTION THRESHOLD-** Odour detection threshold is the lowest Odourant concentration necessary for detection by a certain percentage of the population, normally 50%. This concentration is defined as **1 odour unit**. (also see **ODOUR UNIT**)
3. **ODOURANT** A substance which stimulates a human olfactory system so that an odour is perceived.
4. **ODOUR INTENSITY** The strength of an odour perceived above its threshold. It is determined by an odour panel and is described in categories which progress from “not perceptible” followed by “very weak” through to “extremely strong”.
5. **HEDONIC TONE** Hedonic tone is the degree to which an odour is perceived as pleasant or unpleasant. Such perceptions differ widely from person to person, and are strongly influenced, inter alia, by previous experience and emotions at the time of odour perception.

HEDONIC TONE SCALE



6. **ODOUR CHARACTER** Odour character is basically what the odour smells like, it allows one to distinguish between different odours. For example, ammonia gas (NH₃) has a pungent and irritating smell. The character of an odour may change with dilution.
7. **ODOUR CHARACTERISTIC** Odour may not cause any direct damage to health but the toxic stimulants may lead to ill effects on the respiratory system. Secondary effects such as nausea, insomnia and discomfort are commonly observed. Very strong odour can trigger the symptoms such as nasal irritation & breathing problems among the individuals. Frequency, Intensity, duration, odour unpleasantness and location are the characteristic of an odour for assessing its offensiveness.
8. **ODOUR CONCENTRATION** ODOUR concentration is measurement in odour units (OU) in one cubic meter of gas at standard conditions and

assigned the dimension of odour units per cubic meter (OU/M³). (also see **ODOUR UNIT**)

9. **ODOUR INTENSITY** Odour intensity is the strength of the perceived odour sensation. Perceived odour intensity is the relative strength of the odour above the recognition threshold, it is related to the odourant concentration. Generally odour intensity increases with the odourant concentration. The relationship between intensity and concentration, is expressed as:

$$I = k (C)^n \quad \text{or} \quad \text{Log } I = \text{Log } K + n \text{ Log } (C)$$

where I – Intensity C – Concentration k – Constant n – Exponent

This is known as Stevens’ law or the power law.

10. **Odour Intensity is expressed in parts per million of butanol.** The odour intensity is usually stated according to a pre-determined rating system, widely used scale for odour intensity is given in Table below. It is usually accepted that a “distinct” odour may just be able to be recognized (i.e. has a concentration equivalent to its recognition threshold), an odour described as “distinct” under highly controlled laboratory conditions is likely to be harder to detect in the ambient environment.

Odour Intensity	Intensity Level
Extremely strong	6
Very strong	5
Strong	4
Distinct	3
Weak	2
Very weak	1
No perceptible	0

11. **ANNOYANCE** It is defined as interference with comfortable enjoyment of life and property.
12. **DILUTION TO THRESHOLD (D/T) RATIO** It is a measure of the number of dilutions required to make the odourous air , non-detectable.
13. **ODOUR PERSISTENCE** It is term used to describe the rate at which an odour’s perceived intensity decreases as it is diluted, it can be represented as a ‘ **Dose – Response** ’ function , a relationship of odour concentration and odour intensity.
14. **ODOUR UNIT** That amount of Odourant(s) when evaporated in one cubic meter of neutral gas at standard conditions elicits a physiological response from a panel (detection threshold) equivalent to that elicited by one **European Reference Odour Mass (EROM)**, evaporated in 1 m³ of neutral gas at standard conditions. One EROM is equivalent to 123 µg n-butanol. Evaporated in 1 m³ of neutral gas this produces a concentration

- of 0.040 $\mu\text{mol}/\text{mol}$ = volume fraction of 40 ppb. The odour concentration (OU_E / m^3) is statistically equal to the dilution factor of the perception threshold; for example, a concentration of 200 (OU_E/m^3) means that the sample has been diluted two hundred times to reach the panel threshold.
15. **ADAPTATION** The phenomena of reduced sensitivity to a stimulus after prolonged exposure, unlike habituation this refers to a reduced physiological response as opposed to psychological response to a stimuli.
 16. **DILUTION FACTOR** The dilution factor is the ratio between flow or volume after dilution and the flow or volume of the odourous gas.
 17. **ODOUR EMISSION** The number of odour units per second discharged from a specific source.
 18. **REFERENCE ODOUR MASS (ROM)** The ROM is equivalent to 123 mg of n-butanol evaporated in 1 m^3 of neutral gas. (also see **ODOUR UNIT**)
 19. **Specific or SURFACE ODOUR EMISSION RATE (SOER)** The SOER per unit area of surface, which has units of odour per unit area per time (e.g. $\text{OU}/\text{M}^2\text{s}$ or $\text{OU}/\text{M}^2\text{h}$).
 20. **OLFACTOMETER** Apparatus in which a sample of odourous gas is diluted with neutral gas in a defined ratio and presented to assessors.
 21. **STATIC OLFACTOMETER** In a static olfactometer dilutes by mixing two known volumes of gas, odourous sample & neutral gas, the rate of dilution is calculated from the known volumes. It is 'static' because only one dilution can be made at a time.
 22. **DYNAMIC OLFACTOMETER** A dynamic olfactometer delivers a flow of mixtures of odourous and neutral gas with known dilution factors in a common outlet. Here the concentration may be change at the will of operator by mechanical means.
 23. **ELECTRONIC NOSE (E-Nose)** It is a device which can simulate the electronic / electrical responses of single or various compounds similar to the human olfactory mechanism to report odour concentration. Technically E-Nose is defined as 'electronic device that uses an array of solid-state sensors, or synthesized protein sensors, that respond to the presence of different chemical compounds. The resulting electronic signals are processed using neural network computing techniques helps to produce a two-dimensional spectral pattern that is specific to a particular mix of chemical compounds. The aim is to create different spectral signatures that can identify / fingerprint specific types of odour character.
 24. **FUGITIVE SOURCE** Any type of odour emission that cannot be readily quantified or defined. This usually refers to such sources as leaks in pipes, flanges, pump seals or structures, openings in buildings, floor spills, occasional sources such as uncovered truck loads or releases from pressure relief valves and leaks in seals on covered tanks.
 25. **GAS CHROMATOGRAPHY** An analytical technique form of chromatography that separates and detects compounds by the rate in which they move through an inert or un-reactive carrier gas such as

- nitrogen, helium or carbon dioxide. The time taken (residence time) to move through the glass or metal tube called 'column' is used to determine the type of compound present within the sample.
26. **ODOUR ISOPLETHS** A line on a map connecting places registering the same amount or ratio of some geographical or meteorological phenomenon or phenomena, commonly used to illustrate the output of odour models.
27. **ODOUR FLOW RATE** The odour flow rate is the quantity of European odour units which crosses a given surface divided by time. It is the product of the odour concentration, the outlet velocity V and the outlet area A or the product of the odour concentration cod and the pertinent volume flow rate, V , the unit are either OU_E/h or OU_E/min or OU_E/s .
28. **PANEL MEMBER** An assessor who is qualified to judge samples of odourous gas, using Dynamic Olfactometer within the scope of the standard.
29. **PANEL** A group of panel members
30. **STATIC FLUX HOOD** An odour-sampling hood that is placed over an area source and which has a low flow-rate of neutral gas injected to allow a mixed air stream to be expelled from the hood. These devices work on the same principle as wind-tunnel sampling hoods except that air within the static hood exhibits minimal turbulence.

ABBREVIATIONS

NAAQS	: National Ambient Air Quality Standards
ALARA	: As Low As Reasonably Achievable
APHA	: American Public Health Association
ASTM	: American Society for Testing Materials
BDL	: Below Detection Level
BOD	: Biochemical Oxygen Demand
C&D	: Construction and Demolition
C&I	: Commercial and Industrial
CEN	: European Committee for Standardization
CERs	: Certified Emission Reductions
CFD	: Computational Fluid Dynamics
Cd	: Cadmium
COD	: Chemical Oxygen Demand
CDM	: Clean Development Mechanism
CH₄	: Methane
CO₂	: Carbon dioxide
COPCs	: Contaminants of Potential Concern
cm	: Centimeter
CPCB	: Central Pollution Control Board
D/T	: Dilution to Threshold ratio
ECD	: Electron Capture Detector
EP(A)	: Environment Protection Act
EROM	: European Reference Odour Mass
EU	: European Union
FPD	: Flame Photometric Detector
GC	: Gas Chromatography
GC-FID	: Gas Chromatography -Flame Ionization Detector
GC-MS	: Gas Chromatography–Mass Spectrometry
GCV	: Gross Calorific Value
GLP	: Good Laboratory Practice
HDPE	: High-density poly-ethylene
HFP	: Hexa Fluro Propylene
HPLC	: High Performance Liquid Chromatography
HS	: Head Space technology
IS	: Indian standards
ISO	: International Standards Organization
ITE	: Individual Threshold Estimates
JMEPL	: JM EnviroNet Pvt. Ltd.
kg	: Kilograms
km	: Kilometers
LFG	: Landfill gas
LU / LC	: Land use / Land Cover ratio
M	: Meters
mbgl	: meters below ground level
MCD	: Municipal Corporation of Delhi
MOEF&CC	: Ministry of the Environment Forests & Climate Change
mm	: Millimeter
MSW	: Municipal Solid Waste
MSMEs	: Micro Small Medium Enterprises

MT	: Million Tons
MTD	: Million Tons per day
MW	: Mega Watt
NABL	: National Accreditation Board (for Testing & Calibration) for Laboratories
NE	: North East
NIOSH	: National Institute for Occupational Safety & Health
NMAM	: NIOSH Manual of Analytical Methods
NGO	: Non Government Organization
NMOCs	: Non-Methane Organic Compounds
NSIC	: National Small Industries Corporation
OU	: Odour Unit
PAHs	: Poly Aromatic Hydrocarbons
Pb	: Lead
PFPD	: Pulse Flame Photometric Detector
POI	: Point of Implement
PCBs	: poly-chlorinated biphenyls
ppb	: Parts per billion
ppm	: Parts per million
PTFE	: Poly tetra Fluoro Ethylene
PET	: Poly ethylene Terephthalate
RDF	: Refused Derived Fuel
ROM	: Reference Odour Mass
RSC	: Reduced Sulfur Compounds
RSO	: Reduced Sulphur Odourants
SOER	: Specific Odour Emission Rate
SOP	: Standard Operating Procedure
SPME	: Solid Phase Micro Extraction
SWDS	: Solid Waste Disposal Site
TD	: Thermal desorption
TDS	: Total Dissolved Solids
TOC	: Total Organic Carbon
ToR	: Terms of Reference
TKN	: Total Kjeldahl Nitrogen
TPD	: Tones per day
USA	: United States of America
USEPA	: United States Environmental Protection Agency
VOCs	: Volatile Organic Compounds
XOCs	: Xenobiotic organic compounds

Part 1

SAMPLING & ANALYSIS PROTOCOLS FOR DETERMINING ODOUR IN MSW LANDFILLS



To the READER

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*The entire study has been brought out in **FOUR parts** in the chronological order that they were prepared hence for a better appreciation readers may follow the same sequence.*

1. **Sampling & analysis protocols for determining odour emission from MSW Landfill site**
2. **Case study – Pilot Study on Odour Monitoring at Municipal Solid Waste (MSW) Landfill Site, Ghazipur, East Delhi in year 2016**
Although Dynamic Olfactometry is recommended in most of the internationally accepted methods which involve field sampling cum laboratory analyses by expert panelists – both being cost prohibitive. In India Odour is a new area , hence the need to familiarize with it and to explore economically feasible and adoptable methods to create a database that can assist in generating mass awareness. For CPCB’s pilot study on Odour monitoring use Field Olfactometry was accepted.
3. **Dispersion modeling & mapping of Odour in Ghazipur MSW Landfill site in East Delhi**
4. **Guidelines on Odour Monitoring in Urban MSW Landfill**

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IMPORTANCE OF SAMPLING & ANALYSIS PROTOCOLS FOR DETERMINING ODOUR IN MSW LANDFILLS

Odour is a public nuisance– need for sampling & monitoring

Many odour generating activities like manufacturing processes (ex pharmaceuticals, distilleries, meat processing etc) and urban waste related activities (ex. sewage, drains and municipal solid waste) generate odour (unpleasant) which affect the quality of life, particularly residential areas in the neighborhood. Complaints about unpleasant odour are frequently received from localities that are affected due odourous nature of activities in their vicinity, it thereby becomes necessary to reduce / control odour. To begin with one needs to identify the odour source(s) to be investigated before suggesting suitable abatement measures. The sampling & monitoring techniques are important for regulatory purposes as they assist in assessing, evaluating and exploring abatement measures to be adopted that are economically sustainable.

Odour basics

Odour analysis involves simultaneous chemical and sensory analysis. When studying reports on odour related issues certain terminologies come across which are shown in the GLOSSARY.

Some important aspects (Ref. Odortech) on Odour is given below:

- a. Olfactometry provides solutions for verifying compliance with standards and regulations, designing waste collection sites, designing equipment for odor mitigation, and for monitoring the respective performance.
- b. Definition of Odour unit: When measuring odor with an olfactometer, panelists are exposed to the odor sample via the dilution unit of the olfactometer. Initially, the odor is highly diluted, all panelists indicate that they cannot smell it. The operator then increases the concentration by diluting the sample a little less with pure air in a given, accurate ratio, and the panelists respond. The operator keeps reducing the odor sample dilution until half of the panelists indicate that they can smell the odor, but the other half still cannot. The point at which 50% of the panelists cannot smell the odor but 50% can, is called the PERCEPTION THRESHOLD and is equal to 1 odor unit per cubic meter.

- c. Odour concentration To find out how many odor units the sample had in the first place, the operator – once the perception threshold has been reached – adds up all the dilutions that were required to reach that threshold; if the sample was diluted, say, 536 times, in order to reach 1 odor unit, then the sample odor concentration was 536 odor units (o.u./m³), initially.

AROMAGRAM is generated by trained human panelist scoring the aroma character, duration, intensity and (un)pleasantness .

Define purpose of odour sampling & monitoring

To achieve a comprehensive characterization of odorous compounds, a sampling & monitoring plan must be drawn up to gather significant information from each single analysis. This prior to finalization of sampling points for characterization of odorous compounds from different sources including MSW landfill site the following should be considered.

1. Objective of the study
2. Study Area
 - a. Zone of Impact/Area of influence in which sampling has to be carried out
 - b. Identification of locations both at the sources and within area of influence
3. Selection of methodology
4. Required characterization & inventorization

The above issues are discussed below.

- 1) Objectives of study : It is vital that the objective(s) are defined prior to monitoring. The goal of study guides the decision making for subsequent steps including selection of the methodology to be adopted. Literature surveys are helpful in formulating the objectives of the study , however to meet the objectives of the study for assessment of odour emission in and around the MSW landfill site, the study area must cover (identify) the emission sources as well as zone of influence (impacts) in the prevalent downwind direction.

For example , if objective of the study is to assess performance of existing landfill gas (LFG) treatment system, the monitoring approach needs to be carried out before and after the treatment of the LFG.

- 2) Study area : Monitoring locations for odour shall be determined taking into consideration the regional landscape (topography), meteorological data , field conditions, prevalent odour generating sources , legal (obligations) requirements including safety & security to satisfy the objectives of the study. The identification of odour sources vis-a-vis the area of influence shall also be governed by the spread of study area beyond the periphery , in this case the landfill site.
- 3) Selection of odour monitoring methodology : The selection of methodology for odour monitoring shall depend on objective(s) of the study which will be governed by other key factors that include availability of necessary field & laboratory infrastructure, skilled & expertise staff , location of study area , financial resources etc besides the importance to undertake the project – regional priority.
- 4) Required characterization & inventorization of odour : The inventorization of odour generating activities in and around an existing landfill site is important as it helps to identify & provide an assessment of the odour compounds and generating potential of the area the besides providing opportunities to design new or expanding existing capacity of existing MSW landfill sites based on the database generated. Hence characterization of the MSW is important.

Importance of sampling - European standard for the measurement of odour

Odour is recognized as a public nuisance, unlike other types of air pollution (SPM,CO, CO₂, SO₂) where there are legal regulations however for odour control it is still in nascent stage in the country mainly due lack of awareness on the subject. Though ‘sampling’ is important however reliability of data quality has great influence on the results of the measurements, however the major challenge is to standardize ‘sampling’ - sampling methods depend on type of odorous sources.

Regarding collection of odour samples for monitoring odour , there are no specific regulations or guidelines, however countries in the European Commission have adopted CEN (EN 13725: 2003) guidelines for collection of odourous samples especially for olfactometric analysis. The detailed regulation and guidelines for sampling of odourous samples / emissions have been documented in two sections of EN 13725:2003 which is broadly accepted and adopted by European countries. The EN 13725 (2003) [DIN EN 13725. 2003 – ‘Air quality--Determination of Odour Concentration by Dynamic Olfactometry’ provides a European standard for the measurement of odour.

There are three recognized methods for odour analysis viz.

- European EN 13725:2003
- Australian / New Zealand AS/NZS43232
- ASTM 679-043 standards

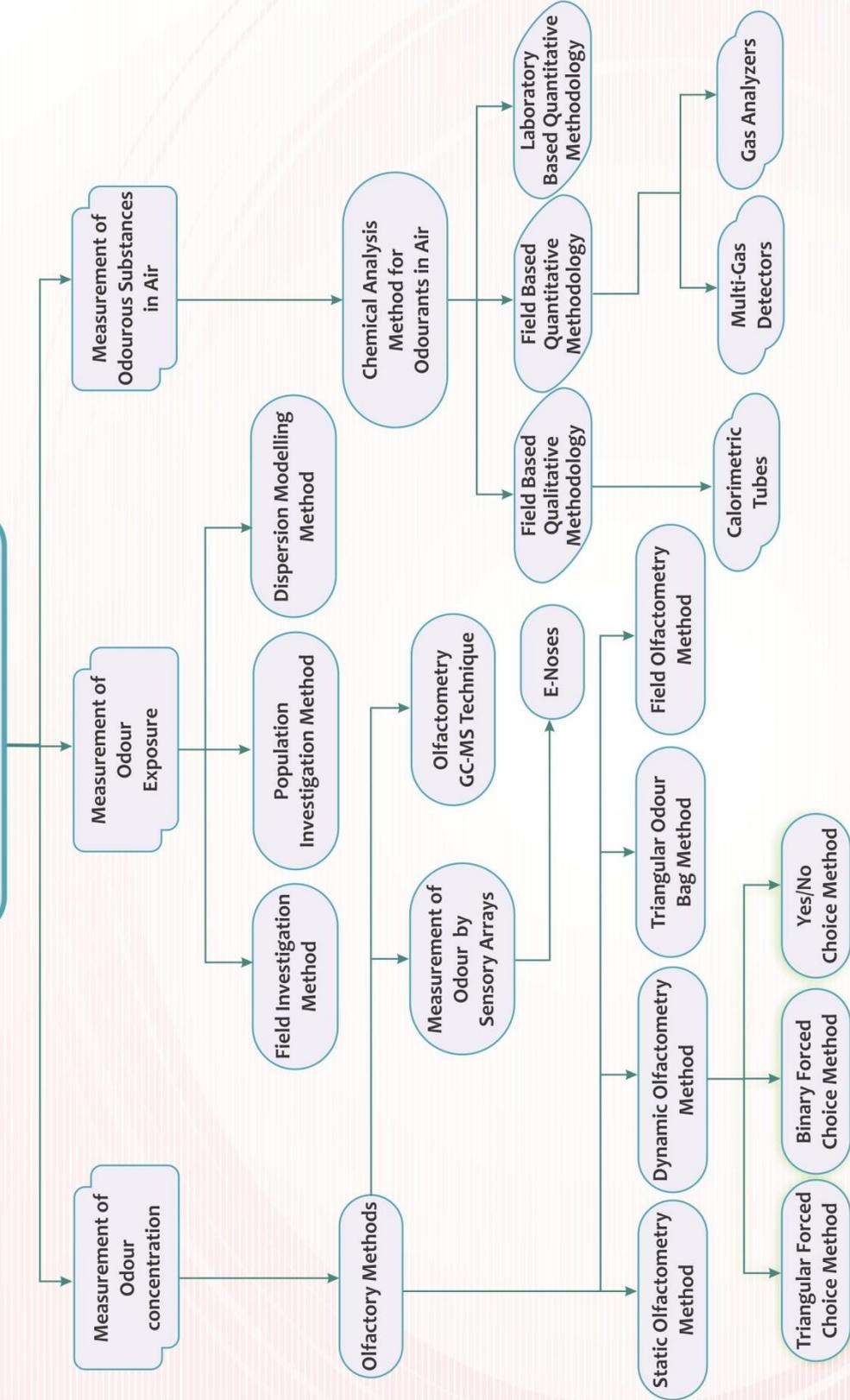
Worldwide odour monitoring methods

Worldwide there are various methods for monitoring of odour depending on the objective(s) of the survey, the THREE key methods observed are :

- a) Measurement of ODOUR CONCENTRATION
- b) Measurement of ODOUR EXPOSURE
- c) Measurement of ODOUROUS SUBSTANCES IN AIR

For guidance, the methods are briefly discussed in subsequent sections, an overview of global practices is shown in below in **FIGURE 1 , OVERVIEW OF GLOBAL METHODS IN MONITORING ODOUR.**

Odour Monitoring Methods



GLOBAL PRACTICES – MEASUREMENT OF ODOUR CONCENTRATION

Measurement of odour concentration - Overview of Olfactory Methods

Olfactory method involves the assessment of odour under controlled conditions by a panel of selected persons (called panelists). This standard sets down rigorous procedures for determining the odour strength of a gaseous sample. The olfactory methods are summarized in Table below and are briefly discussed in subsequent sections.

OLFACTORY METHODS	a. Static Olfactometry method b. Dynamic Olfactometry method iii. Triangular Odour bag method c. Field Olfactometry Method
	GC - Olfactometry (GC-O) Technique
	Measurement of odour by sensory arrays

Static Olfactometry method

In the static olfactometry method, there are two stages for analyses :

- the sample must be pressed into a suitable container and
- then analyzed

In this method, the sample is diluted in a calibrated glass syringe (100 ml & 200 ml) at various dilution levels. The diluted samples are expelled into the nostrils of the panelists. The odour detection threshold is determined graphically from the dilution levels and panelist response data. To avoid adsorption processes or condensation during sample storage, the container of suitable material should be used.

Dynamic Olfactometry method

Dynamic Olfactometry is widespread technique for the quantification of odour emissions in terms of odour concentration. The odour sample is diluted in a continuous mode, the diluted odourous sample is mixed with controlled flows of sample and odourless air. In a dynamic olfactometric method, large volume of representative sample is employed in a more reproducible flow rate to the panelist for proper judgment.

Australia, New Zealand and North America and some European countries use the method of dynamic olfactometry analysis

Note, generally the response of a panelist depends on three sensory attributes, they are :

- i. Judgment criterion- Determines the odour sensing criteria of the panelist. Generally 'Yes' or 'No' answer is requested based on the sensation of odour.
- ii. Anticipation- Tendency to expect an odour to occur when odourless or weak samples are consecutively presented.
- iii. Adaptation- Loss of sensitivity are after smelling odour (require some time to recover his/her Olfactory sense)

The adaptability of panelist to stimuli is avoided by adopting a forced choice stimulus method combined with a systematic ascending order of odourous sample concentrations.

Dynamic Olfactometry methods	All of the techniques use the approach of decreasing / increasing dilution series.	
	Advantages	Disadvantages
a. Triangular Forced Choice Method In Japan, China and some South East Asian countries, the Triangular Bag Method with <u>increasing dilution series</u> is commonly used.	Statistically the most accurate method	<ul style="list-style-type: none"> • Long duration • Long analyses may incur fatigue among the panelist. • Less samples analyzed per session
Binary Forced Choice Method (approach of <u>decreasing dilution series</u>)	It takes less time than triangular forced choice method	Less accurate
Yes / No Method (approach of <u>decreasing dilution series</u>)		

a) Triangular Forced Choice Method - Procedure

- i. The Panelist is presented with three ports, one of which contains diluted sample and the other two contain neutral gas.
- ii. The sample is presented randomly over the three ports and the panelist is forced to indicate the port with the sample.
- iii. The panelist is also asked if his/her choice was a guess, inkling or certain.
- iv. By the combination of the choice results and the indicated level of certainty, the response is classified as false or true.
- v. Each panelist observes an odour sample in the ascending concentration (decreasing dilution) series with the Dilution Factor (DF)

of 0.5. The odour concentration is increased until the sample is faintly recognizable.

- vi. The value of odour concentration is equal to the dilution factor that is required to reach the recognition threshold. Recognition Threshold in Olfactometry is defined as the number of times a sample is diluted so that becomes just detectable to 50% of the panelists.

b) Binary Forced Choice Method - Procedure

- i. The Panelist is presented with two ports, one of which contains diluted sample and the other contains neutral gas. The sample is presented randomly over the two ports and the panelist is forced to indicate the port with the sample.
- ii. Similar steps as given under 'Triangular Forced Choice Method'

c) Yes / No Method - Procedure

- i. The panelist is asked to evaluate a diluted gas flow presented from at a sniffing port and to indicate whether an odour is perceived or not.
- ii. A second port with blank is always provided as a reference.
- iii. The presentation of dilution is halted when the entire panel obtains at least two 'Yes' responses for the presentation with the highest concentration following a 'No' response.
- iv. The value of odour concentration is equal to the dilution factor that is required to reach the recognition threshold.

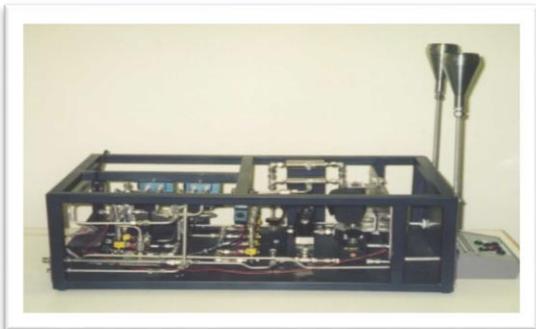


Figure 2 : An Olfactometer



Figure 3 : Presentation of a dilution to a panelist

Triangular Odour Bag Method

Procedure Each panelist is given three bags with one being a sample and two blanks of clean air. Panelist is asked to sniff the bag directly, if the panelist can identify the correct bag, then the odour is diluted and the test is continued until panelist is unable to distinguish the bag with odourous sample. The value of odour concentration is equal to the dilution factor that is required to reach the detection threshold. (*Detection Threshold in Olfactometry is defined as the number of times the sample is diluted so that it becomes non-detectable by 50% of the panelists.*)

Olfactory method – measurement of odour concentration TRIANGULAR ODOUR BAG METHOD	
Advantages	Disadvantages
Simple process to carry out.	If panelists are exposed to high levels of odour concentration in the beginning of evaluations, there is a possibility of “overexposure of the human nose” which may result in not only fatigue, but also in errors within test results.



Figure 4 : An Assessor performing the Triangular Bag Method

Field Olfactometry Method

Odour concentration measurement in the field may be conducted using portable olfactometer commonly known to as Scentometers or Field Olfactometer (a portable hand held device). Field olfactometer provides the same basic function of a laboratory olfactometer but is designed to be used by a single panelist to measure odour. It is a simplified portable dilution device that helps to determine the ambient odour concentration and it gives a reading of the odour detection threshold. Field Olfactometry methods can be useful tool in validating odour complaints or determining odour concentration for various locations and can be used to characterize odour concentrations in an environment. *Although Dynamic Olfactometry is recommended in most of the internationally accepted methods which involve field sampling cum laboratory analyses by expert panelists – both being cost prohibitive. In India Odour is a new area , hence the need to familiarize with it and to explore economically feasible and adoptable methods to create a database that can assist in generating mass awareness.* For CPCB’s pilot study on Odour monitoring use Field Olfactometry was accepted. Field Olfactometry standards are listed in some US odour regulations.

Procedure

- i. The field assessor sniffs ambient air which is filtered through carbon filters attached to the instrument from a high pressure compressed air tank, this air is used as dilution air. While sniffing the ambient air the field assessor adjusts the dilution ratio between odourous and non – odourous air.
- ii. Similar to dynamic Olfactometry, the field olfactometer is also used to determine the number dilutions of filtered air to odour sample air at which an odour concentration can be detected.



Figure 5 : Identification of Odour hotspots and measured odour concentration using Field Olfactometer in MSW GHazipur landfill site Delhi

Measurement of odour concentration by Sensory Arrays-ELECTRONIC NOSE

With the technological advancement Electronic Nose / instruments have been developed for odour measurement through sensory arrays (no intervention of only panelists in the field as is required in above mentioned olfactometry methods). The electronic nose is a mimic of human brain, fitted with array of sensors for sensing the odourants and sending information to a PC board and data processing. Instrument consists of an array of ‘electronic chemical receptors’ which detect volatile chemicals or categories of chemicals then processes the information to predict sensory-like attributes. Generally metal oxide sensors are used which are manufactured by Figaro with trademarks (TGS822, TGS2620, TGS2180, TGS842, TGS2610, and TGS880). Each of these sensors has a specific sensitivity to organic constituents such as alcohols and organic solvents, natural gases, methane and low molecular weight VOCs. Some of the sensors are also very sensitive to reduced sulphur.

Procedure : The sensors are based on conducting composites that change resistance on exposure to a vapour, the change in resistance of individual sensors from baseline resistance produces a pattern of resistance changes across the array. The measured response is then converted to a signal using a computer processor. To identify the type, quantity and quality of the odour, the computer uses changes in the pattern generated in the entire sensory array thus significant

data is generated that can be processed into useful information using statistical analysis software to conduct principal component analysis and discriminate factor analysis.

Measurement of odour concentration – ELECTRONIC NOSE (E-NOSE)	
Advantages	Disadvantages
The E-Nose can measure a complex group of substances very rapidly. It can be programmed to discriminate “good” from “bad” aromas.	Biggest challenge for E-Noses is detecting complex odours against intricate background matrix. They do not allow for the direct measurement of odour intensity nor odour quality.

Measurement of odour concentration - GC - Olfactometry (GC-O) Technique

Combining any sensory method with analytical method or dispersion modeling to get reliable results is an added advantage though there are few such combinations to develop a Gas Chromatography - Olfactometry (GC - O) analytical tool for monitoring the odourous compounds of complex mixtures. The GC - O consists of the conventional GC where a split column distributes the eluate between conventional detector such as FID or MS and sniffing port where a properly trained person or panelist could detect the active odour species. This tool is preferably used to identify the unknown odourants and their potential odour concentration.

All commercially available olfactometric ports are made of glass or PTFE cones, fitting the nose shape; the eluate is delivered through a dedicated transfer line which is heated to avoid the condensation of semi volatile analytes. In order to prevent the nasal mucus membrane drying, especially in a long time analysis auxiliary gas is added to the eluate. The sensory responses are recorded in an OLFACTOGRAM. The eluate splitting occurs allowing the analytes to reach both human and instrumental detectors simultaneously, in order to compare the chromatogram with the Olfactogram.

Measurement of odour concentration GC - Olfactometry (GC-O) Technique	
Advantages	Disadvantages
The combination of mass spectrometer with an olfactometric detector is particularly advantageous as it allows the identification of odour active compounds.	The disadvantage for such system is that MS detector operates under vacuum while olfactometer works normal atmospheric conditions. <i>Such techniques of GS-O is widely used for evaluation of food aromas but its application in the environment field is limited.</i>

GLOBAL PRACTICES – MEASUREMENT OF ODOUR EXPOSURE

Field Investigation Method

This method requires one or more human assessor(s) to use their own sense of smell perception to assess odours. Here, olfactory testing is used to assess 'emission' (i.e. the odour impact at a receptor location) in accordance with VDI 3940. The estimation of odour emission rate from landfills using this method has been demonstrated to be reliable in comparison with other methods of assessment. Odour can be monitored throughout the day and observations can be made of specific activities such as any odourous materials arriving, the working face, gas wells, leachate collection and treatment systems. Observations can also be made at pre-determined locations such as at the facility boundary and at sensitive receptors. Observations should be recorded mentioning date, time, prevailing winds, temperature, etc. as this information assist in identifying likely causes of odour complaints.

It is a direct determination of the odour frequency in the

environment of an odour emitting plant. Trained & accepted assessors note odour in selected places representing grids in study area according to a specific plan. Locations TSDF Bharuch, Ankleshwar



Figure 6 : Demonstration of Field Investigation Method (CPCB – VTT Finland bilateral project)

Some advantages of this method include :

- i. Measurement of the ambient odour levels surrounding an odour source is a proactive approach to monitoring source performance. Field Investigations can be used for every odour case; these are especially good for land use and town planning. Hedonic tone and annoyance can also be determined; also temperature dependence of odour emissions could be specified.
- ii. Field Investigation (VDI 3940:1993) is recommended to be used in situations, where it is not possible to identify primary odour emission exactly e.g. large emission areas, such as landfills, & large plants with fugitive emission.

- iii. Monitoring and documenting ambient odours supports community understanding of nuisance situations and the specific sources or activities that may be causing the community nuisance.
- iv. Facilities and /or communities may choose to use ambient odour monitoring to measure performance to mitigation efforts and compliance agreements.
- v. Knowing the extent of actual odours in the community and their frequency of occurrence will also improve understanding of air quality and guide facilities and community officials in addressing odour causes.
- vi. A community and a group of neighboring facilities may also come to recognize levels of acceptable and unacceptable odour and develop plans to mitigate the nuisance odours.

The constraints include :

- i. Complexities in terrain and variability in wind conditions can frustrate field investigators and limit data collection.
- ii. Odour complexity and odour emission variability can produce ambient odours that are significantly different than from source odours. Difference in the character of source and ambient odours may present challenges to field investigators that are trying to track odour plumes.
- iii. It is extremely difficult to use field studies to demonstrate compliance; A single field observation is inadequate to demonstrate non- compliance hence comprehensive study to be conducted over an extended period with representative sampling throughout the neighborhood under a wide range of meteorological conditions.

Population Investigation Method

This method is used to assess odour exposure, panelists living near an odour source write down odour perception in a diary, observations done in home indicate the address (location). Short-term investigation covers 2-3 months while long-term investigation covers 10-12 months. Odour exposures are presented as relative odour frequency and odour annoyances are presented as percentages of panelists , both results are indicative. Panelists record observations every day in their diary and this is returned to an organizer monthly. Different odour sources can be separated, if panelists can identify different odours. Some basic features are :

1. Odour intensity & Odour annoyance is recorded in terms of scale (0 to 4).
2. Selection of investigation area for population investigation : To select investigation area there should be some preliminary information on how far odour may be disperse. Assessment area and sectors are fixed depending on dispersion distances. Assessment area should be divided into sectors. The control zone can be also selected outside the odour load area.

3. Selection and number of population panelists : The panel is a collectively chosen from persons residing in the region / control zones who meet certain requirements as being representatives and who are present at certain times of day. These requirements include age over 18 years, sex, marital status and education. Names and addresses of panelists assure the necessary geographical distribution of the annoyance replies. Daily home hours should be known to estimate observation time of each panelist in each assessment sector, there must be at least 10 Panelists. One household is considered as one panelist. Direct neighbors should not be selected to avoid possible mutual influence.

Ref. improved Capacities in Odour measurements Technologies (CPCB - PROBES/143/2014-15).

Dispersion Modeling Method

Odour annoyance an environmental odour can only be assessed by including the temporal dimension and the spatial extent. Dispersion models provide the ambient odour concentration for each time step (mainly half-hour or one hour mean values of the ambient concentration). Evaluating time series of ambient odour concentrations, the probability of annoyance can be assessed. Two classes of dispersion models are currently (regulatory) used for odour dispersion,

- Gauss Models
- Lagrange models.

Both model classes belong to non-CFD (computational fluid dynamics) models, they do not explicitly resolve fluid-dynamics equations but physical processes are parameterized.

AERMOD is a steady-state plume model developed by a working group of AMS/EPA Regulatory Model Improvement Committee, AERMIC, (USEPA, 2005). In the stable boundary layer (SBL), it assumes the concentration distribution to be Gaussian in both, vertical and horizontal fields. In the CBL, the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function. AERMOD is applicable to rural and urban areas, flat and complex terrain, surface and elevated releases and multiple sources including, point, area and volume. **Refer to report on ‘Odour Dispersion Modelling of MSW Landfill Site’ - Ghazipur, Delhi’ done by IIT Delhi for CPCB’s project.**

CHEMICAL ANALYSES OF ODOUROUS SUBSTANCES IN AIR

Chemical analyses of odourous substances in air - groundwork

The representative sample collection, sample transportation, sample preservation and handling need to comply with the guidelines of Good Laboratory Practices (GLPs). Groundwork to be undertaken before handling samples in a contamination-free manner to achieve the data quality objective for analyses of odourous substances in air are :

1. Nature of material used for handling samples
2. Sample duration & number of samples
3. Sampling programme
4. Sample handling features

Nature of material used for handling samples

Nature of material used for handling samples of odourous substances must have following properties :

- i. **INERTIA** To ensure that the air sample collected is not interacting chemically with the material in which it is preserved and transported , worldwide practice recommends use of inert / non reactive and odourless material like PTFE and others.
- ii. **SMOOTH SURFACE** Containers and accessories for sampling must have smooth surfaces in order to avoid any hindrance in flow of sample.
- iii. **OPAQUENESS** The containers and accessories must be opaque to ensure that material inside is not exposed to sunlight.
- iv. **LOW PERMEABILITY** The containers and accessories should not result in sample losses by diffusion or incoming of external air.
- v. **DIFFUSION COEFFICIENT** Worldwide researches have concluded that the sampling bags should have negligible diffusion coefficient w.r.t. odourous constituent's viz. ammonia, hydrogen sulphide, formaldehyde etc.
- vi. **IMPERVIOUS** The sample containers must have preventive property in order to minimize significant loss of odour compounds between the collection and measurement time.
- vii. **SUFFICIENT VOLUMETRIC CAPACITY** The container must have adequate capacity to be representative of the gaseous sample.
- viii. **INTRINSIC & EXTRINSIC FACTORS** Diffusion of specific odourous molecules may depend on intrinsic factors such as bag thickness as well as extrinsic factors viz. temperature and humidity at which sample is stored.

THREE polymeric materials commonly used for the manufacturing of containers and accessories for odour sampling are :

- a) Polytetra Fluoro Ethylene (PTFE, Teflon – TM)
- b) Polyethylene Terephthalate (PET Nelophen-TM)
- c) Polyvinyl Fluoride (TEDLAR - R)

Sample duration & number of samples

Duration of sampling depends on the characteristics of the sources and odourous emissions however to guarantee the representativeness of sample , VDI 3880 defines 30 minutes of minimum sampling duration for the collection of each sample. The number of sample required is a sole decision of researcher / investigator as s/he has to perform the detailed survey in and around the study area - ex. sampling source / landfill site as per project requirements.

Sampling programme

The study plan shall be initiated with a detailed survey of the site to collect following information:

- i. Production cycle of a plant in this case - frequency of dumping of MSW at the particular landfill site
- ii. Prior to sampling schedule , identification of sampling locations w.r.t. meteorological parameters like wind velocity, wind direction, temperature, pressure, humidity, etc.)
- iii. Location of impact stations - Atmospheric conditions, such as high pressure, calm wind conditions, fog or temperature inversion can intensify, prolong or increase the range of any odour present as a result of operational conditions on any site.
- iv. Information regarding specific operating processes of the plant emitting emission /landfill site due to :
 - Physical processes - ex dumping of MSW wastes
 - chemical processes - ex. generation of landfill gas
 - biochemical processes - decomposition of organic waste
- v. Knowledge about likely / tentative chemical composition of emission, to ascertain presence of toxic odourants to keep security and safety of sampling operators

Sampling program must be meticulously planned so that sampling & analysis are performed simultaneously to obtain results that should be representative of the planned emissivity.

Sample handling

Under this section 'sampling handling' should address the following :

1. **STORAGE TIME** As indicated by CEN (EN13725:2003), the odourous samples collected from air sources must be analyzed within the 30 hours of sampling. However, there is no worldwide agreement on storage time of the sample prior to analysis.
2. **TEMPERATURE** The storage temperature for the sample should not exceed more than 25° centigrade, but it must be kept above the sample dew point to avoid condensation.
3. **TRANSPORT CONDITIONS** The collected sample to be protected from :
 - i. Mechanical damage
 - ii. External contamination
 - iii. Sunlight (to minimize photochemical reactions)
 - iv. Diffusion of the odourous molecules

GLOBAL PRACTICES- CHEMICAL ANALYSES OF ODOUROUS SUBSTANCES IN AIR

FIVE major groups of odourants

The odourous gaseous emission from MSW landfill contain various types of odourous compounds , the odourants are categorized into FIVE groups viz.:

- a) Reduced Sulphur Odourants (RSO)
- b) Volatile fatty acids
- c) Carbonyls
- d) Nitrogenous odourants (inorganic)
- e) Volatile organics (non-methanogenic organics (NMOC) & Contaminants of Potential Concern (COPCs)

The selection of analytical methods for chemical constituents responsible for odour to be related to the respective potential of odour generation. The selection of methodologies for above mentioned group of odourants depends on requirement and objective(s) of the study and may be extended from the either qualitative or / and quantitative methods, though the qualitative methods are handy for survey purpose however to have in-depth information the quantitative methodology are applied.

Chemical analyses of odourants - Qualitative methodology (Field based - Colorimetric tubes)

Colorimetric tubes the colorimetric tubes are transparent vials filled with particular chemical compounds capable of reacting with. They are used to measure the concentration of certain compounds on site and can be used only once.

PROCEDURE

The concentration is determined by applying a pump (manual / automatic) to put inside the colorimetric tubes a specific air volume which will react with the compound inside the tube. This will change the color and make it possible to read the concentration of the compound on the basis of the length of the color. In fact outside the box of the tube there is a scale that indicates the concentration of the substance according to the length of the colour obtained.

Chemical analyses of odourous substances in air Qualitative methodology - Field based (Colorimetric tubes)	
Advantages	The colorimetric tubes present available in commercially are very practical, cheap and are available for 600 different kinds of substances.
Limitations	<ol style="list-style-type: none"> 1. Reactions with compounds which are different from the one being monitored could be present; 2. The reacting compound, inside the tube, could be damaged over time; 3. The tubes can present mistakes, but not with a constant rate, it depends on batch production error. 4. The correct tube must be carefully chosen according to the expected concentration. 5. Effects of particular temperature, humidity and atmospheric pressure conditions. <p>From the above it is useful only for occasional and screening monitoring.</p>

Chemical analyses of odourants– Quantitative methodology (Field based)

1. Multi-gas detectors : The portable multi-gas detectors can detect and analyze continuously and simultaneously.

PROCEDURE The substances analyzed are acquired by means of electrochemical sensors composed of an immersed electrolyte, a measuring electrode (anode), a counter-electrode and a reference electrode. A potentiostat keeps a constant voltage between the measuring electrode and the reference electrode. The voltage is maintained such that a specific gas or vapors in air will oxidize on the anode and concentration can be detected. The orders of detectable concentration are usually included in a range from 0–200 ppm. These devices make it possible (once a key substance is identified) to monitor its continuous development, immediately showing any possible anomalies.

Chemical analyses of odourous substances in air Quantitative methodology - Field based (Multi-gas detectors)	
Advantages	Limitations
The main uses of such instruments are in the monitoring of emissions of <u>H₂S</u> and <u>NH₃</u> in wastewater treatment plants and composting facilities.	<p>Their main drawback is related to the considerable influence of the external ambient air conditions (for example temperature, humidity, etc.).</p> <p>For these reasons, they might be useful only for occasional and screening monitoring.</p>

2. Gas analysers Gas analyzers are laboratory instruments that are generally installed in static cabins or mobile laboratories (a van) that carry out the sampling and analysis phase measuring the concentrations of individual compounds.

Chemical analyses of odourous substances in air	
Quantitative methodology - Field based (<u>Gas analysers</u>)	
Advantages	Limitations
Unlike the portable multi-gas detectors, the gas analyzers allow for a high precision. Their use is recommended where there is a need to monitor a single parameter with high precision for a relatively long duration.	Gas analyzers are not easily movable; they need a power supply and are more expensive.

3. Fourier transforms infrared spectroscopy (FTIR) : Quantitative Field based FTIR relies on the fact that the most molecules absorb light in the infra-red region of the electromagnetic spectrum. This absorption corresponds specifically to the bonds present in the molecule. The ratio of the sample spectrum to the background spectrum is directly related to the sample's absorption spectrum. FTIR is a technique which is used to obtain an infrared spectrum of absorption or emission of a solid, liquid or gas. A FTIR spectrometer simultaneously collects high spectral resolution data over a wide spectral range. This confers a significant advantage over a dispersive spectrometer which measures intensity over a narrow range of wavelengths at a time. The term Fourier transform infrared spectroscopy originates from the fact that a Fourier transform (a mathematical process) is required to convert the raw data into the actual spectrum.

The advantages include :

- i. Unlike the portable multi-gas detectors, the gas analyzers allow for a high precision.
- ii. It can be used to monitor multi parameter with high precision for a relatively long time
- iii. It can be used for both type of monitoring Source and ambient.

4. **O-A ICOS Analyzer** : Quantitative methodology - Field based

Off-Axis Integrated Cavity Output Spectroscopy (**O-A ICOS**) is another laser based analyzer option for multiple gas analysis. It is extensively used in greenhouse gas monitoring in ppb level to percentage level. High-end optic design helps to increase the path length within the cavity and facilitate measurement with high accuracy and precision. Basic analyzer has three gas monitoring module, however it is possible for more gas modules to be hyphenated. This portable analyzer can monitor, CO₂, CH₄, H₂O, NH₃, H₂S, C₂H₂, SF₆ etc. The advantages include :

- a) It can be used to monitor multi parameter with high precision for a relatively long time
- b) Latest and advanced technology

Chemical analyses of odourants –Quantitative methodology (Laboratory based)

1. The quantitative methodologies are the ultimate when detailed and precise information of odourants are required. These techniques are not only expensive but also need expertise for quantification. As most of the odourants are organic in nature except few (Ammonia, Sulphur compounds) and the concentration levels are very low the sampling and pre-treatment of samples is important before analysis. For direct air sample collection and analysis without pre concentration the use of canisters, sorbent tubes, Tedlar bags etc. are very popular.

To enhance the detectability pre-treatment of sample may be necessary and the popular technologies are as under:

- a) Static Headspace Sampling Technique
 - b) Solid – Phase Micro extraction Technique
 - c) Purge and Trap (P and T) Technique
 - d) Cryogenic Trapping Technique
 - e) Sorption on adsorbent tubes
2. Analytical Methodologies being Practiced Worldwide for Odourant Groups
As mentioned earlier the odourous gaseous emission from MSW landfill contains odourants of various types, which are categorized into FIVE groups:
 - i. Reduced Sulphur Odourants (RSO)
 - ii. Volatile fatty acids
 - iii. Carbonyls
 - iv. Nitrogenous odourants (inorganic)
 - v. Volatile organics (non-methanogenic organics (NMOC) & Contaminants of Potential Concern (COPCs)

The general analytical methodologies practiced worldwide for analysis of each of the odourous compounds are summarized below.

- a) REDUCED SULPHUR ODOURANTS (RSO) - RSO may be analyzed chemically or by instrumentation. The popular analytical technique for RSO is GC-FPD/PFPD. Use of GC-MS is also reported but GC FPD and PFPD system are more specific and sensitive to RSO.

Limitation of chemical method	Advantage of instrumental method
The limitation of chemical method is that there are different protocols (Sampling and analytical) for different constituents of RSO (H ₂ S, CS ₂ , Mercaptans). The detection limit is also a constraint in selection of chemical methods.	The instrumental method has advantages over chemical method as most of the constituents can be quantified in a single sample with single run.

- b) VOLATILE FATTY ACIDS** - Due to anaerobic degradation of MSW some volatile fatty acids like propionic acid, butyric acids, isovaleric acid and valeric acid etc. are emitted causing odour nuisance. These constituents may be analyzed by using TD system with a GC-FID fitted with specific analytical column, however the sensitivity analysis for organic acid in gas chromatography system is not adequately satisfactory unless it is converted to suitable derivatives separated by GC Colum. Some of the researchers have used absorption media viz. NaOH to make their salt and analyzed in a HPLC. Most of the analyses have been reported using liquids samples, however it may be explored how to standardize an appropriate methodology for analysis of gaseous odourants containing fatty acid present in landfill gas.
- c) CARBONYLS** - The carbonyls likely to be present in MSW landfill gas are Formaldehyde, Acetaldehyde and Carbonyl Sulphide. The analysis of carbonyls is generally carried out by HPLC with a UV-detector. Carbonyls are generally collected by adsorption on DNPH coated silica gel matrix which is eluted with Acetonitrile and finally analyzed in HPLC with UV- detector.
- d) NITROGENOUS ODOURANTS (inorganic)** - The nitrogenous odourants present in MSW landfill gas are both organic (Methyl amine) and inorganic (Ammonia).
- Methyl amine is generally analyzed using GC-FID fitted with pora-pack Colum at suitable operating conditions. However there are only few evidences available citing the presence of tri-methyl amine in landfill gases.
 - Ammonia is generally analyzed chemically using indophenols blue method.
- e) VOLATILE ORGANICS (NMOC & COPCs)**
The volatile organic compound
- excluding methane
 - includes different group viz. aromatic (Benzene, Toluene, Xylene, Styrene), Methyl Ethyl Ketone, Methyl Iso Butyl Ketone, Butyl Acetate and Isobutyl Alcohol. ((Non-Methanogenic organics (NMOC) & Contaminants of Potential Concern (COPCs))

The NMOCs are generally analyzed by USEPA compendium test method TO-12 while other volatile acids can be analyzed using To-14A, TO-15 and TO-13A, TO-17. In most of this method pre concentration is carried out using cryogenic method and analyzed with GC method with GC-FID and GC-MS. The method TO-17 needs coupling of GC-MS/FID with a TD system.

ODOUR MONITORING TECHNIQUES AT MSW LANDFILL SITE

Activities contributing to odour nuisance at MSW landfill sites

MSW landfills emit odours in varying degrees from many potential sources and directly / indirectly from other activities that may include the following :

1. Arriving and queuing of hauling trucks carrying MSW
2. On-site vehicles and heavy equipment deployed to handle MSW
3. Quantum of biodegradable waste
4. Sewage sludge
5. Working face
6. Temporary cover
7. Capped cells
8. Access road construction
9. Leachate collection systems
10. Leachate treatment systems
11. Monitoring wells
12. Gas well construction
13. Gas wells and collection piping
14. Gas treatment systems
15. Gas flares
16. Associated landfill activities, i.e. yard wastes and composting.
17. Adjacent unrelated landfill activities (ex vegetable mandis, fish markets, slaughter house, poultry houses, refuse derived fuel etc)

Processes generating odour in typical Indian MSW landfill site

The processes generating odour in typical Indian MSW landfill site are :

- i.** VOLATILIZATION Volatilization is the most important mechanism for odour emissions and occurs when odourants of a dissolved or pure substance skip to an adjacent gas layer for waste at this surface, this action results in immediate transport into the atmosphere.
- ii.** BIODEGRADATION Biodegradation is the disintegration of organic by bacteria, fungi or other biological means. Biodegradable matter being organic based serves as a nutrient for microorganisms, the decomposition of biodegradable substances may proceed through both aerobic and anaerobic process. Anaerobic processes generates more odourous compounds.
- iii.** PHOTO-DECOMPOSITION Photo dissociation, photolysis, or photo-decomposition are chemical reactions induced by physical energy in which a chemical compound is broken down by photons. As landfill site

particularly in India having tropical climate receives enormous solar flux which accelerates the rate of biodegradation and volatilization thereby increases odour nuisance.

- iv. **HYDROLYSIS** MSW generally have high moisture content. Hydrolysis is the reverse of a condensation reaction wherein two molecules combine into a larger one and eject a water molecule. Thus hydrolysis adds water to break down, whereas condensation builds up by removing water. The odourants soluble in water pass to leachate which in turn gives rise to odour emission through volatilization.
- v. **COMBUSTION** Combustion is a chemical reaction that occurs between a fuel and an oxidizing agent that produces energy, usually in the form of heat and light. In a MSW landfill site auto burning may also occur due to production of methane and the heat generated at the dump site trigger the ignition automatically producing obnoxious odourous gases.

Approaches for odour assessment - Proposed & Existing MSW Landfill site

There are several features which are to be considered in order to obtain reliable and representative results while characterizing the odour emissions from MSW landfill site. The sampling protocol has to be chosen based on:-

- a) Nature of odour sources and their emissions to ascertain suitable instruments, materials and methods etc.
 - b) Characterization of odour sources (point , area and volume sources)
 - c) Physical characteristics of the sources to be investigated
 - d) Frequency of emission from the sources
 - e) Duration of their emissions
- a) For Proposed MSW Landfill site
In any odour assessment study for a proposed landfill, potential sources of odour, what actions can be taken to minimize or eliminate odour, the proximity, direction and sensitivity of likely receptors, factors such as prevailing weather conditions and other pathways which need to be considered to assess impacts though odour is a localized problem.
- b) For Existing Landfill Site
For existing landfills, an odour assessment study may include the following:
- i. Olfactometric or chemical measurements of all significant odour releases and appropriate air dispersion modeling of measurements.
 - ii. On-site and off-site odour monitoring.
 - iii. Complaints analysis, e.g. location of complaints, time and weather conditions to which complaints relate to
 - iv. Prepare questionnaire to assess odour complaints from nearby localities.
 - v. Details of any control and treatment systems for leachate and landfill gas.

Types of odour sources monitored for impact assessment

There are mainly three types of odour sources encountered during the monitoring for impact assessment of odourous constituents in the MSW landfill sites, they are :

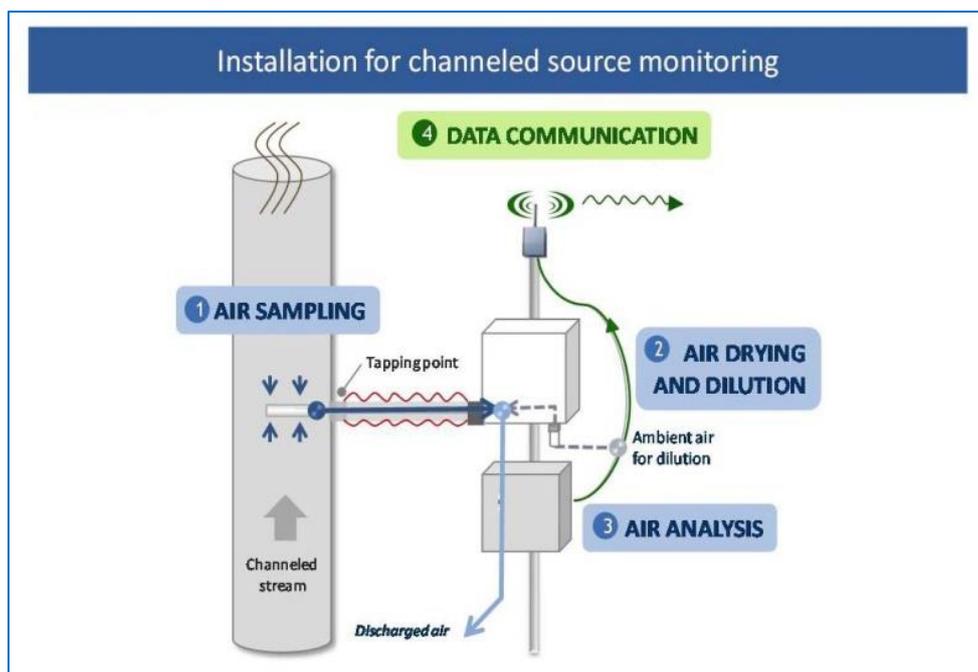
1. POINT SOURCE – Discharges from a small openings such as stack or vent. A point source of pollution is a single identifiable source of air, water, thermal, noise or light pollution. A point source makes negligible contribution, distinguishing it from other pollution source geometries. The sources are called point sources because in mathematical modeling, they can be approximated as a mathematical point to simplify analysis.
2. AREA SOURCE – examples include large surface areas such as landfill surface, a pile of solid material or liquid surface. Another classification of these sources based on the outflow of the emission from the source and w.r.t. MSW landfill site are:-
 - a) Active source – Source with outflow of emission.
 - b) Passive source – Source with very limited, non measurable to a certain extent, outflow of emission.
3. VOLUME SOURCE -- Diffuser stacks from building or other constructed structures similar to building with appropriate venting, such as windows, etc.

Odour Measurement at MSW landfill site - From POINT SOURCES

a. Quantification of odour emission

Point sources in the landfill site can be observed in places from where emission is likely to be released through a defined channel or from a designated area like leachate collection tank. In case of landfill sites the point source may be monitoring wells, gas well construction, gas wells , gas treatment systems, etc .

A 10 feet tubing running from suction inlet of odour measuring instrument is directly introduced inside point source and measurement for odour concentration is performed.



For quantification of odour emission two options suggested are :

1. Installing the E-NOSE or Odour Analyzer to get real time continuous odour concentration.
2. Alternatively the air from the point source may be collected in a Tedlar bag.

The latter option is the conventional one.

Option 1 : Installing the E-NOSE or Odour Analyzer to get real time continuous odour concentration.

Option 2 : Alternatively the air from the point source may be collected in a **Tedlar bag** using a vacuum chamber, sometimes called a sampling lung. The bag is placed in the vacuum chamber with a Teflon tubing line placed in the exhaust stream. A pump is used to create a vacuum in the chamber, which causes the odourous air sample to flow into the bag. The bag is first partially filled, then emptied and finally filled with the sample. This method, called “conditioning the bag”, is believed to minimize the loss of odour on the bags inside surface. The odourous air sample will then be transported to a laboratory for evaluation of the odour and odour generating compounds for identification and characterization by established laboratory techniques

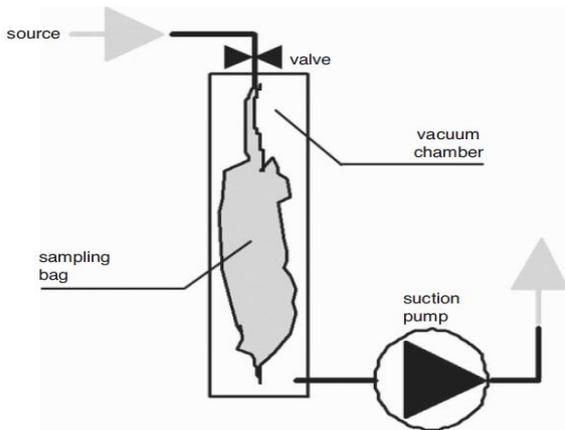


Figure 1: Measurement of odour concentration in Tedlar Bag in laboratory (CPCB's project)

b. Estimation of Odour Emission rate (OER)

When measuring odours with the objective of assessing impact evaluation, it is not sufficient to measure odour concentration in isolation , but it is necessary to ascertain the air flow associated with the monitored odour source. The fundamental parameter Odour Emission Rate (OER) is expressed in odour units per second (OU_E/s) and is the product of the odour concentration and the air flow associated with the source. The volumetric air flow should be evaluated under normal conditions for Olfactometry. The technique used for sampling depends on the source typology (Gostelow et al., 2003; Bockreis and Steinberg, 2005) and is as important as the chosen measurement method and 101.3 kPa on wet basis.



Figure 7 : Sampling at POINT SOURCE (Gas collection well)

In the case of point sources, it is possible to calculate the emitted air flow by measuring the air velocity as well as the duct transversal section ,the OER is computed as follows:

$$\text{OER} = Q_{\text{air}} \cdot C_{\text{od}}$$

where:

OER=Odour Emission Rate (ou_E/s)

Q_{air} =effluent volumetric air flow (m³/s)

C_{od} =measured odour concentration (ou_E/m³)

Odour Measurements from area source – Types of AREA SOURCES

1. Types of area sources

An existing MSW landfill site may have areas earmarked for staggered activities like daily cover, temporary cover, old dump cell, active dump cell etc. which varying potential to generate odourous substances. The variation in emission rates and characterization of odorous gases determine the sampling techniques. The areas may be broadly classified in to active area sources and passive areas sources.

- a. Active area sources: sources having an outward air flow (e.g., bio-filters or aerated heaps)
- b. Passive area sources: sources without outward air flow, the mass flow from the solid or liquid surface to the air due to natural phenomena of volatilization such as equilibrium or convection. The mass flow of air in this case is very less.

2. Identification of active and passive sites : For identification of active and passive sites by estimation of volumetric emission the area shall be gridded logically @ 30 m X 30 m. The collection of odours from surfaces requires the use of a device called a static hood. Where the distinction between the two kinds of sources is not be clear, it is necessary to establish a volumetric air flow limit to distinguish between active and passive sources. The VDI 3880 sets a specific flux limit of 30 m³/h/m².

Odour Measurements from AREA SOURCES – Active area source

1. Features of Static hood for collection of odourous compounds

The collection of odours from surfaces requires the use of a device called a static hood. For active surface sources sampling is performed by means of a “static” hood that isolates a part of the emitting surface thus channeling the outward air flow into the hood outlet duct where the sample is collected using the same method as for point sources. In general, a static hood consists of two main parts (a) a cone or pyramid frustum with a known base area (e.g., 1 m²), and (b) a stack, generally cylindrical and with a diameter of 10–20 cm, on top of it. One or more openings are made in the stack to allow sample collection and the measurement of physical parameters, such as temperature, relative humidity or velocity. The sampling hood to be made from materials that are odourless and inert.

Before sampling the hood to be positioned on the emitting surface to isolate the sampling point from the outside atmosphere thus preventing the sampled gas being diluted by wind.

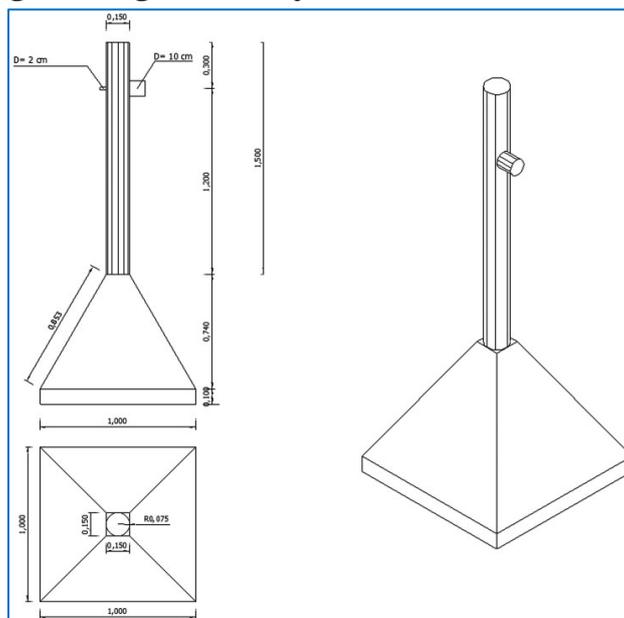


Figure 8: Static hood for active area source sampling

After placing the static hood on the test surface, sufficient time has to be given for the odourous flux to fill the whole hood uniformly. Then the sample is collected by inserting the PTFE tube of the sampling bag into the proper sampling port in the hood stack. The same opening used for the sample collection should also be used for the insertion of the instrumentation for the determination of the emission related physical parameters with caution so that the system is not directly connected to open atmosphere. The velocity of flue gas is measured by using suitable device at steady state to calculate the emission rate.

2. Types of Active area sources - homogeneous & non homogeneous flow distribution

The friction of the flow uniformity throughout the emitting surface is important in order to define the average emitted odour concentration to calculate OER, two different cases may be distinguished:

- a. Active area sources with homogeneous flow distribution;
- b. Active area sources with non-homogeneous flow distribution.

3. Active area source - homogeneous flow distribution

Active area sources should be considered to have a homogeneous flow distribution if the differences between the measured effluent velocities on the monitored surface portions are below a defined factor (for this purpose, the VDI suggests a factor of 2). In such cases, the average odour

concentration is obtained as a geometric mean of the odour concentration values of the collected samples, according to the following equation.

$$\bar{C}_{od} = \sqrt[n]{\prod_{i=1}^n C_i}$$

where:

C_{od} = average odour concentration (ouE/m³)

C_i = odour concentration measured on the i-th surface portion (ouE/m³).

4. Active area source - non-homogeneous flow distribution

In the case of active area sources with non-homogeneous flow distribution (the differences between the velocities measured on the different surface portion are higher than the fixed factor, e.g. 2) the average odour concentration is calculated as a weighted geometric mean; according to the following equation:

$$\bar{C}_{od} = \frac{\sqrt[n]{\prod_{i=1}^n (C_i \cdot v_i)}}{\sum_{i=1}^n v_i}$$

where: C_{od} = average odour concentration (ouE/m³)

C_i = odour concentration measured on the i-th surface portion (ouE/m³)

V_i = effluent velocity measured on the i-th surface portion (m/s).

The aforementioned equation is valid if the surface portion considered has the same area, otherwise the average odour concentration should be further weighted as "

$$C_{od} = \left[\left(\prod_{l=1}^N C_l \cdot V_l \cdot S_l \right)^{1/2} \right] / \sum_{l=1}^n (V_l \cdot S_l)$$

where: C_{od} = av

C_i = odour concentration measured on the i-th surface portion (ouE/m³)

V_i = effluent velocity measured on the i-th surface portion (m/s).

S_i = Area of the i- th surface portion (m²)

In order to obtain representative data of the entire source, it is necessary to carry out several samplings at different points, which should be uniformly distributed over the emitting surface. As an indicative guide, the surface portion sampled by means of the static hood should be about 1% of the total emitting surface.

At Ghazipur Municipal Solid waste Landfill Site, area sources like Active dumping sites old dumped sites (i.e. more than one year old) and leachate collection tanks were treated as active area sources with non-homogeneous flow distribution because velocity of odourous gases emitting from 01 m² area source varied between 0.15m/s to 1.0m/s i.e. Specific flux emission was greater than 30 m³/hr/m² (as per limit of specific flux of VDI 3880) during both , the summer and post monsoon season.



Figure 2: Sampling of odour emission using Static hood at active dump cell

5. Quantification of odour from ACTIVE AREA SOURCE using static hood

- i. Measurement of odour can be performed by collecting sample of odourous gas in through stack of static hood by using field olfactometer.
 - a. Connect a new sample bag to the Teflon tube that normally connects to the mask. If conducting stack sampling connect the probe to the sample output port.
 - b. Select the desired pre-dilution , remember to choose a higher pre-dilution for hot or high odour stack samples.
 - c. Open the shut off valve and allow the sample bag to be filled up to 90% of capacity.
- ii. Measurement by E- Nose or Olfactometry
 The E-NOSE has little more flexibility with a built-in pump by which known volume of sample can be drawn and measured. In case of measurement of a distant source , provision of sampling tube (inert and odourless) is also available. Continuous odour measurement can be carried out by E-NOSE for a defined period, which fairly gives an idea of change in emission flux.
- iii. Handy sampler : The sampled air through handy sampler is sent to laboratory for chemical descriptor identification by proven technologies like Gas Chromatographs (GCs), Head Space technology (GC-HS), Thermal Desorption (GC-TD), Solid Phase Micro Extraction (SPME) and/or Mass Spectrometers (GC-MS) etc .

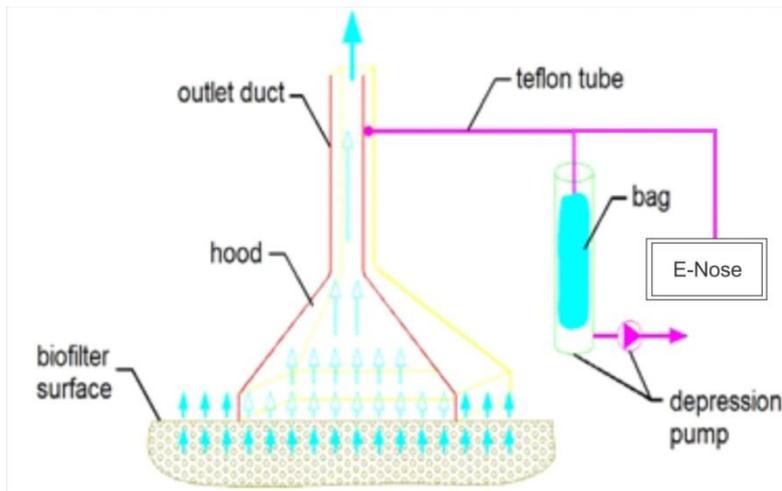


Figure 9 : Scheme of sampling from an active surface source using static hood



Figure 10: Sampling at Active area source (active dump cell) using static hood

Odour Measurements from area source - PASSIVE AREA SOURCE

The estimation of the OER in passive sources is a rather complicated process, as it is difficult to measure a representative odour concentration due to absence of well-defined air flow rate. To activate these areas two different approaches (Gostel owetal., 2003; Hudsonand Ayoko, 2008a) are adopted for the estimation of emission rate values from passive area sources:

- i. Indirect measurements using micro-meteorological methods, where emission rates are derived from the simultaneous measurements of wind velocities and concentrations across the plume profile downwind of the source. Indirect techniques such as micro-meteorology do not perturb the emission process because a sampling device is not used. However, a large number of samples are required to characterize the considered emission, thus making such techniques impractical for odour assessments.

- ii. To activate the passive sources it is necessary to purge the air (odour neutral) in the system so that the emission reaches the sampling port. The recommended controlled condition for passive area source activation is done with purging of neutral air having the wind effect 0.20 m/s on emission surface. Care should be taken in case of purging so that the over dilution of constituent does not occur.

There are three types of hoods used for passive area source sampling:

- A. The static flux hood
- B. The wind tunnel
- C. Isolation Flux Chamber

a. Passive area source sampling - Static flux hood

Sampling on passive area sources is carried out using a static hood consisting of a hood placed over the emitting surface. Air collection is carried out after a contact time of 10 minutes during which air flow is forced into the hood in order to provide a flux velocity equal to 0.2 m/s. The sampling and analytical procedure shall follow as detailed under static hood section discussed already.

Estimation of Odour emission rate (OER) from area sources with static flux hood (flux hood method) The estimation of the OER requires the calculation of another significant parameter that is the Specific Odour Emission Rate (SOER), expressed in odour units emitted per surface and time unit ($OU_E/m^2/s$), according to the following equation:

$$SOER = \frac{Q_{air} \cdot C_{od}}{A_{base}}$$

Where:

SOER= Specific Odour Emission Rate

Q_{air} = Air Flow inside the Hood (m^3/s)

C_{od} = Measured Odour Concentration (OU_E/m^3)

A_{base} = Base area of the Hood (m^2)

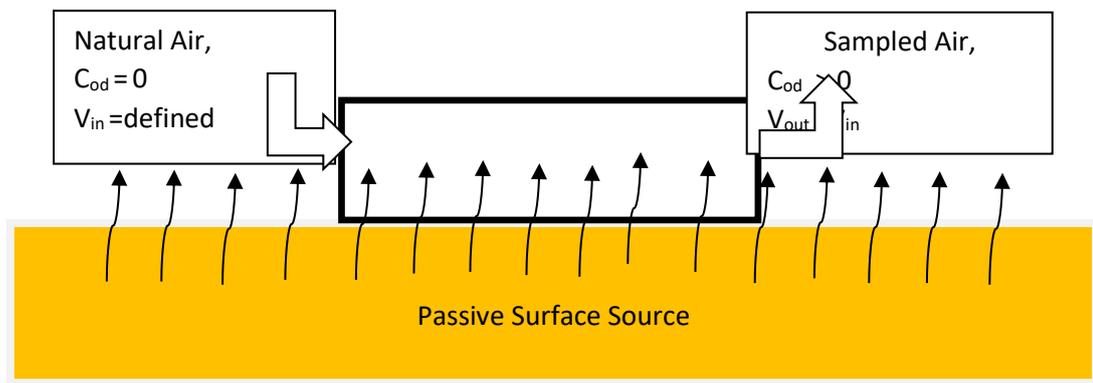


Figure 11 : Principal of hood sampling on a passive surface source



Figure12 : Measurement of Velocity, temperature and odour from Static Flux hood

b. Passive area source sampling - WIND TUNNEL METHOD

Wind tunnel is a tool used in aerodynamic research to study the constituents of air in a laminar flow path or to calibrate a test component against standard object. For the calibration the test object is mounted at the middle of a tubular passage which is subjected to a constant flow of air mass with suitable air blowing device. A wind tunnel model is instrumented with suitable sensors to measure aerodynamic forces, pressure distribution, or other aerodynamic-related characteristics.

Wind tunnels are generally much larger than flux hoods and require more air supply to sweep across the surface being sampled. Depending on the requirement the wind tunnel may be designed for high and low flow emission, generally for high flow wind tunnel with chicanes (sharp bends in flow path) has push air control system, however some of the leaner wind tunnel with high flow have push and pull air control system for the odour monitoring in MSW sites.

Wind tunnels can also be used on a variety of area emission sources, sample is collected by keeping it appropriately on the **surface of solid**. The odour emission is calculated using odour concentration and volume flow rate of the purged and emitted air. Air flow is measured in wind tunnel using anemometer with hot wire. The area emission is calculated in term of odour unit/m²/time. The wind tunnel demonstrated under CPCB's bilateral project with VTT, Finland was made from odourless hard plastic with surface



Figure13: Demonstration of Odour monitoring at source – Wind tunnel method (bilateral project - Finland)

area 0.785 m². The odour sample was taken using bag sample method and sampling time kept about 2 minutes w.r.t. for acceptable quality and quantity of sample. *(Ref. improved Capacities in Odour measurements Technologies document of CPCB (PROBES/143/2014-15*

f) Isolation Flux Chamber: - This method is also applicable for passive surface sources as discussed under 'Emission from Leachate Collection Tank/ Leachate Treatment Plant' below.

Odour Measurements - From Volume Sources

The volume sources at the landfill site may include the building, other enclosures viz. site laboratory are other structures which may not have either a stack for venting are roof exhaust however it may have a side vent (window or doors) such sources are regarded as volume sources. The sampling procedure adopted for the volume sources may adopt indoor sampling methodology however such sources are treated also as a point source. Based on the literature survey the enclosure methods adopted for sampling are *INDOOR AIR SAMPLING AND EVALUATION GUIDE WSC POLICY #02-430*).

Emission from Leachate Collection Tank or Treatment Plant

The 'enclosure approach' referred to as an emission isolation flux chamber (flux chamber) to sample gaseous emissions from a defined surface area is adopted. Clean, dry sweep air is added to the chamber at a fixed controlled rate (e.g. 0.005 m³/min) based on site conditions. The volumetric flow rate of sweep air through the chamber is recorded and the concentration of the species of interest is measured at the exit of the chamber. The emission flux is calculated as:

$$\text{Emission Flux (EF}_i\text{)} = (C_i) (Q) / A$$

Where: EF_i = emission rate of species, i (µg/m²min)

C_i = measured concentration of species i (ppmv converted to ug/m³)

Q = sweep air flow rate (m³/ min)

A = exposed surface area (m²).

All parameters in above equation are measured directly. For the sampling of aerated surface impoundments the addition of sweep air is usually not necessary. In such situations, the rate at which air is entering the chamber from the aeration source is determined (i.e. the off-gas rate) and emission fluxes using above equation. The flux chamber is effectively isolated from most external environmental conditions such as wind speed hence the measurement data are not strongly dependent on the meteorological conditions present at the site on the days of sampling. The data are thus directly comparable from day to day and site to site. There is a practical limit as to the size of a flux chamber that is used in the field. Therefore, it is necessary to make a series of flux measurements to assess the spatial variability in emissions for a given source. Repeated measurements at a given location can be performed to assess temporal

variability. These data allow estimation of an emission rate with a known confidence limit i.e. a set of emission flux (mass/ time-area) measurements is necessary to estimate are emission rate (mass/ time) for the entire source. For measurement of odour concentration, emissions of source are collected into Tedlar bag which are taken to the laboratory for analyzing odour concentration based on Olfactometry method.

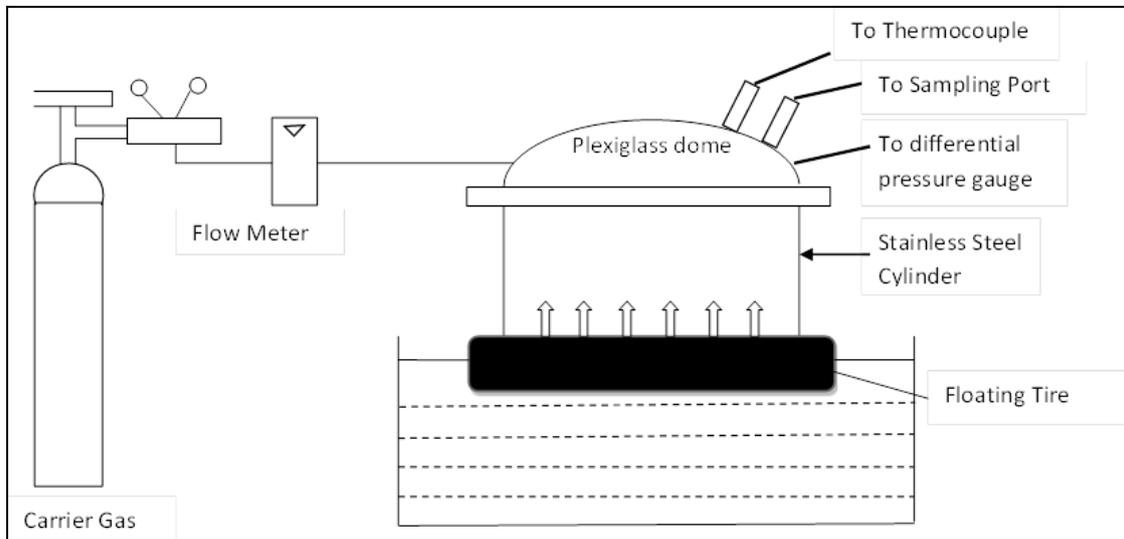


Figure 3: Isolation Flux Chamber

ODOUR MONITORING IN AMBIENT AIR - UPWIND & DOWNWIND SAMPLING METHOD

Upwind & Downwind Sampling Method – Impact stations

In order to assess the impact of odour emission from MSW landfill sites, there is need to monitor the odour concentration around the landfill sites at various distances. Assessment of impact could be measured by comparison of odour concentration in upwind and downwind of the landfill site. This method quantifies the emissions of odour w.r.t. odourous compounds from sources as the difference between the concentrations measured in the ambient air approaching (upwind) and leaving (downwind) the source site.

In the upwind-downwind method, have minimum points to ascertain concentration at upwind direction of the pollution source and several concentrations at several points selected on the basis of prevalent wind direction are obtained in downwind directions. The difference between the upwind and downwind concentrations is considered to be the contribution of the source. Wind speed, wind direction and other meteorological variables are monitored during the sampling procedures. Methods for sampling for this method are obtained from the USEPA (USEPA, 1993). Using a dispersion model and available meteorological information, the net concentration is used to solve for the emission rate. Air dispersion models such as AUSPLUME, AERMOD and CALPUFF may be used to estimate emissions from volume and area sources in this manner to obtain downwind concentrations for this method.

Features of Upwind & Downwind Sampling Method

The features of Upwind & Downwind Sampling Method include :

1. This method is utilized to measure the fugitive emissions from sources typically covering large areas that cannot be temporarily hooded and are not enclosed in structures allowing the use of the roof monitor methods.
2. It may also be utilized in combination with mathematical models and tracer tests to define the contributions to total measured emissions of specific sources among a group of sources.
3. The emissions measured by the upwind – downwind method may be the total contribution from single sources or from a mixture of many sources in a large area.
4. Continuity of the emissions is generally of secondary importance since the magnitude of the ambient air volume into which the emissions are

dispersed is large enough to provide a degree of smoothing to cyclic emissions.

5. The measurements have no effect on the emissions or processes involved.
6. Generation rates must be high enough to provide measureable concentration at the sampling locations after dilution with the ambient air.

ODOUR MONITORING - UPWIND & DOWNWIND SAMPLING METHOD	
Advantages	Disadvantages
<p>The upwind – downwind method, generally utilized where neither of other methods may be successful.</p> <ol style="list-style-type: none"> 1. It is not influenced by the number or location of the emission sources except as they influence the locating of sampling device. 2. Most air born pollutants can be measured by the upwind – downwind method 	<p>The method is strongly influenced by the meteorological conditions, requiring a wind consistent in direction and velocity throughout the sampling period including temperature, humidity and ground moisture representative of normal ambient conditions.</p>

Odour Monitoring Techniques for Ambient Air

Considering the field challenges and complexities of task for odour monitoring in the ambient air, methods or tools which could be useful for monitoring in upwind and downwind of MSW site are mentioned below , the techniques have been discussed in preceding sections of the report :

- a. Olfactometry method
- b. E- Nose : Online continuous monitoring of landfill site gases
- c. Field Investigations Methodology
- d. Population investigation method

SITING CRITERIA FOR ESTABLISHING ODOUR MONITORING STATIONS

Biological decomposition of MSW

Factors responsible for biological decomposition of MSW are:

- i. The effective age of the landfill and the on-going activities
- ii. Inhibition of biological activities by un-intentional mixing of other wastes with MSW
- iii. Composition of waste
- iv. Physico-chemical characteristics of waste (moisture, pH, temperature, O₂ availability, volatility & diffusion coefficient of different constituents of waste)
- v. Availability of nutrients for micro-organisms in the waste
- vi. Presence of suitable microbes
- vii. The meteorological and boundary conditions also play an important role in dispersion of odour nuisance in and around the selected site.

There may be several other factors however it is a challenge to quantify impacts from each of the above aspects as the overall effect (impact) is a combination of all or some of the above factors.

Landfill gas (LFG) responsible for odorous nature of MSW

Landfill gas is a complex mix of different gases created by the action of micro-organisms within a landfill. Odors in landfill gas are caused primarily by hydrogen sulfide and ammonia, which are produced during breakdown of organic waste material. Landfill gas is approximately 40 – 60 percent methane, hydrogen sulfide and ammonia, carbon dioxide and trace amounts of other volatile organic compounds (<1%). Sulfides produce a strong, rotten -egg smell that humans can detect even at very low concentrations, ammonia produces a pungent odor. Ordinarily people can detect hydrogen sulfide and ammonia odors at very low levels in air, high levels may disturb lifestyle.

Globally many landfills install gas control measures because of regulatory requirements, in some countries the state have landfill – specific regulations. The objective of a landfill gas (LGG) control plan is to prevent people from being exposed to landfill gas emissions (includes odour) some important approaches :

- By collecting and treating landfill gas at the landfill (in situ) or

- by preventing landfill gas from influencing localities particularly in the downwind direction

Technologies used to control landfill gas at the landfill or abate its impact on nearby localities may be applied separately or in combination and varies i.e it is landfill – specific based on surrounding regional activities.

Criteria to fulfill Odour sampling objectives

The criteria to fulfill odour sampling objectives w.r.t. siting of sampling locations are listed below as follows :

- Objective of the study of the sampling - The site selection for any scientific investigation is governed by the objective of the study. There is no thumb rule for odour monitoring site selection criteria applicable to satisfy all the study objectives like risk evaluation, obtaining permits, regulatory compliance, public complaints, designing emission control systems & odour management, Environmental clearance under EIA etc. For example if the requirement is to study the Environment Impact Assessment (EIA) study, prior to development of a MSW landfill site, there are the USEPA guidelines, wherein it is suggested to divide the periphery of planned landfill site in equal quadrants of 15°. Approximately 24 monitoring locations are required to be equally distributed at the periphery of landfill site.
- Organic nature of MSW varies : The site selection criteria for monitoring of odour can never be a uniform one, as there are several influencing factors ranging from on type of waste being disposed, how it is being disposed, where it is being disposed at the landfill site, characteristics of the waste depends on the type of locality from where waste is being collected, quantity of waste being disposed, activities at the MSW site, age of the site etc (also refer list given above).
- Meteorological conditions prevails : The dispersion of odour happens mainly through diffusion and hence under favourable climatic conditions it may have significant influences in the downwind, hence the site selection criteria needs to take into account this factor too.
- Criteria for locating odour monitoring station differ : existing MSW landfill The site selection criteria for odour monitoring will be different for different landfill sites as the potential for odour generation will be highly dependent on the climatic zone of the region, age of the dumpsite, other odour generating activities at site and MSW management, disposal & treatment practices of existing landfill site.
- Spatial & temporal variability of odour – regional ‘harmonization’ a challenge
‘Disposal in landfill sites’ is preferred MSW practice as it is cheap. It has been observed that most of the MSW landfill sites in India receive non-segregated waste having heterogeneous characteristics and reported to

have less bio-degradable content. There are not only variations across the country w.r.t MSW characteristics but also within a given state ex. West Bengal a relatively small state is bordered on with an estuarine region (river meeting sea) coastline to the south, cold hilly northern region there several larger states like Uttar Pradesh , Madhya Pradesh, Karnataka and Maharashtra have major cities located in the hilly regions and in the plains. Hence formulating an harmonized protocol ('one shoe fits all') for the entire country or for a State is a major challenge. In addition to the spatial variation the soil characteristics also vary widely affecting the pathways of different odourous constituents generated in landfill site. Hence odour surveys should be based on case to case i.e. MSW landfill-specific.

Criteria Odour Sampling Objectives - for AREA sources

In view of above, to have a fair representation of the existing characteristics for odour nuisance it is suggested to divide the area of activity (MSW land fill site) in uniform grids. The minimum grid size of 1/900 square meter (30 m X 30 m) has been suggested as available in international references.

Criteria Odour Sampling Objectives - for Impact zone

Though the regions in near proximity from the boundary of landfill sites are exposed to odour nuisance, however it is difficult to define the boundary of impact zone not that the distances between the periphery and the source of odour alter because of MSW dumping patterns / practices however the meteorological conditions play a dominant role w.r.t ear marking impact zones or areas of influences. In international references 1000 meters buffer from the boundary of the landfill site is considered as impact zone However generally the sampling location for odour monitoring in ambient air for assessing the impact around landfill sites are distributed at 500 meter, 1000 meter and sometimes 2000 meter distance from the periphery to study zone of influence. The actual location to evaluate the impact of landfill site may be decided after physical survey of the area and acquiring the knowledge of dominant wind direction and other weather issues. It is recommended to select judiciously one upwind and at least three sites evenly distributed in the quadrant of downwind direction.

Other criteria for locating the odour monitoring site

Location of the monitoring site is initially dependent on the monitoring objective. The first task when evaluating a possible site location is to determine the scale for which a candidate location can qualify by considering the following:

1. Location and emissions strengths of sources in and around MSW land fill site If MSW landfill site having other odourous emission sources in and around it, this will also form the criteria for selection of odour monitoring site for the given landfill site. It is required to prepare schematic map describing the activities starting from receipt from to its final disposal.
2. Prevailing atmospheric conditions & wind speed, wind direction and variability in and around the MSW landfill site : considerations may include the spatial and temporal variability of the pollutants and its transport to the monitoring site. Effects of buildings, terrain, and heat sources or sinks on the air trajectories can produce local anomalies of excessive pollutant concentrations. Meteorology must be considered in determining not only the geographical location of a monitoring site but also such factors as height, direction, and extension of sampling probes. The following meteorological factors can greatly influence the dispersion odour : Wind speed, wind direction, wind variability, solar radiation, relative humidity, rainfall, temperature are the governing factors for potential odour and its dispersion.
3. Topography - Both the transport and the diffusion of odour is influenced by the regional topographical features , such as deep river valleys or mountain ranges, high rise buildings in urban areas The identified site should preferably have free flow of air at least from three quadrants. Other land uses viz. inhabitation of community, buildings of historical importance, geological monuments, structure with reference to ecological significance (protected forest area), agriculture use etc. may also be considered.
4. Health and Demographic Information- Information on age and socio-economic status of population is also important for making a decision on initiation of monitoring. Location of monitoring station in such areas will help in finding exposure levels to population which can be help in creating a database on health effects of air pollutants.
5. Physical access: The selected location at landfill site shall be accessible, safe and representative.
6. Safety & security of monitoring devices: The safety and security of equipment , material and staff on duty are important while selecting a monitoring location particularly for existing MSW landfill sites.

A good MSW management practice(s) can ensure the minimization of odour nuisance in and around the landfill site and not total removal of odour. The major challenge in India is the high population density in cities, scarcity of land for waste management & disposal in addition there are other odour generating sources in urban areas like open drains which further aggravate the situation , hence pin pointing the zone of influence for odour in and around MSW landfill site remains a challenge.

Procedure for Estimation of Representative Location – area sources

In order to determine the location of sampling sites within and in impact zone, dispersion modeling technique (screening and refining) may be used. Inputs into the dispersion model to include landfill waste emissions, representative meteorological data, populations close to the site, and sensitive populations. The model outputs should be plotted as concentration isopleths for odour unit. It is recommended a baseline survey using field olfactometer / field investigation method be undertaken to enable making a reasonable assessment of inventory and potential estimation of emission sources in and around proposed / existing landfill sites for model inputs to minimize uncertainty in outputs. This information will assist in siting of monitoring locations for point, area, volume and ambient air in addition to identification of hotspot. The model outputs can cover the following range of issues:

- i. The area of highest ground level concentration (GLC) from the plume of expected source.
- ii. The maximum distance the odour impact may cover
- iii. In case of existing site if the historical data is available for both odour and emission inventory including meteorological data a comparison with existing status the help of model outputs may be a handy tool to plan further expansion of site and its potential impacts in surrounding areas

Depending on the purpose of study and to cover different various odour generating activities w.r.t. the impact study following steps may also to be considered :

1. Grids formation
Any grid size less than as proposed (30 m x 30 meters) is acceptable as it increases the representativeness. If the activity within the landfill site and height of the plume discharge suggest the dispersion with the site itself a smaller grid size 10 m X 30 m is desirable. In normal cases four sampling location is suggested to cover one acre (4000 m²).
2. **Hotspots identification on the surface of the landfill:** Landfill surface should be marked with a grid using specific design with patterns of variable design and spacing which will be more effective in achieving the project objectives of obtaining a representative sample from a large geographical area. This approach has allowed the investigation of large landfills to be accomplished at much reduced cost and needing less manpower. In Indian context it is recommended to identify the hotspots where active dumping is going on. To have a representative investigation it is advised to subdivide 30 m X 30 meters grid falling at hotspot into 10m X30 meters grid
3. The passive site adjacent to the active grid may also be considered for holistic representation. It is suggested that the passive areas shall also be covered in monitoring network

RATIONALE FOR NUMBER OF REPRESENTATIVE ODOUR SAMPLES

Review groundwork and analyze constraints

Before initiating any odour survey it is important that detailed groundwork is done and the constraints are appropriately analyzed, some key issues are highlighted below :

- a. **Objective** : The objectives of the survey may be to comply with regulatory requirements, to identify long and short term trends, to detect accidental releases or to develop a data base or inventory of pollutant levels. It is important to design the study scientifically so that it is cost effective and generate statistically significant information.
- b. **Sampling PLAN** – discussed in next Section
- c. **Importance of the sample** : The importance of good sampling cannot be overstressed, care must be taken to avoid any introduction of bias or error and contamination of sample. The sample is the source of information about the environment. If it is not collected properly and does not fully represent the system that is being analyzed, else all groundwork (including laboratory facilities) is futile.
- d. **Number of samples to be taken depend on project objectives** : The cost incurred for laboratory analyses of samples account significantly of the total budgetary provision, hence project objectives needs to be carefully examined. The number of samples to effectively represent the project area depends upon the project objectives.
- e. **Need for Infrastructure (includes on-site & off-site field reqmt & laboratory facilities)**) and manpower - This covers this cover availability of techniques for sampling and analysis i.e. locally available facilities for sampling and analysis, , range of of parameters , nature of samples , import of facilities for sampling and analysis, technically competent persons for sampling & analysis, nature of sampling source- volume, point and area source, ambient air quality monitoring , provision for manual sampling or continuous sampling etc.
- f. **Time and duration (short / long term of study)** : for example an odour survey may cover one season of a year or cover all seasons depending on the project objectives, however it is commonly observed that longer the project duration

implies more samples to be collected hence more analytical work thus more staff may need to be involved

- g. Budgetary provisions : Need to plan within the budgetary estimates , it has been observed that the cost for collection and analysis of samples constitutes a significant part of total budgetary provision of a project.

Procedure for Estimation of Sample Number – area sources

For area sources refer to previous section ‘SITING CRITERIA FOR ESTABLISHING ODOUR MONITORING STATIONS (Section VIII)’ . The procedure for estimation of sample number for area sources to consider the following :

1. Hotspots identification on the surface of the landfill: Landfill surface should be marked with a grid using specific design with patterns of variable design and spacing which will be more effective in achieving the project objectives of obtaining a representative sample from a large geographical area. This approach has allowed the investigation of large landfills to be accomplished at much reduced cost and needing less manpower. In Indian context it is recommended to identify the hotspots where active dumping is going on. To have a representative investigation it is advised to subdivide 30 m X 30 meters grid falling at hotspot into 10m X 30 meters grid, to enable at least three samples be collected within 900 square meters in active site.
2. The passive site adjacent to the active grid may also be considered for holistic representation. It is suggested that the passive areas shall also be covered in monitoring network and at least one sample in the middle of the grid be taken.
3. Leachate storage tank : Each and every landfill site has leachate collection system, which also emits unpleasant odour. It may also be considered as an area source and the sample number required to have a representation shall be similar to soil gas / vent sampling.

Procedure for Estimation of Sample Number– point sources

- a. Soil gas sampling: Geo probe sampling system has been accepted worldwide as a useful device for collecting soil gas and ground water samples at the specific depth below ground level. To make the sampling representative it is required to collect the sample addressing the impacts of diurnal temperature variation. At least three samples a day (morning, post noon, and night) should be taken and measured to represent average emission.
- b. Vent sampling: In vent sampling, investigator needs to select low volume sampling devices to collect odour and odourants emitted from the vent. The number and representativeness of sample shall be similar to soil gas sampling.

Procedure for Estimation of Sample Number – other sources

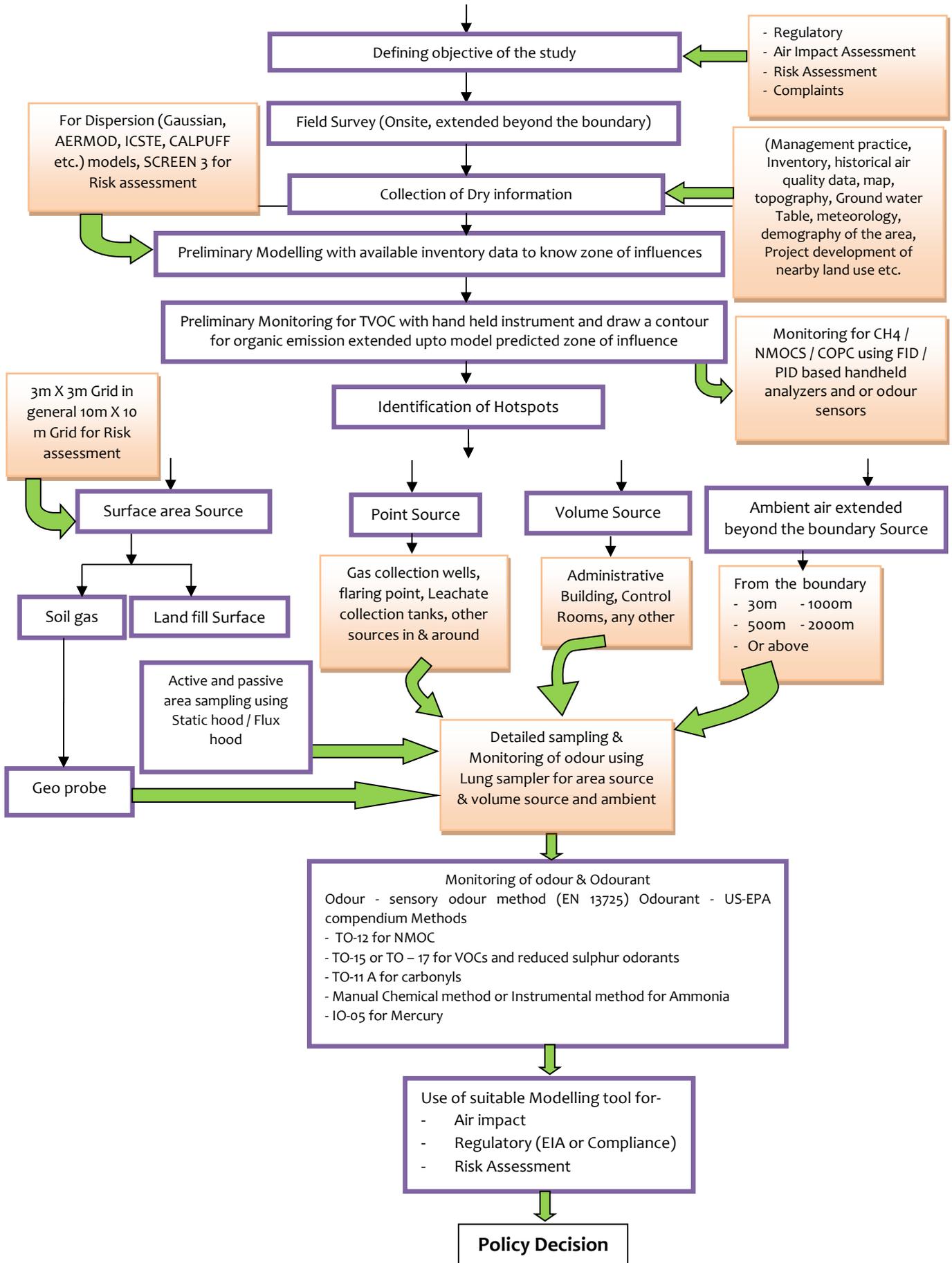
In addition to the above there may be another source of emission in landfill site like ‘ stabilized cell’. Sometimes the stabilized cells are equipped with vent pipe and in such cases the sampling and sample number shall be similar to vent sampling. In case the cell lacks vent system it is suggested that the passive areas shall also be covered in monitoring network and at least one sample at the middle position of the grid is required to be taken.

Overview

From the above discussion it may be concluded that for new / proposed landfill areas, at least 24 samples distributed up to the periphery of selected site may be recommended as minimum criteria if there are no other influencing factors. For abandoned / stabilized landfill site, at least 12 location distributed evenly up to the periphery shall be considered.

In case of odour impact assessment or handling the public complaint, additional four more sampling locations are required to be identified (one upwind & three downwind) at an appropriate pre decided distance from the site. The pre-decided sampling locations could be at a distance range of 100 m to 500 m depending upon objectives of the study / investigation. Refer Figure below.

ACTIVITY CHART FOR ODOUR AND ODOURANT MONITORING IN EXISTING MSW LANDFILL SITES



SAMPLING & MONITORING PROTOCOLS FOR DETERMINING ODOUR IN MSW LANDFILL SITES (CPCB 2017)

ENSURE EVIDENCE BASED ODOUR SAMPLING - IMPORTANCE OF DOCUMENTATION

Quality of analytical results depends on proper sampling

Sampling may be done for various purposes (routine monitoring, short / long durations for research) which generate data. It is important to design these studies scientifically so that they are cost effective and generate statistically significant information. Data is generated and analyzed to monitor air, sewage, effluent or to characterize waste for example MSW wherein pollutants in environmental media (air, water, soil, etc) are spread. Proper, systematic and adequate documentation is essential to ensure evidence based sampling and monitoring for any study, project or research work. The importance of good sampling cannot be overstressed.

To begin with the objectives of the study to be clearly documented which may range from complying with regulatory requirements, to identify long and short term trends, to detect accidental releases, or to develop a data base or inventory of pollutant levels.

Though only a small amount of sample (a few grams or milliliters) is collected from a vast heterogeneous area, however it is important that the samples collected represent the environment as accurately as possible as major decisions are based on the results of the analyses.

The steps involved in environmental sampling are:

- a. Development of a sampling plan, including where and when samples will be collected and the number of samples required.
- b. Collection of the samples.
- c. Preservation of samples during transportation and storage.

The sampling plan

Sampling is essential to understanding odour characterization and measurement. The aim of sampling is to obtain representative information on the typical characteristics of an odour source by means of collection of a suitable volume fraction of the compound.

For the preparing odour management plan, there is a need to conduct the odour sampling and monitoring to assess odour concentration of the odourants present at the site. Before initiating sampling it is important the sampling locations are marked on the key plan or the Google image of the study area. For

the collection of representative samples, criteria for selection sampling location to be documented based on the meteorological data i.e. wind speed, wind direction, temperature and relative humidity of the site under study.

Documentation & equipment at site

A number of methods are employed to collect gaseous pollutants such as using absorbents, adsorbents, vessels and the specific collection procedures. For conducting odour monitoring and sampling at site the panel will be carrying certain equipments as well as documents / field data sheets so that the onsite observations are prepared. The data generated will be helpful for subsequent surveys.

Sample collection, preservation, and transport – checklist

Even a perfect analytical procedure cannot rectify the problems created by faulty sample collection. A good sampling plan will ensure that the samples obtained will closely represent the bulk composition of the environment being measured. Proper steps should be taken so that the sample characteristics are not lost or chemically altered during sample collection, preservation, and transport. Finally, the sampling must be done with the requirements of the analytical methods adopted. The following precautions are generally suggested while carrying out the sampling and monitoring at site and post monitoring.

a. During monitoring

- i. The sampling location selected should have flat terrain for the adequate installation of E-Nose, Handy Samplers and other required instruments.
- ii. The E-Nose, Handy Sampler etc. installed should be checked for adequate power supply & filters should be adequately fitted before commencing.
- iii. The field data sheets to be accurately filled.
- iv. The impingers to be checked for leakages.
- v. Absorbing solution should be filled in impinger properly and refrigerated in ice box.
- vi. Absorbing solution in sample bottle should be taken from impinger and marked with sample ID and information

b. Post monitoring

- i. The sample should be carefully stored in ice box.
- ii. Labeled Tedlar bags be marked and conditioned.
- iii. The filters should be removed from the E-Nose only after the power supply is stopped.
- iv. Sample and Instrument be well arranged and safely transported.
- v. Samples should be immediately transported to laboratory for analyses, if delayed proper conditioning of all samples should be ensured.

On-site documentation - Odour Monitoring at MSW Landfill

For the conducting odour sampling and monitoring at MSW landfill site a detailed project execution plan & check list, field data sheet p for CPCB's pilot project is given reproduced below. Refer Fig. Sample PROJECT EXECUTION PLAN & CHECK LIST

Action Plan & Check List for Monitoring Job			
Name of the Project: Odour monitoring at MSW Landfill Site---			
Scope of Work:-			
Details of Work to be monitor for Odour and odourous compound are given in table--			
S. No.	Particular	Parameters	
1.	Odour Level	Odour Level, Emission rate for Source location	
3.	Micro Meteorological Data	Wind Speed, Wind Direction, Temperature and Relative Humidity	
Details of the Project Proponent:-			
Monitoring Period/Season: -			
Names of Panelists for Odour level by Field Olfactometer:- (minimum Number of required Panelists Four)			
1.			
2.			
3.			
4.			
5.			
No. of Sampling/Monitoring Locations			
Sampling/Monitoring locations on key plan as decided according to International Methodology of sampling and monitoring of MSW landfill site considering various aspects or as per location decided by regulatory authorities.			
Work Schedule: - Schedule to be prepared in accordance with scope of work, frequency of monitoring, season of monitoring, number of monitoring location and type of monitoring Ambient/Source.			
Basic Requirement			
Basic requirements for field monitoring are:			
S.No.	PARTICULAR	YES	NO
1.	Field data sheet for Olfactometric Analysis		
2.	Extension Wire		
3.	Power Backup facility (Inverter/ Power generator)		
4.	Vacuum Pump		
5.	Tedler Bag/ Sampling bag		
6.	Stand for RQ box		

7.	Labels, stickers, Pen Marker		
8.	Camera		
9.	Tape (BOPP/Cello tape)		
10.	Engineering Tool Kit		
11.	First Aid Box		
12.	Digital camera with provision for recording Latitude, Longitude, date and time		
13.	Drinking water bottles		

Detail of Monitoring Equipments: List of equipments required for Odour & Odorous compound monitoring are given as per below table:

S.No	Instrument	Suggested Number	Remarks
1	E-Nose	1	
2	Olfactometer	1	
3	Thermo Meter	1	
4	Anemometer	1	
5	Weather Monitoring Station	1	

Detail of Safety Accessories:-

S.No.	Particular	Yes/No
1	Safety Shoes	
2	Safety Helmet	
3	Safety Goggle	
4	Safety Belt	
5	Safety Jacket	
6	Hand Gloves	
7	Mask	
8	Raincoats and umbrella wherever required	

Team Leader

On site field data sheets

For accomplishing the above sampling and monitoring of odourous compound at site following field data sheets are required.

FIELD DATA SHEET FOR SOURCE/AMBIENT AIR MONITORING FOR ODOUROUS COMPOUND			
1. Name & Address of MSW Site	:		
2. Authorized Person & Designation of MMSW Site:	:		
3. Nature of MSW Site	:		
4. Date of commencement of monitoring	:		
5. Time of commencement of monitoring	:		
6. Date of end of monitoring	:		
7. Time of end of monitoring	:		
8. Sampling location and code	:		
9. Type of Instrument Used	:		
10. Instrument code & Calibration Status	:		
11. Type of rotameter and Range	:		
12. Source of Air Pollution	:		
13. GPS Data with elevation	:	Lat.	N, Long. E, ELV.-
14. Meteorological Information	:		
i. Ambient Temperature (°C)	:		
ii. Wind Speed	:		
iii. Meteorological phenomenon (if any)	:		
15. Tedler Bladder (use for filling gaseous Sample) :	:		
16. Volume of Absorbing Solution (ml)	:		
17. Detail of Absorbing Tube	:		
18. Flow Rate (initial)-(LPM), (m3/minute)	:	(i) H ₂ S:-.... (ii)NH ₃ :-.... (iii)TRS:-..... (iv)VOC:-..... (v) B.A.... (vi).....	
19. Flow Rate (Final) (LPM)(m3/minute)	:	(i) H ₂ S:-.... (ii)NH ₃ :-.... (iii)TRS:-..... (iv)VOC:-..... (v) B.A.... (vi).....	
		(If required)	
20. Remark (if any)	:		
Sample Collected by (Name & Signature)		Clients Representative (Name & Signature)	

Data sheet format for odour monitoring by Olfactometer

For the calculation of odour concentration in OUE/m³ at site the , the format (data sheet) that a panelist should carry is provided below

DATA SHEET FOR ODOUR MONITORING BY OLFACTOMETER

Date-

1. Name of the Project/Party:
2. Location-
3. Latitude-
4. Longitude-
5. Temperature-
6. Humidity-

Odor Measurement Data

Name of panel member	Time	Dilution ratio															Panel's Threshold	To be Discarded	
		Valve Position	15	14	13	12	11	10	9	8	7	6	5	4	3	2			1
		Value	2000	2140	2300	2500	2700	3000	3330	3750	4300	5000	6000	7500	10000	15000			30000
Log	4.48	4.18	4.00	3.87	3.78	3.69	3.63	3.57	3.52	3.48	3.43	3.40	3.36	3.33	3.30				
Panelist 1						X	√	√	√	√	√	√	√	√	√	√	√	3.74	X
Panelist 2					X	√	√	√	√	√	√	√	√	√	√	√	√	3.83	

Name of panel member	Time	Dilution ratio															Panel's Threshold	To be Discarded	
		Valve Position	15	14	13	12	11	10	9	8	7	6	5	4	3	2			1
		Value	2000	2140	2300	2500	2700	3000	3330	3750	4300	5000	6000	7500	10000	15000			30000
Log	4.48	4.18	4.00	3.87	3.78	3.69	3.63	3.57	3.52	3.48	3.43	3.40	3.36	3.33	3.30				
Panelist 3						X	√	√	√	√	√	√	√	√	√	√	√	3.74	
Panelist 4				X	√	√	√	√	√	√	√	√	√	√	√	√	√	3.94	X
Panelist 5						X	√	√	√	√	√	√	√	√	√	√	√	3.74	

Each Panel Member Threshold = $(\text{Log } a_1 + \text{Log } a_2)/2$

Where=
 a_1 = Max. Dilution ratio for the Correct Answer
 a_2 = Dilution Ratio at which answer become incorrect

$Y=10^x$

Where
 X- Log avg. after discarding higher and lower value
 Y-Odour concentration

Odour (ou/m³) =

Note- All these templates are prepared as a guideline, the executing agency is free to improve the same according to the requirement.

SOPs FOR PANELIST SELECTION & MONITORING ODOUR

Methodology for selection of Odour Panel

1. Code of behavior for assessors and panel members

As per available literature when recruiting panelists the following conditions shall be met:

- a) Panel members should be at least 16 years of age.
- b) The members selected for odour measurement panel following the procedure mention in the method are authorized for next five years. However the member selected above 40 years of age need re-calibration of their odour perception following the same method in every three years.
- c) The panel member should be motivated to carry out his / her job conscientiously. The panel member should be available for a complete measurement session (series of measurements on a day, interrupted by short breaks only).
- d) The panel member should be engaged for a sufficient period to build up and monitor a history of measurement.
- e) Panel member must have normal level of olfactory sense for smell. In standard Olfactometry method EN 13725 acceptable sensitivity of sense of smell is defined using n-butanol as a reference compound. The method describes that the member shall have the ability to detect odour at minimum level of concentration ($62 \mu\text{g}/\text{m}^3$) as threshold and the persons unable to detect the maximum concentration of ($246 \mu\text{g}/\text{m}^3$) would be rejected in panel selection.
- f) It is mandatory for the panel members to refrain from smoking, eating, drinking (except water) or use chewing gum or sweets since at least 30 minutes prior to the Olfactometry measurements.
- g) Panel members should take highest care in not causing any interference with their own perception or that of others in the odour rooms due to lack of personal hygiene or the use of perfumes, deodorants, body lotions or cosmetics.
- h) Panel members suffering from cold or any other ailment affecting their perception of smell (e.g. allergic fits, sinusitis) should be excluded from participating in measurements.
- i) Panel members should be present in the odour room or in a room with comparable conditions 15 minutes before the measurements start to get adapted to the actual odour environment of the measuring room.
- j) During measurements, panel members should not communicate with each other about the results of their choices. When using 'forced choice' mode, informing them of the correctness of their choices after the measurement can enhance the motivation of the assessors during the

measurements.

- i. The operator should ensure that the code of conduct is fully known to each panel member. The enforcement of the code of conduct directly influence on the test results, and therefore of great importance. The operator should ensure that the motivation of panel members is maintained throughout the measurements, and corrective action should be taken when required.

2. Selection of assessors on individual variability and sensitivity

- ii. In order to obtain a reliable sensor, composed of a number of panel members, assessors with specific qualities should be selected from the general population to serve as panel members.
- iii. In order to ensure repeatability of their result, their olfactory responses should be as constant as possible from day to day, and within a day.
- iv. In order to ensure repeatability of the sensor, formed by a panel composed of individual members, their olfactory sensitivity should be within a defined bandwidth, much narrower than the variability within the population. To achieve this aim assessors with a specific sensitivity to the reference Odourant n-butanol are selected to be panel members.
- v. To make new assessors familiar with the olfactometric procedures they should first be trained by performing at least one single measurement. These results are discarded.
- vi. Then at least 10 individual threshold estimates (ITE) for the reference gas shall be collected for selection purposes. As a reference n-butanol in nitrogen should be used. The data for each assessor should be collected in at least 3 sessions on separate days with a pause of at least one day between sessions.
- vii. To become a panel member, the data collected for that assessor should comply with the following criteria:
 - The antilog of the standard deviation site calculated from the logarithms (\log_{10}) of the individual threshold estimates, expressed in mass concentration units of the reference gas, has to be less than 2,3
 - The geometric mean of the individual threshold estimates ITE substance, expressed in mass concentration units of the reference gas, has to fall between 0.5 times and 2 times the accepted reference value for that reference material (for n-butanol $62 \mu\text{g}/\text{m}^3$ to $246 \mu\text{g}/\text{m}^3$ $0.020 \mu\text{mol}/\text{mol}$ to $0.080 \mu\text{mol}/\text{mol}$). These ranges are equivalent to half an odour unit and twice the odour unit.

A measuring history for each panel member should be recorded and maintained by determining one individual threshold estimate for the reference Odourant for at least once for each twelve regular measurements in which the panel member is used. Each time such

an individual threshold estimate for the reference Odourant is collected; the measuring history of the panel member in question should be completed and evaluated. Evaluation should be done by calculating the selection parameters as defined above from at least the 10 and at most 20 most recent individual threshold estimates, and comparing the results with the selection criteria. If the panel member does not comply, he/she is excluded from all further measurements until compliance is established once again

Sampling Methodology for analysis of Odour by Dynamic Olfactometry

Sampling is carried out by adopting procedure as mentioned in the EN-13725:2003

Sampling Methodology for analysis of Odour by Field Olfactometry

This methodology was adopted in CPCB's project in MSW landfill at Ghazipur , Delhi.

1. Description of Field Olfactometer

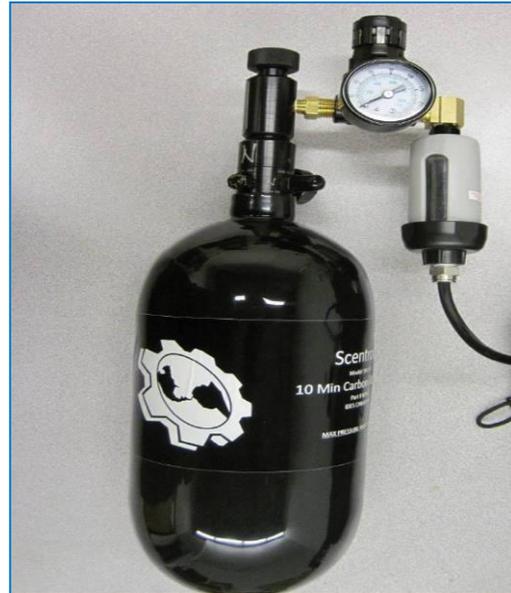
a) Device summary & layout :

Field Olfactometer is designed to provide accurate in-field odour measurement of ambient air and stack emissions. The self-contained manual olfactometer uses compressed air from a high-pressure carbon-fiber tank to dilute sample air prior and present it to the panelist. Sample is drawn using vacuum generated by the flow of compressed diluting air through a venture pump. Dilution ratio of clean air to sample air is controlled via patented flow regulator valve. Minimum dilution is 2 and maximum dilution is 30000.



b) Air Supply backpack

The Air-supply backpack houses the high-pressure compressed air tank, the pressure regulator and the active carbon filter. The carbon-fiber air tank can be filled with clean air to a pressure of 4500 psi (31 MPa). A high accuracy pressure regulator is used to ensure a constant flow of diluting air through the device. Models are calibrated and factory set at 80 PSI line pressure.



c) Flow Regulator and the Venture Vacuum Pump

The diluting air flows through a venture vacuum pump to create the necessary suction to draw in the sample. The venture vacuum pump also creates the turbulent flow to mix the drawn sample air with the diluting air from the tank. The amount of sample air that is pulled in and mixed with the diluting air is controlled via the flow regulator valve. The panelist can select between 15 dilution levels within the devices dilution range.



d) Mask

The mask comes in 3 sizes: Standard, Small, and extra small. The user should select the correct size to minimize the gap between the mask and the bridge of his/her nose. The constant 20 LPM of air ensures that there is always positive pressure inside to prevent ambient air from entering the mask.



2. Operating Procedure

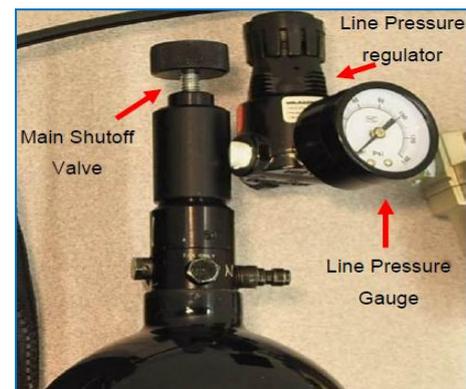
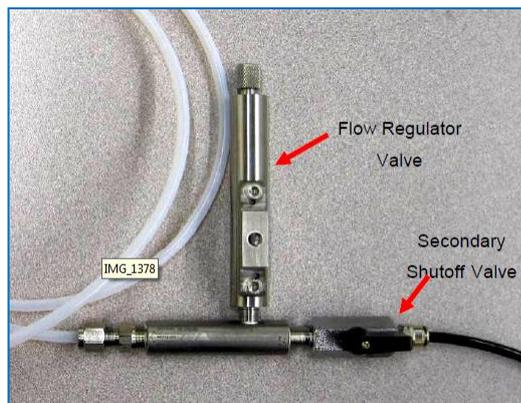
- A. Use first time: Instruments is disinfected and de-odourized before shipment from factory. Verify mask is clean and de-odourized. If odours are present follow cleaning procedures outlined in section.
- B. Tank Refills: The unit will be shipped without compressed air in the cylinder to facilitate safe shipping procedures. Before use the cylinder(s) need to be filled with compressed clean air. Local scuba stores are ideal as they have installed in-line particulate, vapour, and odour filters. Fill tanks to 4500 PSI to achieve optimum test time. (Warning: do not exceed 4500 PSI)

C. Using stationary air compressor instead of the high-pressure air tank The Olfactometer can be configured to use compressed air from a standard air compressor in place of the high-pressure air tank. Minimum requirements are 20L SLPM (4.5GPM) at 551 KPa (80 PSI). A standard particulate filter and mist separator is highly recommended. The unit's odour filter is sufficient to remove all common odours that may be present in the air line.



2. Operation - Ambient Odour (air) Measurement

1. Verify that the tank is filled to 4500 PSI pressure.



2. Verify that the secondary shutoff valve is closed (90 degree to the valve body) and the flow regulator valve is set to zero (fully closed).
3. Open the main shutoff valve located on the top of the Tank (to open turn clockwise until fully it is tightened).
4. Verify the line pressure gauge reads 80 PSI. If not adjust the pressure regulator.



5. Wear facemask and the portable compressed air tank and move to measurement site.
6. Open the secondary shutoff valve to purge nose with 2 to 3 min of odourless air.
7. Slowly opens the sliding valve to increase the concentration of until the odour becomes detectable
8. Read the flow indicator valve position indicator.

9. Lookup the dilution threshold (D/T) or Odour unit (OU) from the calibration chart

3. Sampling with pre-dilution

The field olfactometer can conduct stack or ambient air sampling. The sample must be pre-diluted (minimum 2 for ambient and 3 for stack). The olfactometer can be used to directly draw air from ambient and store it in a Tedlar bag (with minimum 2 dilution) or to draw Stack air via a probe/Teflon tube (with a minimum of 3 dilution). If sampling a hot or extremely odorous air it is recommended to use a higher pre-dilution (i.e. 20 or more) to ensure stack air does not condense in the sample bag as well as to avoid contaminating the sample bag and the sample port on the FIELD OLFACROMETER.

4. To perform ambient or stack sampling:

- a) Connect a new sample bag to the Teflon tube that normally connects to the mask.
- b) If conducting stack sampling connect the probe to the sample input port.
- c) Select the desired pre-dilution. Remember to choose a higher pre-dilution for hot or high odour stack samples.
- d) Open the shut off valve and allow the sample bag to fill up to 90% of capacity.

Do not overfill to avoid pressurizing the sample.

- a. Close the main shut off valve
- b. Close and remove the sample bag

5. Changing the Dilution Range

The FIELD OLFACROMETER has the capability to perform odour analysis in a range of 2 to 4000 odour units, however smaller ranges can be selected within the device's full operating range to increase accuracy and resolution. For example most common range selected for ambient odour analysis is 2 to 100 odour units while smoke stack samples may use a range of 1000 to 4000 odour units.

Ranges are defined by selecting and installing an appropriate restrictor plate. To replace a restrictor plate:

1. Remove the two bolts holding the adapter plate to the flow regulators body using a 6 mm Allen key.



2. Remove the top adapter plate and carefully remove the restrictor plate.
3. Install the desired restrictor plate on the flow regulator body and ensure the bolt holes match (dowel pins help to locate the two parts together).
4. Carefully place the adapter plate back (dowel pins help to locate all three parts together).
6. Maintenance - ROUTINE MAINTENANCE
 - i. General Maintenance Recommendations
 - a. The unit is equipped with a with active Odour Filter (carbon cartridge) which is used for zero – setting. This cartridge should be replaced once a year to ensure no residual odour is present in the diluting air.
 - b. Routinely inspect the gas tank for signs of physical damage. Any damage on the tank body or stem should be inspected by a qualified technician.
 - c. Never use lubricated oil with the FIELD OLFACTOMETER.
 - ii. De-odourization
 - a. To deodourize the mask or Teflon tubing non-scented soap and water should be used. If the odour persists a more aggressive hydrogen peroxide can be used.
 - b. An alternative method is to heat the mask to a temperature of 110°C (230 Fahrenheit)
7. Calibration
The FIELD OLFACTOMETER is factory calibrated and does not require frequent re-calibration however to conform to international olfactometry standards (i.e. EN13725) annual calibration must be completed.
8. Storage Information
 - a. Do not store in temperature above 70°C. Excessive temperature could cause damage to the compressed air tank.
 - b. If the unit is going to be stored for extended period of time, empty the air tank.
9. Representation of Result
 - a. Conditions: T: 21.5°C ± 2°C P: 80 PSI ± 1 PSI
 - b. Plate #s: H,A,3,2,1 (
 - c. Results: Based upon the specification of the plate and reading of valve position, inferences are drawn for odour concentration (OU_E/M³). Calibration example as under

Position of Value	TYPE OF PLATE & RESPECTED ODOUR CONCENTRATION IN (OU _E /m ³).				
	H	A	3	2	1
1	101	678	656	3600	30000
2	60	319	328	1441	15000
3	45	176	219	1201	10000
4	35	98	164	721	7500
5	28	62	131	600	6000
6	24	35	109	515	5000
7	19	24	94	450	4300
8	13	17	82	390	3750
9	11	13	73	350	3330
10	9	10	66	300	3000
11	7	8	60	280	2700
12	6	7	55	260	2500
13	5	6	51	235	2300
14	4	5	47	222	2140
15	3	4	44	200	2000
NP	2	2	2	2	2

- Uncertainty of Measurement: ±5% of TARGET value based on a confidence ≥95%.

10. Health & Safety Statement

- This instrument is not designed to be used as a Self-Contained Breathing Apparatus (SCBA).
- The high-pressure air tank should not be exposed to excessive heat or direct flame.
- Do not overfill beyond 4500 psi.
- Avoid hard impact and if any structure damage is detected open the shutoff valve and empty the tank. Tank should be inspected by a qualified technician before being put back in service.
- Fill tank only with clean odourless breathing air. Do not fill tank with oxygen as breathing pure oxygen for extended periods of time poses serious health risks.

LABORATORY BASED QUANTITATIVE METHODOLOGY

CPCB's ToR for analysis of odourous compounds

As per the CPCB's Project's ToR the odourants identified for study for at MSW landfill site are :

1. Ammonia
2. Hydrogen sulphide
3. Methyl Mercaptan
4. Ethyl Mercaptan
5. Dimethyl sulphide
6. Butyric acid
7. Methane
8. VOCs (total)

As per SOP and worldwide adopted analytical methods, based on their precision and accuracy were selected for meeting the objective of the project's ToR. As mentioned earlier the method for estimation of identified parameters can be grouped in five categories:

1. Ammonia
2. Total reduced sulphur (*Methyl Mercaptan, Ethyl Mercaptan, Dimethyl Sulphide, Hydrogen Sulphide*)
3. Methane
4. Butyric Acid
5. VOCs (total)

In the present study, the methodology followed for both **ambient and sources** is chemical method referred by different international agencies. As the emission from the MSW landfill site is typical one and mostly governed by atmospheric condition so the presence of odourants both in source and ambient are of same nature. The selection of methodology for source and ambient are conventionally separate, however, considering the concentration ranges and above mentioned conditions, it was observed technically feasible and suitable to select same methodologies for monitoring from source and ambient. It is pertinent to mention that the methodology is selected in study is not the ultimate one as there are other technology and methodology which are also followed to quantify the target compounds. With technical advancement in analytical methodologies, use of different sensors and analyzer based instrument specific for measurement of different pollutants are gaining popularity as they are capable to generate real time data continuous basis.

Sampling Methodology for analysis of Odourants by GAS

CHROMATOGRAPHY - MASS SPECTROMETRY

1. ESTIMATION OF AMMONIA

- A. **Purpose:** This document is to provide the method of sampling & analysis to determine the ammonia gas concentration in air
- B. **Scope:** - The colorimetric indophenol blue technique was used to analyse the aerosol samples for the concentration of ammonium ions and the air samples for their gaseous ammonia.
- C. **Responsibility:** Lab Manager and authorized chemists/ field monitoring persons.
- D. **Principle:** - (Indophenol method) Ammonia in the atmosphere is collected by bubbling a measured volume of air through a dilute solution of sulphuric acid to form ammonium sulphate. The ammonium sulphate formed in the sample is analyzed calorimetrically by reaction with phenol and alkaline sodium hypochlorite to produce Indophenol. The reaction is accelerated by the addition of Sodium Nitroprusside as catalyst.
- E. **Interferences:** Complexing magnesium and calcium with citrate eliminates interference produced by precipitation of these ions at high pH. There is no interference from other trivalent forms of nitrogen. Remove interfering turbidity by distillation or filtration. If hydrogen sulfide is present, remove by acidifying samples to pH 3 with dilute HCl and aerating vigorously until sulfide odour no longer can be detected.
- F. **Linear range:** With sampling rate of 1-2LPM a concentration range of 20 to 700 $\mu\text{g}/\text{m}^3$ ammonia in air may be determined with sampling of time of 1 hour.
- G. **Minimum Detection Limit:** Minimum 0.02 μg NH_3/ml in air can be determined.
- H. **Apparatus:** Spectrophotometer for use at 640 nm with a light path of 1 cm or greater.
- I. **Reagents:**
- Phenol solution: Mix 11.1 ml liquefied phenol (>89%) with 95% v/v ethyl alcohol to a final volume of 100 ml. Prepare weekly.
- CAUTION:** Wear gloves and eye protection when handling phenol; use good ventilation to minimize all personnel exposure to this toxic volatile substance.
- Sodium nitroprusside : 0.5% w/v: Dissolve 0.5 g sodium nitroprusside in 100 mL deionized water. Store in amber bottle for up to 1 month.
 - Alkaline citrate: Dissolve 200 g trisodium citrate and 10 g sodium hydroxide in de-ionized water. Dilute to 1000 ml.

- d. Sodium hypochlorite commercial solution, about 5%. This solution slowly decomposes once the seal on the bottle cap is broken. Replace about every 2 months.
- e. Oxidizing solution: Mix 100 mL alkaline citrate solution with 25 ml sodium hypochlorite. Prepare fresh daily.
- f. Stock ammonium solution: See Section 4500-NH₃.D.3d. (APHA)
- g. Standard ammonium solution: Use stock ammonium solution and water to prepare a calibration curve in a range appropriate for the concentrations of the samples.
- J. Procedure for Sampling: Ammonia in the air is estimated by using Sulphuric acid as absorbing solution in the impinge tube placed in the HVS.

For Analysis To a 25-ml sample in a 50-ml Erlenmeyer flask, add, with thorough mixing after each addition, 1 ml phenol solution, 1 ml sodium nitroprusside solution, and 2.5 ml oxidizing solution. Cover samples with plastic wrap or paraffin wrapper film. Let color develop at room temperature (22 to 27°C) in subdued light for at least 1 hour. Color is stable for 24 h. Measure absorbance at 640 nm. Prepare a blank and at least two other standards by diluting stock ammonia solution into the sample concentration range. Treat standards the same as samples.

- K. **Calibration:** Prepare a blank and series of standard solutions covering the concentration of 1000, 100, 10, 1 and 0.1 mg NH₃ – N/ml. Prepare at least two other standards by diluting stock ammonia solution into the sample concentration range. Treat standards the same as samples
- L. **Calculations:** - Prepare a standard curve by plotting absorbance readings of standards against ammonia concentrations of standards. Compute sample concentration by comparing sample absorbance with the standard curve.

$$\text{Ammonia as NH}_3, \mu\text{g}/\text{m}_3 = \frac{\text{Sample Absorbance } \mu\text{g NH}_3 \times \text{Factor X 35}}{\text{Volume of sample taken 10 ml X Volume of Air}}$$

- M. **Precision & Accuracy:** Replicate samples, collected with glass pre filters and analyzed manually showed a relative coefficient of variation of 30% in the 0.7 to 21 µg/m³ (1 to 30ppb) range. This coefficient varies with concentration of atmospheric ammonia and decreases to 5% in the range of 700 µg/m³ (1ppm) range.
- N. Limitation of this method:- As indophenols blue method required a very unsuitable reagent (hypochlorite) and the reaction needs curtained amount of free chlorine in the reagent it is very cumbersome to mention the required strength of hypochlorite in

laboratory condition. Therefore the analyst shall prepare the hypochlorite solution freshly and the required calibration curve should be updated with each and every batch analyzed.

Reference:

- APHA 3rd edn: 1998
- Institute of oceanography, university of Gdańsk
- Method of air sampling and analysis 3rd edition James p. Indophenols' method 401.

2. ESTIMATION OF REDUCED SULPHUR ODOURANTS

Estimation of reduced sulphur compound mainly includes analytical concentration for **Hydrogen Sulphide, Mercaptans (Methyl Mercaptans, Ethyl Mercaptans) and Dimethyl Sulphide**. Reduced sulphur odourants is absorbed in two different absorbing solutions :

- The hydrogen sulphide present in landfill gas emission is absorbed in cadmium sulphate with sodium hydroxide in water.
- While others Methyl Mercaptan, Ethyl Mercaptan and Dimethyl Sulphide are absorbed in aqueous solution of mercuric acetate.

3. Estimation of Hydrogen Sulphide

- A. Scope:** This method consists of determination of Hydrogen Sulphide in Air.
- B. Purpose:** Purpose of this document is to provide the method of sampling & analysis to determine the hydrogen sulphide gas concentration in air.
- C. Responsibility:** Lab Manager and authorized chemists/ field monitoring persons
- D. Principle:** The determination of hydrogen sulphide by colorimetric method is based on the reaction which takes place under suitable conditions between N, N-dimethyl-p-phenylenediamine sulphate, ferric sulphate and sulphide ions, resulting in the formation of methylene blue.
- E. Interferences:** Some strong reducing agents like sulphites and thiosulphates prevent the formation of the colour or diminish its intensity. These may be eliminated by adding sufficient amount of ferric sulphate solution. Atmospheric oxides of nitrogen cause interference. They may be avoided by adding sulphamic acid after the sampling is over. Other possible atmospheric interferences like sulphur dioxide, ozone, and ammonia are not serious at their normal existing levels of concentrations.
- F. Linear range:** The range of concentration covered in this method is $6\mu\text{g}/\text{m}^3$ to $600\mu\text{g}/\text{m}^3$ of H_2S in air.

- G. Minimum Detection Limit:** Minimum $6\mu\text{g}/\text{m}^3$ hydrogen sulphide in air can be determined.
- H. Sensitivity:-** Minimum detectable concentration of hydrogen sulphide is $0.03\ \mu\text{g}$ per millilitre of the absorbing solution with an overall accuracy of ± 20 percent. Berr's law is obeyed up to $2\ \mu\text{g}$ of hydrogen sulphide per millilitre of absorbing solution.
- I. Apparatus:** Spectrophotometer for use at $670\ \text{nm}$ with a light path of $1\ \text{cm}$ or greater.
- J. Reagents:**
- Absorbing Solution:** Dissolve $4.3\ \text{g}$ of cadmium sulphate ($\text{CdSO}_4 \cdot 8\text{H}_2\text{O}$) in water. Add $0.3\ \text{g}$ of sodium hydroxide dissolved in a small amount of water and dilute to one litre. Mix well before use. Store the solution in a refrigerator.
 - N, N-Dimethyl-p-Phenylene-Diamine-Sulphate Solution:** Add $50\ \text{ml}$ of concentrated sulphuric acid (conforming to IS : 266-1961*) to $30\ \text{ml}$ of distilled water and cool. Add $12\ \text{g}$ of N, N-dimethyl-p-phenylene diamine or $27.2\ \text{g}$ of N, N-dimethyl-p-phenylene-diamine sulphate. Stir the bulk solution till it is completely dissolved. Store it as stock solution in refrigerator. For the purpose of preparing standards, dilute $25\ \text{ml}$ of the stock solution to one litre with dilute sulphuric acid (1:1).
 - Ferric Sulphate Solution:** Add excess of ferric sulphate in $100\ \text{ml}$ of water to obtain a saturated solution.
 - Sulphamic Acid Solution:** 1 percent (m/v). Dissolve one gram of sulphamic acid in $100\ \text{ml}$ of water.
 - Sodium Sulphide Solution:** Dissolve $1.2\ \text{g}$ of sodium sulphide of analytical grade ($\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$), in one litre of pre-refrigerated distilled water and stopper it since the solution is very unstable it shall be prepared just before use. It shall be stored in a refrigerator. Standardize this solution against standard sodium thiosulphate solution ($0.025\ \text{N}$) as follows.
Take $100\ \text{ml}$ of distilled water in 250-ml conical flask and add $20\ \text{ml}$ of standard iodine solution ($0.025\ \text{N}$). Add $25\ \text{ml}$ of hydrochloric acid ($0.1\ \text{N}$) and titrate with the thiosulphate solution using starch solution as indicator. Note the titrant reading as **A**.
Take $100\ \text{ml}$ of distilled water in 250-ml conical flask and add $20\ \text{ml}$ of standard iodine solution ($0.025\ \text{N}$). Add $25\ \text{ml}$ of hydrochloric acid ($0.1\ \text{N}$) and $20\ \text{ml}$ of sodium sulphide solution and repeat the titration with the thiosulphate solution. Note the titrant reading as **B**.
 - Calculate the strength of sodium sulphide solution in terms of hydrogen sulphide as follows:
Hydrogen sulphide, $\mu\text{g}/\text{ml} = \frac{(\text{A}-\text{B}) \times \text{Normality of thiosulphate solution} \times 17 \times 10^8}{20}$

For the purpose of preparing standards for comparison, dilute a portion of the sodium sulphide solution so that it contains equivalent of 10 µg/ml of hydrogen sulphide.

A. PROCEDURE

a. Sampling: Hydrogen sulphide in the air was estimated by using cadmium sulphate and Sodium hydroxide as absorbing solution in the impinge tube placed in the HVS. Procedures are described for short term (30 minutes and 1 hour) and for long term (24 hours) sampling.

One can select different combinations of sampling rate and time to meet special requirements. Sample volumes shall be adjusted, so that linearity is maintained between transmission and concentration over the dynamic range.

b. Sample Preparation: If a precipitate is observed in the sample, remove it by centrifugation.

c. For Analysis: To a 10-mL sample in a 50-ml Erlenmeyer flask, add, with thorough mixing after each addition, 1 ml of sulphamic acid solution, 0.6 ml of N,N-dimethyl-pphenylene-diamine sulphate solution and 0.05 ml of ferric sulphate solution shaking well. Make up the volumes to 25 ml in distilled water and mix thoroughly. Allow 30 minutes for the development of full colour in the Standard flask. Measure the colour intensity of the solutions in a spectrophotometer at 670 nm on transmission scale. Use the reagent blank as control.

d. Calibration: Prepare a series of standard solutions in the range of 0.04 to 0.32 µg/ml from diluted sodium sulphide solution and reagent blank in 25 ml volumetric flask for making calibration graph. Draw the calibration curve of percent transmission versus micrograms of hydrogen sulphide.

e. Calculations:

$$\frac{\text{Sample Absorbance} \times \text{Factor} \times 35}{\text{Volume of sample taken}} = \text{Hydrogen Sulphide, } \mu\text{g}/\text{m}^3$$

$$\text{Hydrogen Sulphide, } \mu\text{g}/\text{m}^3 = \frac{\text{Volume of sample taken} \times 10 \text{ ml} \times \text{Volume of Air}}{\text{Volume of Air}}$$

B. Precision & Accuracy: The overall coefficient of variation of the method, including sampling & analysis, for occupational health applications has been reported to be 12.1%. At low concentration (0.6 to 1.4 µg/m³), the collection efficiency of sampling rates up to 1.7 LPM is typically 95.1 ± 1.5%. Essentially quantitative collection has been reported at a concentration level of 1mg/m³ with a sampling rate of 1LPM.

Results that average 54% of the true values have been observed for 24hrs sampling of standard atmospheric containing 25-56 µg H₂S/m³.

Reference: IS: 5182 (Part VII) - 1973 (Reaff:2009)

4. ESTIMATION OF Methyl Mercaptan, Ethyl Mercaptan, Dimethyl Sulphide:

- A. Purpose:** Purpose of this document is to provide the method of sampling & analysis to determine the TRS in Environment.
- B. Scope:** TRS are collected by aspirating a measured volume of air through an aqueous solution of Mercuric acetate / Glass Fiber, 37 mm, impregnated with Mercuric Acetate.
- C. Responsibility:** Lab Manager and authorized chemists/ field monitoring persons.
- D. Principle:** Methyl Mercaptan is regenerated from the Mercuric Mercaptide, formed during sampling by treatment with hydrochloric acid. The Methyl Mercaptan is extracted into Dichloroethane and analyzed by Gas chromatography. Aqueous solutions are subsequently determined by Spectrophotometric measurement of the red complex produced by the reaction between Mercaptans and a strongly acid solution of N,N'-Dimethyl-p-Phenylenediamine and Ferric chloride. Spectrophotometric method determines total Mercaptans and does not differentiate among individual Mercaptans although it is most sensitive to lower molecular weight alkanethiols.

E. Methodology

This method includes the qualitative and quantitative analysis of Mercaptans by GC-FID. (Methyl Mercaptan (CH₃SH), Ethyl Mercaptan (CH₃CH₂SH), Butyl Mercaptan (CH₃CH₂CH₂CH₂SH))

a. For Spectrophotometer method gives Total Mercaptans:-

This Method is applicable for analysis of samples taken from ambient and Stack provided that the contaminant adsorbs on to Glass Fiber / aq. Solution of Mercuric Acetate and that it can be analyzed.

The above samples are analyzed with the help of GC-FID / MS method.

When optimization to reagent purity and analytical conditions, the detection limits for the GC-FID method ranges are 0.050 ppm to 10 ppm for 20 L sample for all three mercaptans. In Spectrophotometer method is intended to provide a measure of mercaptans in the range below 102 ppb. The minimum detectable amount of Methyl Mercaptan is 0.04 µg / ml in a final liquid volume of 25 ml.

b. For Gas Chromatography:-

This method is complementary to Practice NIOSH 2542 (for Ambient Air Quality) and APHA Method 118 (combined with OSHA method). Mercaptans (organic thiols R-SH) are collected by aspirating a measured volume of air through an aqueous solution of mercuric acetate-acetic acid.

Glass fiber filters are impregnated with Mercuric acetate. The filters are prepared by immersing 5% aqueous solution of Mercuric

acetate, dried in the air, and then assembled in two-piece filter cassettes without backup pads. The filters exhibit yellowish colour, but it does not affect their collection efficiency.

F. Materials and Reagents :

- Methyl Mercaptan – 99.5+%
- Ethyl Mercaptan – 99.0+%
- N- Butyl Mercaptan – 99.0+%
- Mercuric Acetate – ACS reagent grade.
- Hydrochloric Acid – ACS reagent grade.
- 1,2-Dichloroethane – ACS reagent grade.
- Methyl Mercaptan calibration stock solution,
- Ethyl Mercaptan calibration stock solution,
- N-Butyl Mercaptan calibration stock solution
- Helium, purified
- Hydrogen, prepurified
- Air, filtered, compressed
- **Amine-Hydrochloric acid stock solution:-** Dissolve 5.0 g N,N'Dimethyl-p-phenylenediamine hydrochloride (p-aminodimethylaniline hydrochloride) in 1 L of Conc. Hydrochloric Acid. Refrigerate and protect from light. This solution is stable for at least 6 months.
- **Reissner Solution:** - Dissolve 67.6 g Ferric chloride hexahydrate in distilled water, dilute to 500 ml and mix with 500 ml nitric acid solution containing 72 ml boiled conc. Nitric acid. This solution is stable.
- **Color Developing Reagent:-** Mix 3 volumes of amine solution and 1 volume of Reissner solution. Prepare this solution freshly for each set of determinations.
- **Absorbing solution:** - Dissolve 50 g mercuric acetate in 400 ml distilled water and add 25 ml glacial acetic acid. Dilute to 1L. The mercuric acetate must be free of mercurous salts to prevent precipitation of mercurous chloride during colour development. Reagent grade mercuric acetate sometimes contains mercurous mercury. Determine the acceptability of each new bottle of mercuric acetate by adding 3 ml of Conc. Hydrochloric acid to 3 ml of the 5% Mercuric acetate. If the solution become cloudy; the mercuric acetate is not acceptable.
- **Lead Methyl Mercaptide. :** Lead Mercaptide may be purchased from commercial sources, if desired.
- **Concentrated, Std. Lead Mercaptide solution:-** Weigh out 156.6 mg of the crystalline Lead Mercaptide and make up to 100 ml with the 5% Mercuric acetate absorbing solution. This solution contains the equivalent of 500µg of methyl mercaptan / ml.

- **Diluted Std. Mercaptan solution:-** Dilute 2 ml of the concentrated std. solution to 100 ml with the 5% Mercuric acetate absorbing solution. This solution contains the equivalent of 10 µg Methyl Mercaptan / ml.
- Separating funnel.
- Spectrophotometer.

G. Analysis procedure for GC-FID:

- Add 20 ml of 25% (v/v) hydrochloric acid and 5mL of 1,2-dichloroethane to a 30 ml separatory funnel. Fold sample filter and insert into the neck of a separatory funnel, without allowing the filter to become wet. While seating the stopper, push filter into funnel.
- Shake funnel for 2 min. without venting.
- Let stand at least 5 min, until the phases completely separate. Then drain the 1,2-dichloroethane into a vial and seal with a PTFE lined cap.
- Calibration:- Calibrate at least 5 working standards covering the range of the samples – Add known amounts of calibration stock solution to 1,2-dichloroethane in 10 ml volumetric flasks and dilute to the mark. Analyze together with samples and blanks. Prepare calibration graphs: either quadratic curves, ie., peak area vs. concentration of mercaptans, or linear curves, ie., In (peak area) vs. In (Concentration)² can be used for calibration.

H. For Spectrophotometer:

- Quantitatively transfer the sample from the impinger to a 25 ml volumetric flask and dilute to approximately 22ml with distilled water that has been used to rinse the fritted bubbler and flask. Add 2.0 ml of freshly prepared colour developing reagent dilute to volume with distilled water and mix well. Prepare a reference blank in the same manner using 15 ml of unspirated 5% mercuric acetate. 2 ml. colour developing reagent and dilute to 25 ml. After 30 min. measure the absorbance at 500 nm with spectrophotometer against the mercaptan free reference blank.
- **Calibration Aqueous Mercaptide:-** Prepare a calibration curve by pipetting appropriate aliquots of the diluted standard lead mercaptide into a series of 25 ml volumetric flasks, diluting each with 15 ml of 5% Mercuric acetate absorbing solution and developing the color in the same manner as the samples. Prepare a reference blank in the same manner without lead mercaptide. Determine the absorbance at 500 nm against the mercaptan – free reference blank. Prepare a standard curve of absorbance Vs. µg Methyl Mercaptan / ml.
- **Calculations & Reporting**
 - a. A standard curve should be constructed, or a linear progression program used to plot standard concentration versus absorbance.
 - b. A 'blank' response is measured

- c. Calculate the corrected absorbance by subtracting the response of the blank
- d. Using the standard curve and from the corrected response read off the concentration ($\mu\text{g/ml}$) of analyte recovered.
- e. Calculate the mass of analyte in each impinger:
 $\text{Mass } (\mu\text{g}) = \text{Conc } (\mu\text{g/ml}) \times \text{Sample volume (ml)}$

I. Interferences:-

- The N,N'-Dimethyl-p-phenylenediamine reaction is also suitable for the determination of other sulfur –containing compounds including Hydrogen sulfide and dimethyl disulfide. Appropriate selection of the color formation conditions minimizes the interferences.
- Hydrogen sulfide, if present in the sampled air, may cause turbidity in the sample absorbing solution. This precipitate must be filtered before proceeding with the analysis.
- An unexplained Yellow tinge has been randomly observed in a few impingers after sampling, it subsequently turned pink. A black precipitate then formed when the colour developing reagent was added. Although the precipitate was removed by filtration just before the absorption was measured.
- The supply of Mercuric acetate must be free of Mercurous ion. If Mercurous ion is present turbidity will result when the chloride ion-containing reagents are added to the last step of the analytical procedure.

J. Preparation of Spiked samples:-

Liquid standards: External standards (enclosed the hard copy of those COA) are directly added in the sample extraction. The blank was prepared using a blank Glass fiber filter from the same batch. Normal spike levels: - 50 ppb, 75 ppb, 100 ppb and 250 ppb.

K. Quality Control:-

System performance check	Ensure validity of sampling train components and analytical procedure.
Sampling equipment leak-check and calibration	Ensure accurate measurement of stack gas flow rate, sample volume.
Analytical calibration	Ensure precision of analytical results within 5 percent.

L. Calibration Drift:

The calibration drift determined from the mean of the three injections made at the beginning and end of any run or series of runs within a 24-hour period must not exceed 5 percent.

M. System Calibration Accuracy: -

Losses through the sample transport system must be measured and a correction factor developed to adjust the calibration accuracy to 100 percent.

N. Instrumentation:

GC-FID conditions:- Model Used:- 6890N GC (Make:- Agilent Technologies Ltd.) Method printout enclosed.

Calculations and data analysis:-

Observed concentration (from the reading) / actually spiked X 100 = Recovery % Mean & Std. Deviation calculation as per EPA method.

O. Health & Safety

1. Mercuric acetate is highly toxic. If spilled on skin, wash off immediately with water. Treat all industrial emissions as potentially hazardous. Store Methyl, ethyl and n-butyl mercaptans from flammable and oxidizing materials. The analytes are highly flammable and irritating to the eyes. Work in a hood. It has been reported that Methyl Mercaptan exhibits a toxicity similar to, but less than that of hydrogen sulfide. Others have reported the toxicity of both compounds being the same. Methyl Mercaptan affects the nervous system and can cause convulsions and narcosis. At high concentrations, it causes paralysis of the respiratory center. At lower levels, it produces pulmonary edema.
2. Disclaimer. This method may involve hazardous materials, operations, and equipment. This test method may not address all of the safety problems associated with its use. It is the responsibility of the user of this test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to performing this test method.
3. Corrosive reagents. The following reagents are hazardous. Personal protective equipment and safe procedures are useful in preventing chemical splashes. If contact occurs, immediately flush with copious amounts of water for at least 15 minutes. Remove clothing under shower and decontaminate. Treat residual chemical burns as thermal burns.
4. Hydrogen Peroxide (H₂O₂). Irritating to eyes, skin, nose, and lungs.
5. Sodium Hydroxide (NaOH). Causes severe damage to eyes and skin. Inhalation causes irritation to nose, throat, and lungs. Reacts exothermically with limited amounts of water.
6. Sulfuric Acid (H₂SO₄). Rapidly destructive to body tissue. Will cause third degree burns. Eye damage may result in blindness. Inhalation may be fatal from spasm of the larynx, usually within 30 minutes. May cause lung tissue damage with edema. 3 mg/m³ will cause lung damage in uninitiated. 1 mg/m³ for 8 hours will cause lung damage or, in higher concentrations, death. Provide ventilation to limit inhalation. Reacts violently with metals and organics.
7. Hydrogen Sulfide (H₂S). A flammable, poisonous gas with the odour of rotten eggs. H₂S is extremely hazardous and can cause collapse, coma, and death within a few seconds of one or two.
8. Inhalations at sufficient concentrations. Low concentrations irritate

the mucous membranes and may cause nausea, dizziness, and headache after exposure.

Reference:-

1. NIOSH manual of Analytical Methods (NMAM), Fourth Edition, 8 / 15 / 94 - Mercaptans - Methyl, Ethyl, and Butyl.
2. Method 118, Determination of Mercaptan content of the atmosphere, APHA intersociety Committee. Methods of Air Sampling and Analysis, 3rd Ed.
3. OSHA Analytical Laboratory, Method 26, Methyl Mercaptan, February 1981.
4. Knarr, R. and Rapport S.M., Determination Methanethiol at Parts-per-million Air Concentration by Gas Chromatography, Anal. Chem. 52, 733-736 (1980).
5. Moore, H.H.L. Helwig and R.J. Graul. 1960. A Spectrophotometric method for the determination of Mercaptans in air. Ind. Hyg. J. 21:466.
6. Method E260 Recommended Practice for General Gas Chromatography Procedures.
7. Method E355 Practice for Gas chromatography Terms and Relationships.
8. Agilent Technologies Ltd. – Instruction Manual.

7. ESTIMATION OF METHANE

A. Purpose: Purpose of this document is to provide the method of sampling & analysis to determine the Methane in Environment.

B. Scope:-

This standard describes the method of measurement of the concentration of individual C1 to C6 hydrocarbons in the atmosphere. The lower limit of measurement is 0.01 parts per million (ppm) by volume. For analysis without concentration of the sample, the elution of the 17 hydrocarbons as given in Table 1 is accomplished within approximately 16 minutes.

C. Responsibility: Lab Manager and authorized chemists/ field monitoring persons.

D. Principle:- Methane is collected in tedler bag through suction of ambient air by using constant flow rate by Vacuum pump. The substance (CH₄) is analyzed by molecular sieve column fitted gas chromatography. A flame ionization detector (FID) and methanizer is used for analysis.

E. Out Line of the Method:-

This is a rapid method intended for routine sampling and analysis. Directions are given for the collection of grab samples and integrated samples; An air sample is collected in a sealed plastic bag fitted with an air valve. The sample is delivered to the laboratory where the C1 to

C5 hydrocarbons can be identified and quantities to 0.01 ppm by analysis of 1 ml of air sample without concentration.

The gas chromatographic analysis is performed on a single packed column, operated isothermally. Flame ionization detector is used for detection with pure oxygen supplied to the hydrogen flame to enhance its sensitivity. 2,2-dimethylpropane and trans-2-butene are the only known compounds that elute from the columns together under conditions of the method.

F. Instruments/Equipment

Gas Chromatography Assembly - A gas chromatograph assembly is shown in below Figure. Operating conditions are specified for a typical instrument. Equivalent apparatus may be substituted with the adjustment of operating conditions to provide the required performance.

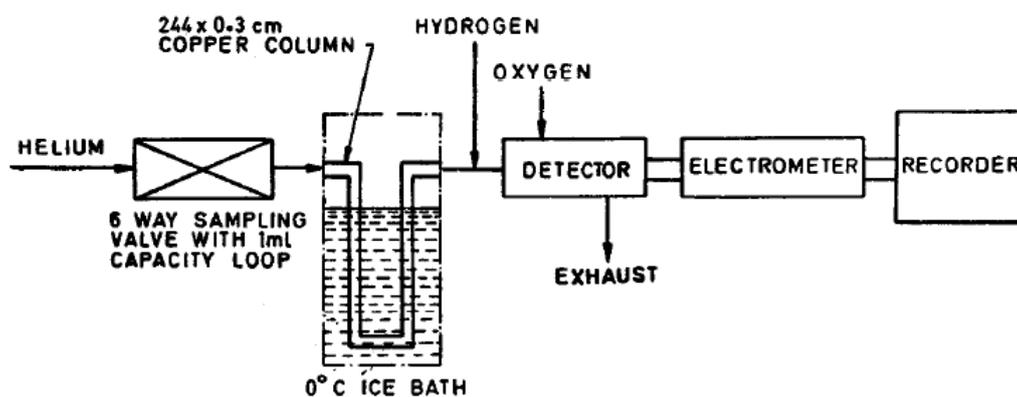


Figure 4: Gas Chromatograph Assembly for Measuring C1 To C5 Atmospheric Hydrocarbons

The specification of the sample injector depends upon whether analysis is to be made of 1 ml of the air sample directly or 100 ml of air sample is to be concentrated in a freeze-trap before analysis. For direct analysis, the sample injector consists of a six-way sampling valve with a 1-ml stainless steel sampling loop.

- Hydrogen Flame Ionization Detector
- The assembly of apparatus for preparing calibration standards is shown in Fig. 15. The principal components are given as under

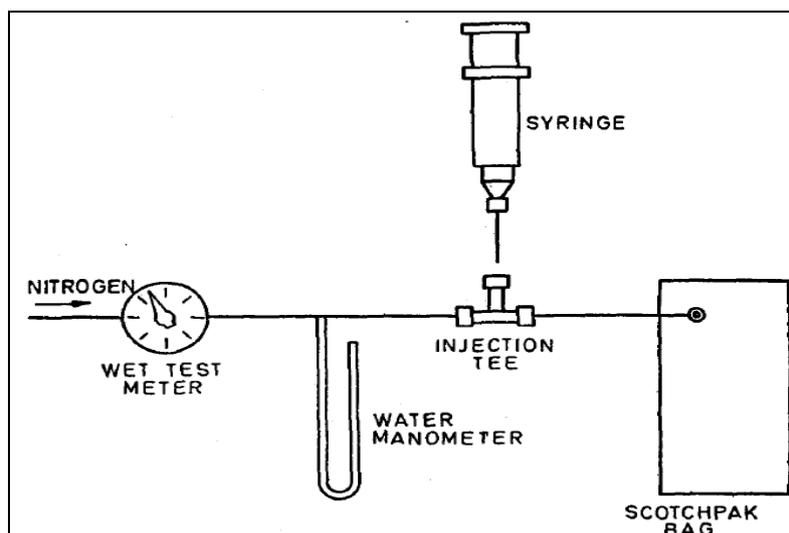


Figure 5: Assembly of Apparatus

G. CALIBRATION STANDARDS

Precision Wet Test Gas Meter

Stainless Steel Injection Tee - with the centre arm fitted with a silicone rubber injection gasket.

- Gastight Syringes - 10-ml and 50-ml.
- Aluminized Plastics Bags - Two sizes: approximately 40-litre and 10-litre capacity. Recommended sizes are 460 x 1220 mm and 460 x 310 mm respectively.
- The following equipment is used for collecting grab samples of air. Aluminized Plastics Bags - fitted with air valves, of approximately 2-litre capacity.

Atomizer Rubber Bulb Set or Automatic Burette Bulb

- Air-Sampling Pump - diaphragm-actuated, capable of providing constant flow up to 10 l/min at 105 Pa and 0,066 l/min at 0.4 x 10⁵ Pa.
- Air-Metering Device - A limiting orifice prepared from a hypodermic needle may also be used as an air-metering device.
- Electric Timer - This automatically shuts off the sampling pump at the end of the sampling interval.
- Rubber Septum - when limiting orifice needles are used. A sleeve type serum bottle stopper is suitable.
- Flow meter - with the range from 1 to 85 ml/min at 100 k Pa and 21°C.
- Filter System - upstream of the pump, is recommended for the entrapment of particulate matter (membrane filter or equivalent filter which does not absorb organic materials).

- Column - 244 cm long, 1-5 mm inside diameter, 17 mass percent oxydipropionitrile on activated alumina, 100 to 150 micron size.
- Carrier Gas - Helium or hydrogen at 30 ml/min and 560 k Pa.
- Detector Gas - Hydrogen flow to the detector maintained at 28 ml/min by means of a restricted stainless steel capillary. Oxygen flow at 300 ml/min.
- Recorder Range - 0 to 1 mV and 1-s response.
- Sample Size - 1 ml for direct analysis
- Electrometer - Sensitivity of 3×10^{-1} s. A full scale on 1-mV recorder, min.
- Electrometer - Attenuation of 10 x for methane, 1 x for the other hydrocarbons in atmospheric air samples.
- Detector Sensitivity - 0.02°C/g with oxygen as combustion gas, min.

H. Quality Of Reagents

- Unless otherwise specified, pure chemicals and distilled water (see IS: 1070-1977*) freshly boiled and cooled, shall be employed.
NOTE - 'Pure chemicals' shall mean chemicals that do not contain impurities which affect the results of analysis.
- The materials used for preparation of the chromatograph column.
- Alumina (A&O,) - 100 to 150 micron size, chromatographic grade.
- Oxydijroflrionitrile, Copper or Stainless Steel Tubing - 3 mm outside diameter and 1.5 mm inside diameter, Dichloromethane
- Hydrogen - pure grade, 99.8 percent, free from water and organic material.
- Oxygen - commercial grade 99.6 percent min.
- Helium -reactor grade shall be used as the column, carrier gas, 99.995 percent Min. In case helium is not available hydrogen, pure grade, 99.8 percent, free from water and organic material may be used as column carrier gas.
Hydrocarbons - pure grade, having a guaranteed minimum purity of 99 mole percent.

I. Column Filling and Preparation

The chromatograph column consists of 17 mass percent of @, p-oxydipropionitrile on activated alumina. Place about 25 to 30 g of alumina in a 15 cm porcelain evaporating dish and wash several times with deionized water. After the excess water has been poured off, activate the alumina at 400°C for 9 h. Allow to cool in a desiccators for about 1 h. Weigh out 16.6 g of the activated alumina and pour immediately into another 15 cm porcelain evaporating dish containing 3.4 g of /3, P-oxydipropionitrile dissolved in 40 ml of dichloromethane. Evaporate the solvent under a reflector infrared heat lamp with frequent stirring; remove residual solvent at 70°C at about 30 kPa for 5 h. Fill a column by gravity flow and continual tapping with the column packing. Coil and condition the column overnight at room temperature with carrier gas at 30 ml/min and inlet pressure 560 kPa.

J. Sampling:-

- i. Grab samples shall be collected.
- ii. Flush the aluminized plastics bag three times with the ambient air to be sampled. This is done with a rubber burette bulb connected to the valve of the bag.
- iii. Fill the bag approximately three fourths full, close the air valve securely, and remove the burette bulb. Do not fill the bag to capacity. Some space should be allowed for expansion due to temperature and pressure variations.
- iv. Give the bag an identifying number and record appropriate field information, for example, date, time and location of sample collection; weather, traffic, air pollution conditions, etc.
- v. The samples should be sent to the laboratory and analyzed as soon as possible
- vi. The air flow into the aluminized plastics bag is measured by attaching a flow meter to the upstream side of the diaphragm pump. If a micro metering valve is used instead of a limiting orifice, the valve is adjusted to the desired flow rate.
- vii. When the desired flow rate is obtained, disconnect the flow meter. Set the electric timer for the period for which the sample is to be collected.
- viii. Near the end of the sampling period, measure the flow rate again.
- ix. Identify the bag sample and record appropriate field data
- x. It is not important to know the exact volume of the sample collected. A 1.0 ml portion of the sample is taken for gas chromatographic analysis and the concentration of hydrocarbons in the sample is based on 1 ml. It is important that a constant flow rate be maintained during the sampling period or the change in flow rate during the period be measured in order to ensure a valid integrated sample.

K. Calibration:-

- i. Calibration Standards - A calibration standard should be prepared for each of the hydrocarbons to be measured. Retention time is used for identification of the hydrocarbon and either peak height or peak area is used for quantitation of the hydrocarbon.
- ii. Purge the wet test meter with nitrogen for half an hour.
- iii. Connect the plastics bag to the system and start metering nitrogen into the bag. 40-litre bags are used for the 40-litre dilution; 10-litre bags are used for the 10-litre dilutions.
- iv. Inject the predetermined amount of each hydrocarbon into the nitrogen stream through the septum in the stainless steel tee. A 50-ml, gastight syringe for volumes greater than 10 ml; a 10-ml gastight syringe for volumes less than 10 ml.
- v. To prepare standards containing less than 10 ppm of a hydrocarbon, a double dilution is required. First, a 1000 ppm standard is

prepared. Aliquots of this standard are diluted to produce standards with less than 10 ppm hydrocarbon.

Table 1: DILUTIONS FOR PREPARATION OF CALIBRATION STANDARDS

HYDROCARBON CONCENTRATION ppm	ALIQUOT OF HYDROCARBON	FINAL DILUTION VOLUME, litres
1000	40 ml pure hydrocarbon	40
10	0.4 ml pure hydrocarbon	40
1	10 ml of 1000 ppm standard mixture	10
0.1	1 ml of 1000 ppm standard mixture	10

Preparation of Cs and higher standards requires the transfer of liquids which should be calculated to their volumes as vapour.

$$V_g = \frac{(V_1 \times G \times T \times P) \times 10^3}{(M \times 273 \times 100)}$$

Where

Vg I volume in µl of vapour at T and P,

v1 = volume in cml of liquid at T and P,

D = specific gravity of liquid in g/ml at T,

M = molecular mass in g/mol,

G = gas constant, 22.4 litres/mol at STP,

I = temperature, in K, and

P = absolute pressure in kPa.

L. Calibration of Chromatograph:-

- i. Set instrument parameters at the values listed above
- ii. Flush approximately 20 ml of the standard gas through the 1-ml stainless steel sampling loop.
- iii. Inject 1 ml of standard gas into the gas chromatograph.
- iv. Record the response of the hydrogen flame ionization detector on the strip chart recorder as the hydrocarbon is eluted from the column.
- v. Record the retention time for each hydrocarbon.
- vi. Peak height is used for quantifying the C1 to C2 hydrocarbons.
- vii. Peak area is used for quantifying the C1 and C5 hydrocarbons. Peak area is defined as the product of the peak height multiplied by the peak width measured at one half the peak height, as shown in Fig.

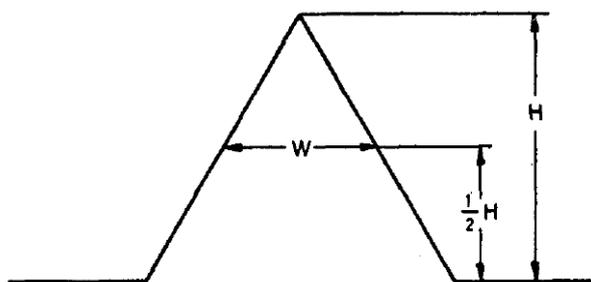


Figure 6: Measurement for Peak Area

H = peak height,

W = peak width at 1/2 peak height, and

H x W = peak area.

Recorder chart speed should be such that peak areas are measurable with a precision of 10 percent. Mechanical or electronic integrators may also be used for peak area measurements.

- viii. Calculate a response factor for each hydrocarbon at 10 ppm, 1.0 ppm, and 0.1 ppm. The response factor equals the concentration of the standard in ppm divided by the product of electrometer attenuation and detector response. The detector response for C1 to C5 hydrocarbons is peak height measured in millimeters. Peak height is the most convenient measure for quantitation of gases with short retention times when the peaks are narrow and high. The detector response for C4 and C5 hydrocarbons is peak area measured in square millimetres. Peak area should be used when peaks are broad and unsymmetrical.

$$f = C/AZ$$

f = response factor, ppm/mm or ppm/mm²;

C = concentration, ppm;

A = detector response, mm peak height or mm² peak area; and

D = electrometer attenuation.

The response of the hydrogen flame ionization detector is linear from 0.01 to 10 ppm for C1 to C5 paraffinic and olefinic atmospheric hydrocarbons.

NOTE- An error in calculation of peak height or peak area or in the calculation of instrument response factor may lead to wrong results.

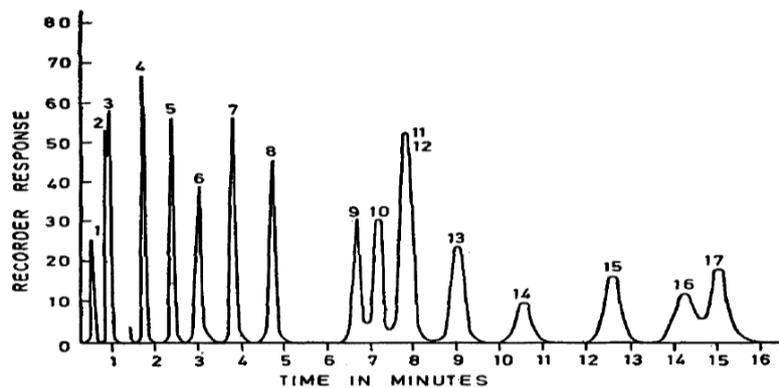
M. PROCEDURE

The analysis of an air sample without prior concentration involves the procedure given as under-

- i. Turn on the recorder.
- ii. Set the electrometer attenuation at 10 X.

- iii. Connect the sample bag to the inlet of the sampling valve on the gas chromatograph and flush 20 ml of sample through the 1-ml stainless steel sampling loop.
- iv. Inject the sample.
- v. After the elution of methane in approximately 30 s, reset the attenuation to 1 x. The sample should be eluted from the column in approximately 16 min.
- vi. Measure the peak height for C1 to C5 hydrocarbons and peak area for C4 and C5 hydrocarbons according to the method outlined in 8.2.6 and '8.2.7.
- vii. Calculate the concentration of each hydrocarbon present in the sample as per calculation.

Below Figure is a sample chromatogram showing the relative position of the C₁ to C₅ hydrocarbon peaks.



- | | | |
|--------------|-------------------------|---------------------------|
| 1. Methane | 7. Isobutane | 13. cis-Butene |
| 2. Ethane | 8. n-Butane | 14. Isopentane |
| 3. Ethylene | 9. I-Butene | 15. 1, 3-Butadiene |
| 4. Propane | 10. 2-Methylpropene | 16. n-Pentane |
| 5. Propene | 11. 2,2-Dimethylpropane | 17. 3-Methyl-1-
Butene |
| 6. Acetylene | 12. Trans-2-Butene | |

N. Calculation

The concentration of each of the hydrocarbons in the chromatogram is determined from the response factor for the hydrocarbon, f , the peak response P and the electrometer attenuation,

$$A: \text{Hydrocarbon, ppm} =$$

$$f \times P \times A$$

Where

f = calibration response factor determined in accordance with ($f = C/AZ$) for each hydrocarbon in units of ppm/mm of peak height or ppm/mm² of peak area

P = peak height in mm for C₁ to C₅ hydrocarbons or the peak area

A = in mm² for C₄ and C₅ hydrocarbons; and
electrometer attenuation setting which is generally 10x for methane and 1 x for other hydrocarbons.

8. ESTIMATION OF BUTYRIC ACID

- A. Purpose:** Purpose of this document is to provide the method of sampling & analysis to determine the Butyric Acid in Environment.
- B. Scope:** -This document describes a Adsorbent tube /thermal desorption gas chromatographic-based monitoring method for Butyric Acid in ambient air.
- C. Method Outline:**-This method intended for routine sampling and analysis of Butyric Acid. Collection of sample in the fresh adsorbent tube with help of suction pump. The sample is delivered to the laboratory where they can be identified and quantities of Butyric Acid. The gas chromatographic analysis is performed the sample help with Flame ionization is used for detection with pure oxygen supplied to the hydrogen flame to enhance its sensitivity.
- D. Responsibility:** Lab Manager and authorized chemists/ field monitoring persons.
- E. Sampling procedure:-**
- a. **Apparatus**
 - A calibrated personal sampling pump, the flow of which can be determined within $\pm 5\%$ at the recommended flow (0.50 LPM)
 - Adsorbent tube: Silica Gel Tube (520/260 mg sections; 20/40 mesh)
 - b. **Procedure:-**
 - i. Mobilized the pre-calibrated sampling equipment to save the time at the sampling site and fine tuning of the flow should be required.
 - ii. Placed the sampling tubes minimum in the breathing zone or depending on the source of emission. The pump and adsorbent tubes are placed on any solid stationary surface.
 - iii. Removed the caps of Butyric acid sampling tubes, to set up the sampling train with adsorbent tube. The manifold is attached to the inlet plug on the pump.
 - iv. Adjusted time on the pump to required sample time i.e. 4 hrs for per cycle. The sampling flow rate of 0.5 LPM is constantly maintained at all locations.
 - v. Verified regularly the sampling flow using the calibrated rotameter. Recorded the final flow rate on the air sampling data sheet. Transport the samples (and corresponding paperwork) to the lab for analysis.

- vi. Bulks submitted for analysis must be shipped in a separate mailing container from other samples.

F. Extraction & Analysis procedure of Sample:-

a. Preparation of sample:

- i. Sample tubes are opened and the front and back section of each tube.
- ii. Each section is desorbed with 1 mL of the desorbing solution (methanol)
- iii. The vials are sealed immediately and allowed to desorb for approx 30 minutes with occasional shaking.

b. Apparatus:-

- Gas chromatograph equipped with a flame ionization detector (FID)
- GC column capable of separating the analyte and an internal standard from any interference. The column used in this study was a 30 meter DB 5 Capillary column 30 mts x 0.25 mm x 0.25 µm film thickness. Other columns that can be used are a longer DB-WAX column, such as a 60 meter column, or a 60 meter DB-1 capillary column 0.32 mm I.D. with a 1.0 µm film thickness.

c. Reagents:-

- Purified GC grade nitrogen, hydrogen, and air.
- Butyric Acid, Reagent grade

d. Standard preparation:-

- At least two separate standards are prepared by diluting a known quantity of butyric acid with the desorbing solution (methanol)

e. Analysis of Sample:- Set the all condition of GC and after inject extracted sample in GC

- Gas chromatograph conditions:-

DB 5 Capillary column or equivalent 30 mts x 0.25 mm x 0.25 µm

Column flow: 1.1 ml

Inject temperature: 300°C

Mode of injection: Split

Temperature program: Column oven temperature

Rate	Tem.(°C)	Hold time (min)
-	60	1
10	300	10

MS conditions:

Ion source temperature: 260°C

Interface temperature: 290 °C

Solvent delay: 2.0 min

Scan: 40 – 600 m/z

G. Safety Precautions:-

- All handling of solvents should be done in a hood. Sampling equipment should be placed on an employee in a manner that does not interfere with work performance or safety.
- Avoid skin contact with all chemicals.
- Wear safety glasses, gloves and a lab coat at all times.

Reference:

- NIOSH manual of Analytical Methods (NMAM), for Butyric Acid.

9. ESTIMATION OF VOLATILE ORGANIC COMPOUND (VOCs TOTAL)

For estimation of total Volatile Organic Compound (VOCs) :

- A. Purpose:** Purpose of this document is to provide the method of sampling & analysis to determine the Volatile organic compounds (VOCs) concentration in air.
- B. Scope:** This method is applicable to determine the concentration of volatile organic compounds in ambient /indoor air.
- C. Responsibility:** Lab Manager and authorized chemists/ field monitoring persons
- D. Principle:** The monitoring procedure involves passing a known volume of air through a sorbent packing to collect VOCs followed by a determination by GC/MS or any other suitable detector (FID/ECD). The available sensor based onsite monitoring instruments for estimation of total VOCs usage PID based sensors.
- E. Linear range:** VOCs in the concentration range of 0.5 to 25 ppbv in air can be measured by use of sorbent tube and thermal desorption/GC-MS.
- F. Minimum Detection Limit:** Minimum 0.5 ppbv, VOCs in air can be determined.
- G. Apparatus:**
- a. Sampling:** Organic vapor sampler or any sampling apparatus with accommodations for two sampling tubes capable of independent control of sampling rate at a settable value in the range 10 to 200 ml/min.
 - b. Analysis:**
 - Gas chromatograph with Mass spectroscopy detector with TDS or any other suitable detector like FID/ECD.
 - Ultra-sonic water bath
- H. Reagents**
- (A) Sorbent Tube with activated charcoal
 - (B) Carbon Disulphide (CS₂)
 - (C) VOCs reference standards

I. Procedure

(A) Sampling: Before sampling prepare the sorbent tube by heating this for 4 hours at 60°C to release any VOC or gases absorbed in charcoal. Put the sampling instrument (organic vapor sampler) in suitable location. Attach one sorbent tube & set the air collection rate at 0.2 LPM. Collect the sample for 4 hours. Draw 48 liter of sample. Check the air sample collection rate at the end of sampling also. Seal the sorbent tube from Teflon tape. & collect the same in cold temperature.

Analysis: Open the sorbent tube and take out the charcoal in glass vial. Add 5 ml carbon disulphide & sonicate in ultrasonic water bath for 15 minutes & collect the extract in 25ml volumetric flask. Repeat the extraction for 2 more times & collect the same in same flask. Make up the volume 25ml with carbon disulphide (care should be taken to avoid evaporation loss target compound during handling, transfer and extraction) Filter this extract through 0.45µ PTFE syringe filter. Prepare the reference standard solution of different concentration. Make GC-MS or GC-FID ready & run the filtered sample in GC-FID. Run reference standard of VOCs, Blank & sample blank also in GC-FID.

(B) GC - MS condition

VF-624 MS or equivalent (60 X 0.25 X 1.4)

Inj vol: 1µL or 1ml

Inj Temp: 230 °c

MASS/M/2

: 35 to 650 °c

	Rate	temp	hold
Oven ramp:	0	50	3
	5	136	2
	6	220	2

Flow rate : 1 ml/min

Run time : 37.12 min

GC- FID condition

VF-624 MS or equivalent (30 X 0.25 X 0.25)

Inj vol : 1ml

Inj Temp: 100 °c

	Rate	temp	hold
Oven ramp:	0	40	5
	5	70	2

Flow rate : 1ml/min

Run time : 13 min

Detector temp: 220°C

H2 45 ml /min

AIR 450 ml/min

(C) Calibration: Record peak area of sample & reference standard solutions. Prepare calibration graph from standard readings.

J. Calculations

$$\text{VOCs } (\mu\text{g}/\text{m}^3) = \frac{\text{Peak area of sample X } 25}{\text{Peak area of reference X Volume of Air}}$$

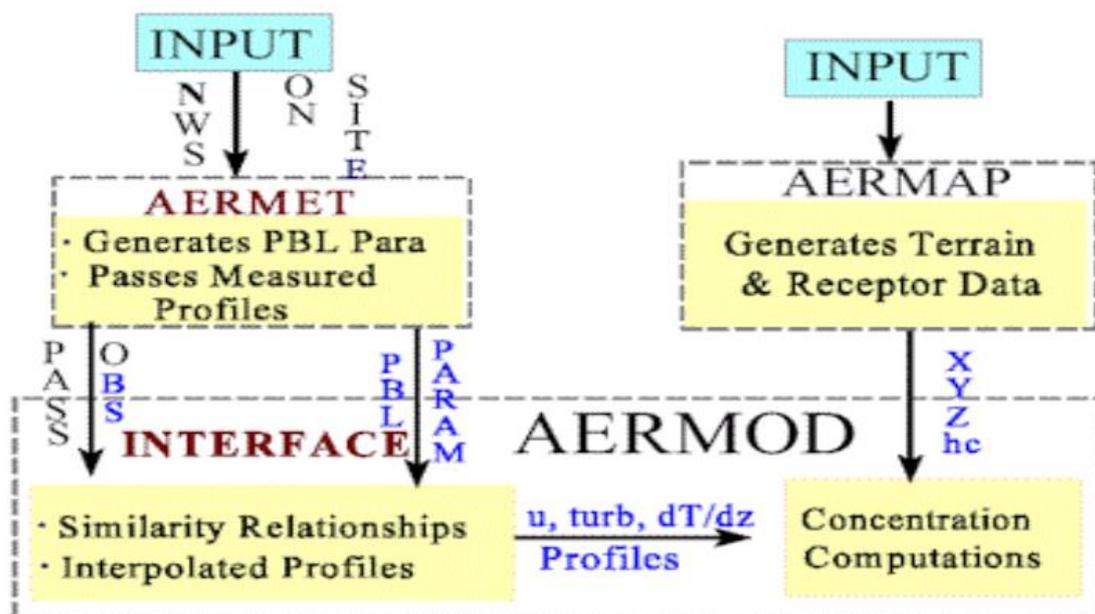
K. Safety Precautions:-

- Avoid skin contact with all chemicals.
- Wear safety glasses, gloves and a lab coat at all times
- All the extraction dilution and handling of solvent of VOC's should be done under the fume hood condition.

L. Reference: USEPA TO-17.

ODOUR MODELING AND MAPPING & DATA MANAGEMENT**SOP for odour modeling and mapping**

AERMOD is a steady-state plume model developed by a working group of AMS/EPA Regulatory Model Improvement Committee, AERMIC, (USEPA, 2005). In the stable boundary layer (SBL), it assumes the concentration distribution to be Gaussian in both, vertical and horizontal fields. In the CBL, the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function. AERMOD is applicable to rural and urban areas, flat and complex terrain, surface and elevated releases and multiple sources including, point, area and volume. AERMOD removes need for defining complex terrain regimes because all terrains are handled in a consistent and continuous manner in stably stratified conditions. AERMOD constructs vertical profiles of required meteorological variables based on measurements and extrapolations of those measurements using similarity (scaling) relationships. Vertical profiles of wind speed, wind direction, turbulence and temperature gradient are estimated using all available meteorological observations. AERMOD requires surface measurement of wind speed, wind direction and ambient temperature, solar radiations, cloud cover, relative humidity and atmospheric pressure. A full morning upper air sounding is required in order to calculate the convective mixing height throughout the day. Surface characteristics (surface roughness, Bowen ratio, and albedo) are also needed in order to construct similarity profiles of the relevant PBL parameters. Surface characteristics in the form of albedo, surface roughness and Bowen ratio and standard meteorological observations (wind speed, wind direction, temperature, and cloud cover) are input to AERMET which calculates the PBL parameters. The AERMAP, terrain pre-processor uses gridded terrain data to calculate a representative terrain-influence height (h_c) also referred to as the terrain height scale which is uniquely defined for each receptor location. Data processing flow chart is given under for AERMOD:-



Data requirement for odour dispersion modeling

In general, for the application of an atmospheric dispersion model, at least three different kinds of input data are needed: meteorological, emission and topographical.

1. Meteorological data

The acquisition and pre-processing of meteorological data is of crucial importance for atmospheric dispersion modeling purposes. In general, the meteorological data required for dispersion modeling include wind speed, wind direction, and information about the atmospheric stability conditions which can be derived from other meteorological parameters, such as humidity, temperature and wind speed profiles, as well as cloud covering or solar radiation (global or net).

2. Emission Rate

As for the simulation of dispersion of any pollutant, also in the case of the dispersion of odours, it is not sufficient to consider the pollutant (odour) concentration, but it is necessary to account for the air flow associated with the monitored odour source. In the case of odour, the parameter to be considered for dispersion modelling purposes is the Odour Emission Rate (OER), which is expressed in odour units per second (OUE s⁻¹) and is obtained as the product of the odour concentration and the air flow associated with the source (EN 13725, Capelli et al., 2013). Emission rate calculation already discussed in chapter III.

3. Topographical parameters

The spatial domain of the simulation has been setup as per actual mean sea level including all the emission sources to be studied, as well as the

receptors that are believed to be impacted by the emitted odours, and their geographical coordinates, i.e. latitude and longitude in the UTM-WGS84 (Universal Transverse of Mercator - World Geodetic System 1984).

4. Receptor Points

Two types of receptors are defined in the model, one discrete receptor points and second grid receptor. The discrete receptor points are those locations where ambient odour monitoring is carried out.

IIT Delhi has prepared Report on model and mapping, also drawn odour isopleths based upon the data generated during the project for “Development of National Guideline on odour monitoring and management in urban municipal solid waste landfill site”

CONTINUOUS ODOUR MONITORING SYSTEM & CHALLENGES**INSTALLATION OF REAL TIME CONTINUOUS MONITORING SYSTEM IN MSW LANDFILL SITE**

Odour monitoring applying portable as well as laboratory based analysis have been described in preceding sections , these techniques are useful to meet the project objectives. However there may be a need to generate data beyond only the abovementioned tools. The performance of MSW management in a landfill site can be better assessed with real time monitoring system. Being cost prohibitive hence phase wise implementation of plan for installation and operation of real time monitoring system in & around MSW landfill site to be initiated to get instantaneous data, trend analysis, inputs to modeling and mapping etc . The following three areas are cover the above aspect :

- a. Online work station for weather monitoring station
- b. Action plans for installation of online (real time continuous monitoring) monitoring system
- c. Need to monitor particulate matter (PM) from MSW landfill site. Although PM are not related to odour menace however handling of MSW in open landfill often contribute to PM load to the ambient air.

WEATHER MONITORING STATION

The online weather monitoring station consist of a monitor indicating wind related parameters on a continuous basis ex. Wind speed, wind direction on hourly basis. It also provides information for temperature, relative humidity and pressure for the MSW landfill site. The data generated on continuous basis can be transmitted to the data logger located at the central laboratory for further statistical analyses .

ONLINE ODOUR MONITORING

Both sensor and analyzers based real-time monitoring system is available in market. The analyzer based instruments have their own limitations w.r.t. parameters identified selectivity and cost viability. The odourants once shortlisted can be monitored through online sensor based instrument and data can be logged, transferred following different IT protocols to facilitate providing inputs for continuous modeling and mapping. The online monitoring system for the odourants can be coupled with E-Nose based odour monitoring system.

ONLINE MONITORING OF PARTICULATE MATTER

Monitoring of particulate matter (which PM₁₀ and PM_{2.5}) and their desired size classes is also recommended for online monitoring. There are high end instrument like beta attenuation monitor (BAM) or Tapered element oscillating microbalance (TEOM) particulate monitors suitable for continuous monitoring system.

ACTION PLAN FOR INSTALLATION OF ONLINE MONITORING SYSTEM WITH REFERENCE TO INDIAN MSW LANDFILL SITE

The objective of installation of online monitoring system is to check the performance of the MSW management system. Considering the cost and other logistics (electricity, security etc.), available at landfill site the optimization of monitoring network is required to be done during planning phase. With the support of the achieved meteorological data two stations at the upwind and downwind direction may be selected to monitor the performance and potential odour generation from MSW site. The selection of monitoring system is governed by their suitability, sustainability and acceptable sensitivity. Harsh field condition in and around MSW site also plays a role in selection.

Keeping in view of above aspects and fund availability the following plan can be formulated for Indian MSW management.

- **SHORT TERM ACTION PLAN**
- **MEDIUM TERM ACTION PLAN**
- **LONG TERM ACTION PLAN**

Action plans for Odour monitoring - SHORT TERM

It is essential to ensure the availability of sources and funds for implementing the action plan. The short term action plan includes:

- Ensuring the funds for installation of real time odour monitoring devices at least at two location (up-wind and downwind), install weather monitoring system providing the meteorological information viz. temperature, relative humidity, wind speed, wind direction and solar radiation.
- Collect and analyze online data along with meteorological information to assess for the need of increases the number of station at downwind or plan for rotation of downwind station as per prevalent wind condition.

Action plans for Odour monitoring – MEDIUM TERM

Once the odour monitoring network is established, TVOC monitor may be added to avail of continuous data too.

Action plans for Odour monitoring – LONG TERM

To achieve project objectives effectively it is important to work within the budgetary provisions. A conventional CAAQMS does not include parameters like reduced sulphur compounds, methane / non-methane hydrocarbons etc., however Installation of continuous monitoring network for impact stations of MSW landfill sites should have flexibility to upgrade to a full-fledged real time monitoring system consisting of E-Nose (Odour), TVOCs monitor, reduced sulphur sensors and ammonia sensor.

It is also proposed that at least one advanced **National Laboratory for Odour Monitoring and Control** be setup for creating a database on odour monitoring for not only for MSW landfill sites but also in other areas ex. Sewage management, odour generating activities of industries (pharmaceuticals, distilleries, tanneries etc) by conducting odour surveys and undertaking R&D work.

Challenges – General & specific

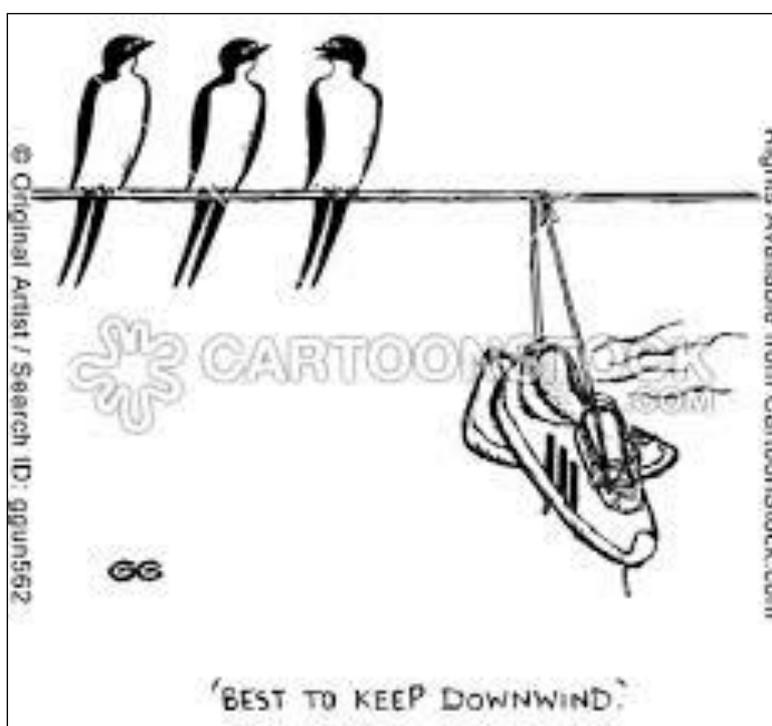
General Limitation

- i. Though MSW management rules 2016 acknowledge odour is a nuisance however there is lack of public awareness
- ii. Minimum public participation in MSW management practices
- iii. Worldwide there are no cogent (rational, convincing) standard for odour; however the issue of odour is gaining thrust and challenges particularly in a country like India where the urban development has vastly ignored designated land-uses.
- iv. Data base on odour is insignificant
- v. Need to address decentralized MSW treatment facilities
- vi. As odour is a perception, the parameter is not yet included in laboratory accreditation / certification process either nationally or internationally.
- vii. The experts in the field of monitoring & analysis have varied views for monitoring & management of odour. Either general limitation for odour measurement by internally practiced monitoring methods may inculcate erroneous odour value due to:-
 - a) Perceived self-interest bias
 - b) Odour adaption
 - c) Odour fatigue
 - d) Hours of exposure

- e) Additional limitations include: - The difficulty for odour investigators to witness odour incidents (especially peaks) & changing dispersion conditions. Emissions from elevated sources (stacks, chimneys etc) which may travel further than anticipated distance and may not reach ground level within the study area.

Specific Limitation

- i. Old existing MSW landfill site (> 20 years) which are still operating do not have design details to plan proper study and management of odour.
- ii. Unavailability of required laboratory infrastructure and skilled manpower to undertake studies
- iii. Overlapping of odour sources , for example in Ghazipur MSW landfill site other than the MSW at the landfill site , there several odour generating activities operating at the periphery of the landfill. (other than MSW activity) which hinder conclusive investigation on sources of odour



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Part 2

CASE STUDY – PILOT STUDY ON ODOUR MONITORING AT MUNICIPAL SOLID WASTE (MSW) LANDFILL SITE, GHAZIPUR, EAST DELHI IN YEAR 2016



Report:

CASE STUDY – PILOT STUDY ON ODOUR MONITORING AT MUNICIPAL SOLID WASTE (MSW) LANDFILL SITE, GHAZIPUR, EAST DELHI IN YEAR 2016

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(pre-monsoon monsoon)

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GRAPHICAL REPRESENTATION OF RESULTS

(post monsoon)

- A. Odour Concentration or Level in Ambient Air post monsoon:-
- B. Odour Concentration or Level at source Emission post monsoon:-
- C. Concentration of odourous compound at source:- VOC and Methane post monsoon
- D. Concentration of odourous compound at source:- Hydrogen Sulphide & Ammonia post monsoon
- E. Concentration of odourous compound in Ambient Air:- VOC & Methane post monsoon
- F. Concentration of odourous compound in Ambient Air:- Hydrogen Sulphide & Ammonia post monsoon

1. ODOUR is a complex air pollutant – Solid Waste Management Rules 2016

ODOUR is the most complex of all the air pollutants, human response to ODOUR is highly subjective. Some commonly familiar odorous sources are:

- Urban wastes - MSW (biodegradable matter) & sewage
- Industry bases - Pulp & paper, tanneries, pharmaceuticals, pesticides distilleries, beverages, paints, organic chemicals etc

Odour is acknowledged as a public nuisance and is highlighted under various sections under Solid Waste Management Rules 2016 (previous version MSW Mgmt Rules 2000) as given below :

A. Definitions

- i. Subrule 40. "SANITARY LAND FILLING" means the final and safe disposal of residual solid waste and inert wastes on land in a facility designed with protective measures against pollution of ground water, surface water and fugitive air dust, wind-blown litter, bad odour, fire hazard, animal menace, bird menace, pests or rodents, greenhouse gas emissions, persistent organic pollutants slope instability and erosion;
- ii. Subrule 52. "TRANSPORTATION" means conveyance of solid waste, either treated, partly treated or untreated from a location to another location in an environmentally sound manner through specially designed and covered transport system so as to prevent the foul odour, littering and unsightly conditions;

B. Duties and responsibilities of local authorities and VILLAGE PANCHAYATS OF CENSUS TOWNS AND URBAN AGGLOMERATIONS. subrule (t) - involve communities in waste management and promotion of home composting, bio-gas generation, de-centralised processing of waste at community level subject to control of odour and maintenance of hygienic conditions around the facility;

C. SCHEDULE I - (F) Criteria for ambient air quality monitoring.-
Sub section (i) Landfill gas control system including gas collection system shall be installed at landfill site to minimize odour, prevent off-site migration of gases, to protect vegetation planted on the rehabilitated landfill surface. For enhancing landfill gas recovery, use of geo membranes in cover systems along with gas collection wells should be considered.

2. Common biodegradable waste disposal facility - MSW landfills

The common biodegradable waste disposal facility for municipal solid wastes (MSW) in urban areas is the landfill. Landfill is a large area of land specifically designed and built to receive wastes also referred to as municipal solid wastes (MSW). Landfill is the most common form of waste disposal facility hence an important component of an integrated waste management system. Open dumps sites in general are uncovered and unlined sites allowing leachate (liquid formed by decomposing waste) to soak into the soil and contaminate groundwater, landfills also attract rodents, insects, and birds (vultures) and emit unpleasant odours due to decaying organic matter, may cause fire hazards due to combustion of landfill gas (high on methane content).



Figure: A view from top of MSW Ghazipur landfill site

The landfill site in urban areas mostly receive waste that may be a mixture of household wastes, non-hazardous solid waste from industrial, commercial and institutional establishments (excluding bio-medical waste) and also whole sale vegetable & fruit market wastes (*mandis*), agricultural wastes and street sweepings.

The gaseous compounds emitted from landfills have various impacts on their surroundings depending on several factors which include spatial & temporal influences. Data on temperature, wind speed, wind direction, relative humidity and rain fall are important meteorological parameters that define the prevailing climatic condition of a region which influence the physical, chemical and biological activities occurring within the dump-heap and on the outer surface of the dump landfill. Therefore, it is important to collect and compile relevant data which on the landfill site for a better assessment of odour dispersion in the region.

3. Health concerns of MSW landfills

As mentioned earlier, open dumps sites are, in general are uncovered and attract rodents and insects, and birds (vultures) and emit foul odours due to the decomposition of the



Figure: Identification of Odour Hotspots using Field Olfactometer in MSW Ghazipur landfill site, Delhi

biodegradable content of MSW. The decaying organic matter may create fire hazards due to generation of landfill gas (combustible). Though LFG may cause temporary discomfort, but it is unlikely to cause permanent health disorders, however at high concentrations it can cause eye irritation, headaches, nausea, and soreness of the nose and throat. People with respiratory ailments such as asthma may be sensitive to these effects. However, the above temporary discomfort is reversed as soon as the gases are reduced or minimised or eliminated.

4. MSW landfill - Choice for 1st pilot study on Odour monitoring

Though there are several activities contributing to significant odour, however CPCB identified MSW landfill for a pilot study on conduct odour monitoring, as the activities pertaining to MSW and its management (ex. composting) is familiar to both – the public and the urban local bodies (ULBs). The familiar offensive ODOUR from MSW dumpsites is caused due to the anaerobic decay of wet organic (biodegradable content) matter such as wastes from slaughter house , poultry market , fish market, dung, vegetable & fruits wastes besides kitchen households - warm temperatures accelerate anaerobic decay which enhances production of foul odour.

The present study is an R&D initiative by CPCB, with main focus to sensitise public (mass awareness) on odour nuisance and develop monitoring tools adaptable to Indian conditions and also develop Guidelines for Odour Monitoring & Management for MSW landfill site. An important conclusion of this project study was that regional influences on odour is significant , hence MSW landfill site is unique due to the temporal & spatial



attributes hence preparation of an action plan for odour monitoring & its abatement need to be studied on a case – to – case basis.

5. MSW Ghazipur , Delhi – choice for pilot study on Odour monitoring in MSW landfill

As mentioned earlier there are several activities generating odours for example :

- Urban wastes - MSW (biodegradable matter) & sewage
- Industry bases - Pulp & paper , tanneries, pharmaceuticals, pesticides distilleries , beverages , paints, organic chemicals etc

The MSW landfill at Ghazipur located in east Delhi was identified for the pilot study on odour monitoring for several reasons mainly due to its unique location

features – it is not only the oldest dumpsite in Delhi but has several odourous activities at the periphery such as fish market , chicken market, slaughter house) and the Ghazipur dairy all emit significant odour besides closure procedure of the MSW landfill has been initiated. Though there may be constraints , however the pilot study however provides a base to guide other institutions proposing to undertake odour monitoring studies in MSW landfills of other activities utilising the experience being shared in this report w.r.t. field work , sampling & monitoring plans, laboratory skills requirement , dispersion modelling features & literatures survey that was done.

6. Salient features MSW landfill site - GHAZIPUR, EAST DELHI

The earlier section highlighted the reasons for selecting MSW landfill for conducting odour monitoring as a pilot study. The MSW landfill at Ghazipur located in east Delhi was chosen as it is perhaps the oldest landfill of all the metro cities in the country. The salient features are given below:

- i. Urban Local Body (ULB)
The East Delhi Municipal Corporation (EDMC) supervises the activities of the MSW Ghazipur landfill site
- ii. Oldest landfill in Delhi
Of the four MSW landfills, MSW Ghazipur is the oldest landfill.

Table: MSW Ghazipur is the OLDEST landfill sites in Delhi

MSW Landfills in Delhi	Bhalswa	Ghazipur	Okhla	Bawana
Dumping w.e.f.	1993	1984	1994	2011

- iii. Location of MSW landfill
The Ghazipur disposal landfill site is located in east of Delhi at the Delhi - Uttar Pradesh (UP) border.

Table: Details of Ghazipur landfill site

Particulars	Details
Latitude	28°37' 22.4" N
Longitude	77°19' 25.7" E
Area	29.62 Ha
Average Side Slope	60°-70°.
District , State	Ghazipur, Delhi

- iv. Area of MSW landfill site
The Ghazipur disposal landfill site is located in Delhi spread over an area of 29.62 Ha.

MSW Landfills in Delhi / Area	Bhalswa	Ghazipur	Okhla	Bawana
Area (ha)	26.22	29.62	22.89	100 ha

v. MSW collection jurisdiction

It receives MSW from Shahdara (North and South) zones in addition to NDMC, Cantonment Board, City and Sadar Paharganj zone. Presently MSW being collected from TWO ZONES within 100 sqkm – North Zone - Shahdara & South Zone – Shahdara

vi. MSW Waste collection & transportation features

a. About 9.75 lakh households covered (as per 2011 census)

b. Waste collection infrastructure :

i. Auto-trippers for door to door collection – 302

ii. Collection bins – 300

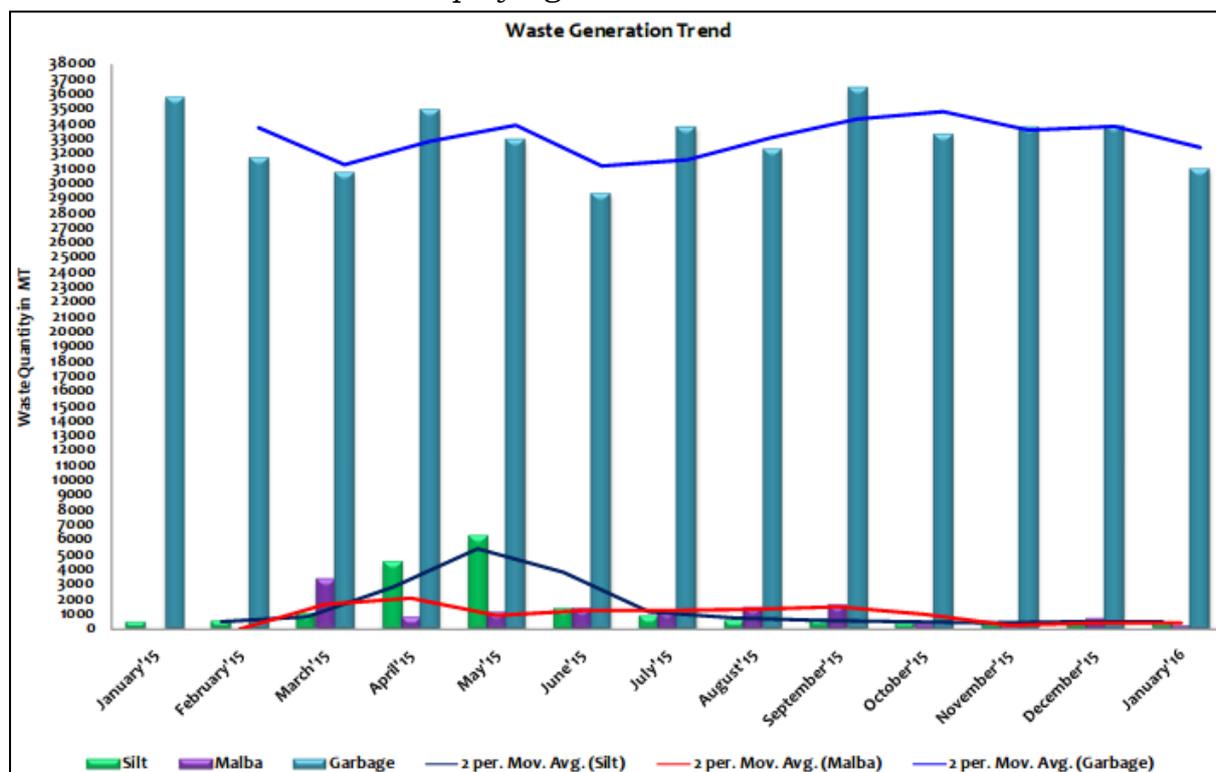
iii. Small size (SS) bins : 600

iv. Transport (garbage) trucks (hired & dept) 3 to 5 trips per day : 130

c. The Ghazipur site receives per day approximately 2000- 2200 metric tons of waste through 550 trucks.

vii. Quantum of MSW (malba) handled by EDMC

The MSW Ghazipur site receives per day approximately 2000- 2200 metric tons of waste deploying 550 trucks.



viii. Other odour generating activities at the MSW landfill

The landfill site emits odour from four-different activity/sources - Refuse Derived Fuel (RDF), landfill gas, active dump areas, leachate tank and old dump area which are located at varying heights from the ground level.

Besides the above , odour is also contributed due to the presence of other odour emitting sources in the nearby regions / at periphery of the MSW such as fish market (in north direction), chicken (poultry) market (in north east), Slaughter house (in east direction) and Ghazipur dairy (in northwest direction).

The Ghazipur dump site has two pilot wastes to energy projects - exploration of landfill gases (LFG) by m/s GAIL and refuse derived fuel (RDF) plant for combustion of biodegradable MSW for generation of 5 MW of electricity by m/s IL&FS.

viii. MSW landfill has exceeded its holding capacity

The MSW landfill site spread over 29.62 ha began receiving wastes w.e.f year 1984, the minimum and maximum height of dump heap is reported to be 26 m and 30.5 m respectively. Ghazipur landfill site has received almost 95% of its waste holding capacity and likely to exceed its limit by the mid of the year of 2017 , though there are on-going measures taken to decrease further waste loading at the site.

The MSW landfill started with 20 years shelf life – the site has exceeded its holding capacity due to high population density in the surrounding regions thereby increase in quantum of waste generation & disposal in the region. The closure procedure of the landfill has begun, the side facing NH-24 has been provided with a green cover.

Table: Features of MSW landfill Ghazipur, Delhi

Particulars	Details
maximum height of Heap	30.5 meters above ground level
minimum height of Heap	26 meters above ground level
Predominant wind	West direction

Seasons covered for odour monitoring

The MSW landfill at Ghazipur located in east Delhi was identified for the pilot study on odour monitoring, the TWO seasons identified were:

- a. Pre Monsoon Season Monitoring (field work done between June 13 to 22 , 2016)
- b. Post Monsoon Season Monitoring (field work done between September 27 to October 15, 2016)

Odourous compounds (odourants) surveyed

The odourous compounds (odourants) surveyed at MSW Ghazipur landfill site is given in Table below.

Table: Odourants surveyed in MSW Ghazipur

Odourant (compound name)	Description of Offensive Odour
1. Ammonia	Pungent, Irritating
2. Hydrogen Sulphide	Rotten eggs
3. Butyric Acid	Rancid butter
4. Ethyl Mercaptan	Decayed Cabbage
5. Methyl Mercaptan	Rotten Cabbage
6. Dimethyl sulphide	Decayed Cabbage
7. Methane	Odourless
8. VOCs (total)	Odour influenced by the dominating compound

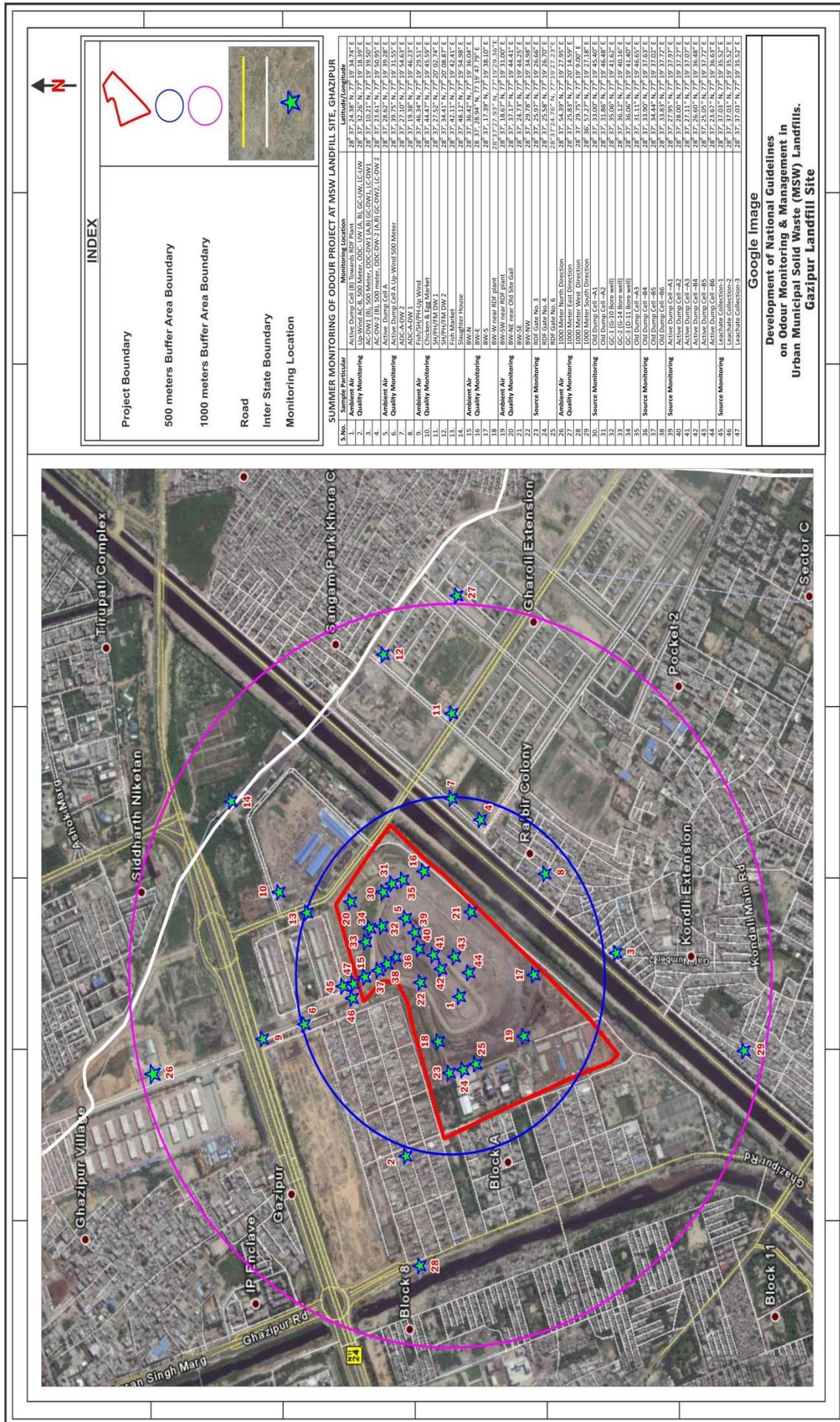
Odour Monitoring network at MSW Ghazipur, Delhi (site map)

Refer Google view of GHAZIPUR LANDFILL SITE, DELHI indicating odour sampling stations

Table: Overview of Odour sampling locations at MSW Ghazipur Delhi

Type of stations	Number of stations
Odour at Source	21
Odour in ambient Air	26
TOTAL	47

Figure : Google view of MSW GHAZIPUR LANDFILL SITE, DELHI indicating odour sampling stations



Locations of odour monitoring in ambient air at Ghazipur MSW landfill

Table : Odour sampling locations (AMBIENT AIR) at MSW Ghazipur Delhi

S.no.	Location Name	Latitude /Longitude
1.	Active Dump Cell (B) Towards RDF Plant (Amb.Air)	28° 37', 24.38" N 077° 19' 34.74" E MSL-249 M
2.	Up-Wind AC-B/500 Meter/ODC- UW (A, B)/GC-UW/LC-UW (Nr. Shive Dharam Kata/Nr. Ghazipur Dairy Farm) (Amb.Air)	28° 37', 32.26" N 077° 19' 18.39" E MSL-249 M
3.	AC-DW1 (B)/500 Meter/ODC-DW1 (A,B)/GC-DW1/LC-DW1 (Nr. Ambedkar Bhawan, Rajveer Colony) (Amb.Air)	28° 37', 10.21" N 077° 19' 39.50" E MSL-240 M
4.	AC-DW-2 (B)/500 meter/ODC-DW-2 (A,B)/GC-DW2/LC-DW 2 (Nr. Police Station, Mulla Colony)(Amb.Air)	28° 37', 23.61" N 077° 19' 50.95" E MSL-240 M
5.	Active Dump Cell A (Amb.Air)	28° 37', 28.62" N 077° 19' 39.28" E MSL-254 M
6.	Active Dump Cell A Up-Wind/500 Meter (Nr. Metro Station/Ghazipur Dairy Farm) (Amb.Air)	28° 37', 39.75" N 077° 19' 31.55" E MSL-209
7.	ADC-A-DW 2 (Nr. Police Thana) (Amb.Air)	28° 37', 27.10" N 077° 19' 54.63" E MSL-200
8.	ADC-A-DW 1 (Mulla Colony) (Amb.Air)	28° 37', 19.38" N 077° 19' 46.23" E MSL-225
9.	Fish/SH/PH-Up Wind (Entry Gate EDMC) (Amb.Air)	28° 37', 46.34" N 077° 19' 29.51" E MSL-175
10.	Chicken & Egg Market (Main Gate) (Amb.Air)	28° 37', 44.47" N 077° 19' 45.59" E MSL-185
11.	SH/PH/FM DW 1 (Back Side Police Thana) (Amb.Air)	28° 37', 27.52" N 077° 20' 02.74" E MSL-181
12.	SH/PH/FM DW 2 (Nr.Ajay Paper Cop.,Plot No. 375, Pocket-C, Nr. Khoda Colony) (Amb.Air)	28° 37', 34.41" N 077° 20' 08.87" E MSL-182
13.	Fish Market (Main Gate) (Amb.Air)	28° 37', 42.11" N 077° 19' 42.41" E MSL-190
14.	Slaughter House (Boiler Room/Utility) (Amb.Air)	28° 37', 48.12" N

S.no.	Location Name	Latitude /Longitude
		077° 19' 54.98" E MSL-198
15.	BW-N (Nr. LC/GC) (Amb.Air)	28° 37', 36.42" N 077° 19' 36.04" E MSL-191
16.	BW-E (Amb.Air)	28° 37', 28.94" N 077° 19' 47.79" E MSL-192
17.	BW-S (Amb.Air)	28° 37', 17.39" N 077° 19' 38.10" E MSL-194
18.	BW-W near RDF plant (Amb.Air)	28° 37', 24.76" N 077° 19' 27.23" E MSL-192
19.	BW-SW near RDF plant (Amb.Air)	28° 37', 18.67" N 077° 19' 31.00" E MSL-211
20.	BW-NE near Old Site Gail (Amb.Air)	28° 37', 37.17" N 077° 19' 44.41" E MSL-206
21.	BW-SE (Amb.Air)	28° 37', 24.73" N 077° 19' 44.25" E MSL-203
22.	BW-NW (Amb.Air)	28° 37', 29.78" N 077° 19' 34.98" E MSL-207
23.	1000 Meter North Direction (Amb.Air)	28° 37', 54.39" N 077° 19' 27.95" E MSL-210 M
24.	1000 Meter East Direction (Amb.Air)	28° 37', 25.83" N 077° 20' 14.59" E MSL-201 m
25.	1000 Meter West Direction (Amb.Air)	28° 37' 29.75" N 77° 19' 9.00" E MSL-242 M
26.	1000 Meter South Direction (Amb.Air)	28° 36', 57.27" N 077° 19' 27.18" E MSL-206 M

Locations of odour monitoring at source at Ghazipur MSW landfill

Table: Odour sampling locations (SOURCE) at MSW Ghazipur Delhi

Sl.	Location Name – SOURCE	Location Name – Source
1.	RDF Gate No. 3 (Source)	28° 37', 25.97" N 077° 19' 26.66" E MSL-210 M
2.	RDF Gate No. 4 (Source)	28° 37', 25.58" N 077° 19' 26.70" E MSL-210 M
3.	RDF Gate No. 2 (Source)	28° 37', 27.93" N 077° 19' 29.36" E MSL-210 M
4.	GC-1 (G-10 Bore well) (Source)	28° 37', 35.06" N 077° 19' 41.62" E MSL-224 M
5.	GC-2 (G-14 Bore well) (Source)	28° 37', 36.12" N 077° 19' 40.16" E MSL-230 M
6.	GC-3 (D-11 Bore well) (Source)	28° 37', 36.06" N 077° 19' 41.40" E MSL-210 M
7.	Old Dump Cell –A1 (Source)	28° 37', 33.00" N 077° 19' 45.40" E MSL-224 M
8.	Old Dump Cell –A2 (Source)	28° 37', 31.86" N 077° 19' 46.48" E MSL-216 M
9.	Old Dump Cell –A3 (Source)	28° 37', 31.11" N 077° 19' 46.65" E MSL-224 M
10.	Old Dump Cell –B4 (Source)	28° 37', 33.90" N 077° 19' 37.63" E MSL-206 M
11.	Old Dump Cell –B5 (Source)	28° 37', 34.44" N 077° 19' 37.02" E MSL-203 M
12.	Old Dump Cell –B6 (Source)	28° 37', 33.83" N 077° 19' 37.72" E MSL-207 M
13.	Active Dump Cell –A1 (Source)	28° 37', 27.95" N 077° 19' 37.97" E MSL-245 M

14.	Active Dump Cell -A2 (Source)	28° 37', 28.00" N 077° 19' 37.27" E MSL-252 M
15.	Active Dump Cell -A3 (Source)	28° 37', 27.11" N 077° 19' 37.07" E MSL-251 M
16.	Active Dump Cell -B4 (Source)	28° 37', 26.60" N 077° 19' 36.48" E MSL-255 M
17.	Active Dump Cell -B5 (Source)	28° 37', 25.05" N 077° 19' 37.72" E MSL-253 M
18.	Active Dump Cell -B6 (Source)	28° 37', 23.67" N 077° 19' 36.63" E MSL-252 M
19.	Leachate Collection-1 (Source)	28° 37', 37.03" N 077° 19' 35.52" E MSL-202 M
20.	Leachate Collection-2 (Source)	28° 37', 37.03" N 077° 19' 35.52" E MSL-202 M
21.	Leachate Collection-3 (Source)	28° 37', 37.03" N 077° 19' 35.52" E MSL-202 M

Odour Detection Threshold of odourants

As per definition the **ODOUR DETECTION THRESHOLD** - is the lowest odourant concentration necessary for detection by a certain percentage of the population, normally 50%. This concentration is defined as one ODOUR UNIT.

The Table below provides information on the Odour Detection Threshold for individual compounds responsible for odour. It is evident that the very low concentration shown against H₂S, ethyl mercaptans, methyl mercaptans and dimethyl sulphide can produce detectable odour independently.

However individually, ammonia concentration should be in mg/m³ level to produce one odour unit. In case of MSW or any other odour generating sources the 'combined impact' could have lower than the threshold



concentration indicated in the Table below. The limitation of instrumental methods adopted / available may not correctly report the concentration of individual parameters with analytical confidence; it is generally reported as below detection limit (BDL)). However even this level (i.e. BDL) of concentration does not rule out the presence of odour in ambient air.

Table: Odour Detection Threshold of odourants & corresponding ambient concentration

Odourant (Compound name & Formula)	Molecular Weight	Odour Detection Threshold in ppm (v/v)	Odour Detection Threshold in $\mu\text{g}/\text{m}^3$
Ammonia NH ₃	17	17	11820
Hydrogen Sulphide H ₂ S	34	0.0005	0.70
Butyric Acid CH ₃ CH ₂ CH ₂ CO OH	88	0.12	432
Ethyl Mercaptan C ₂ H ₅ SH	62	0.0003	0.76
Methyl Mercaptan CH ₃ SH	48	0.0005	0.98
Dimethyl sulphide (CH ₃) ₂ S	62	0.001	2.6

Equipment for monitoring odourants

Odour and odourous compound monitoring was conducted for two seasons wherein the instruments and methodology used and sampling locations identified were the same for both seasons.

**Table: Equipment for odour & odourous compound Monitoring
(Ambient & source)**

Equipment	Features
Field Olfactometer (SM110C)	Odour measurements apparatus used for accurately quantification of ambient /source odour strength in OU/M ³ .
Weather monitoring station	Monitoring & data collection for various weather parameters i.e. wind speed, wind direction, temperature, humidity, rain fall
Handy Sampler with impingers (handy sampler of any good company may be used)	Device for collection of source emission or ambient air samples for analysis of Methyl Mercaptan, Ethyl Mercaptan, Dimethyl Sulphide, Ammonia, Hydrogen Sulphide, Butyric Acid, TVOC and its composition
Tedlar Bags	Polyvinyl fluoride bag for collection of source emission or ambient air samples with use of low flow pump for analysis of methane
Static Hood (Aluminium made Teflon coated hood)	Structure for collection of area source emission gases

Sampling Methodology for Odourous compounds

Table : Sampling methodology Odourous compounds - Ambient air & Source

Technical detail of the instrument along with operation including methodology is discussed in under report on Sampling & Monitoring Protocols.

Odourous compounds	Sampling Methodology for source and ambient (Name of absorbent/Solution)	Reference
Total VOCs	Sampling by multibed sorbent tubes (Tenax + Carbopack); PID VOC Analyser	EPA TO- 17
Hydrogen Sulphide	Absorbing Solution for Hydrogen Sulphide: Cadmium sulphate + sodium hydroxide.	IS: 5182 (Part VII) - 1973 (Reaff:2009)
Dimethyl Sulphide, Methyl Mercaptan, Ethyl Mercaptan	Dimethyl Sulphide, Methyl Mercaptan, Ethyl Mercaptan: Mercuric acetate + Glacial acetic acid buffer	NIOSH manual of Analytical Methods (NMAM), Fourth Edition
Butyric Acid	Absorbing Media for Butyric Acid: Silica Gel Tube (520/260 mg sections; 20/40 mesh)	Gas Chromatography; GC/FID (NIOSH Manual)
Methane	Collection of sample in Tedlar Bags	Method IS: 5182 (Part XVII) – 1979
Ammonia	Absorbing Solution for Ammonia : 0.1 N Sulphuric Acid Solution	APHA 3 rd edn: 1998,

Meteorological Data - Wind speed & wind direction

Table : Wind speed - Pre monsoon & Post monsoon at MSW Ghazipur

PARTICULARS	PRE-MONSOON Weather monitoring station established at site On 23rd May 2016.		POST MONSOON Weather monitoring station established at site on 26th September 2016.	
	Max.	Min.	Max.	Min.
Wind Speed(m/sec)*	7.2	0.1	3.6	0

Table: Windrose data - Pre monsoon & Post monsoon at MSW Ghazipur

PARTICULARS	PRE-MONSOON	POST MONSOON
	Weather monitoring station established at site on 23 rd May 2016.	Weather monitoring station established at site on 26 th Sept. 2016.
Wind Direction (windrose data)	<u>Pre monsoon season :</u> <ul style="list-style-type: none"> The dominant wind direction Westwards followed by Northwest direction ; Wind speed 51 % of the times in range of 1-2 m/s *Prominent Wind Speed- 1.28 m/s 	
	<u>Post monsoon season :</u> <ul style="list-style-type: none"> The dominant wind direction Westwards followed by West-Northwest direction. ; wind 35.8% of the times were calm, 30.7 % of the times blowing with wind speed in range of 0.5-1.0 m/s, 28% of the times in range of 1-2 m/s ; *Prominent Wind Speed- 0.59 m/s 	

Meteorological Data - temperature, humidity & rainfall

PARTICULARS	PRE-MONSOON Weather monitoring station established at site on 23 rd May 2016.		POST MONSOON Weather monitoring station established at site on 26 th September 2016.	
	Max.	Min.	Max.	Min.
Temperature (°C)	43.1	28.0	37.6	24.2
Relative Humidity (%)	88.5	29.2	87	20.1
Rainfall (in mm)	8.0	0	26	0

Characterization of MSW

Table: Characterization of MSW of Ghazipur, Delhi

Sl.	PARAMETERS	MSW analyses on dd/mm/yy	
		07/01/2016	08/01/2016
1.	Moisture Content, % by mass	28.1	32.9
2.	pH (30 mg/75 ml)	7.9	8.7
3.	PHYSICAL COMPOSITION (DRY BASIS %)		
	i. Food Waste	5.4	0.3
	ii. Garden & Park waste, non food Organic biodegradable material.	20.9	41.5
	iii. Straw/Hay /Stalk / Wooden Pieces	0.5	0.3
	iv. Paper / Card Board	1.7	1.3
	v. Textiles/ Cloth	6.6	3.2
	vi. Rubber	Nil	Nil
	vii. Plastics	8.3	3.1
	viii. Metals	0.3	Nil
	ix. Glass	0.5	Nil
	x. Stones / Bricks/ Concrete / Ceramic, Sand/Soil/Earth	31.0	13.0
	xi. Leather	1.1	0.7
	xii. Poultry wastes (feather, skin etc)	23.8	37.0
4.	PROXIMATE ANALYSIS		
	i. Volatile matter (loss at 600°C), % by mass	17.89	15.49
	ii. Ash content (850°C), % by mass	79.51	81.49
	iii. Organic Matter, % by mass	18.06	15.54
	iv. Phosphorus (as P), % by	3.6	3.4
	v. Potassium (as K), % by mass	0.33	0.30
	vi. Chromium (as Cr), mg/kg	68	108
	vii. Lead (as Pb), mg/kg	50	207
	viii. Nitrogen (as N), % by mass	0.09	0.15
	ix. Gross Calorific Value, GCV, Cal/gm	780	740
	x. Mercury (as Hg), mg/kg	BDL*	BDL*

Figure (below): Windrose diagram for summer period (1-30 June 2016)

Windrose data (premonsoon & post monsoon)

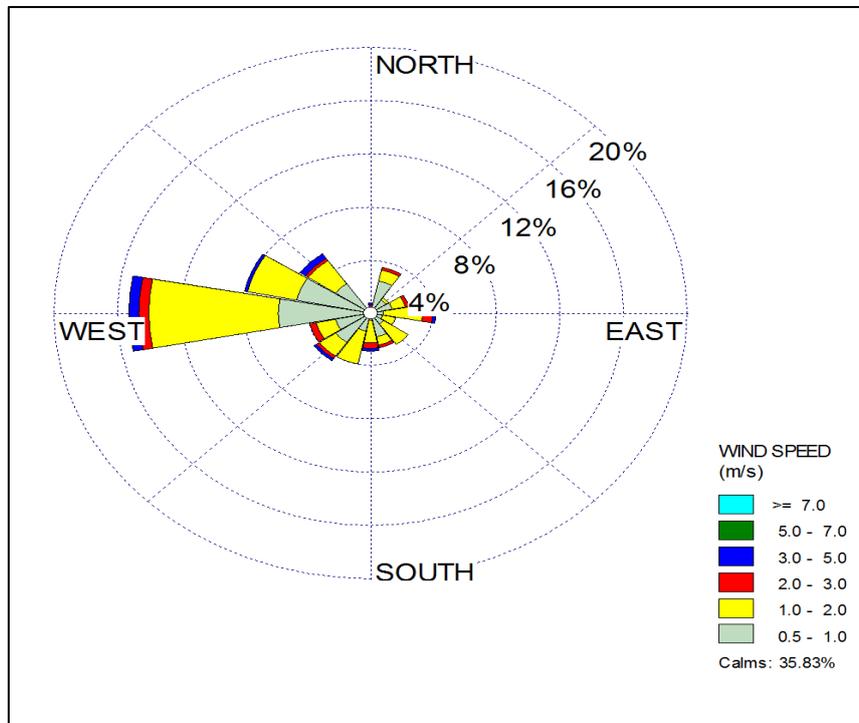
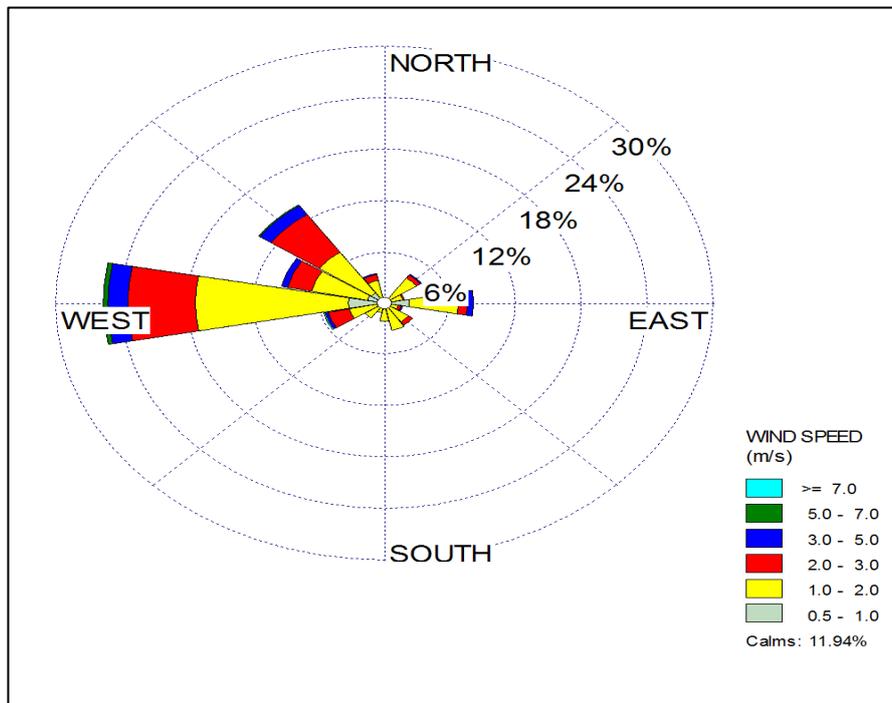


Figure: Windrose diagram for (a) Fig (above) for summer period (1-30 June 2016) (b) Fig (below) post-monsoon period (26 Sept.- 15th Oct., 2016)

Odour analyses at MSW Ghazipur landfill - Ambient air

Key observations:

- i. There is significant odour around the MSW landfill.
- ii. The post monsoon odour data higher than pre-monsoon in majority of the cases indicating that the embedded summer heat within MSW heap , the moisture due to rains and the sunshine (heat) post monsoon have accelerated the decomposition process of the organic waste hence the increase in odour observed post-monsoon.
- iii. It was highlighted that besides activities at MSW landfill odour is also being emitted from on-going activities at its periphery namely fish market (in North direction), chicken (poultry) market (in North east), Slaughter house (in east direction) and Ghazipur dairy (in Northwest direction). The data below indicates that following activities are odourous - Chicken & Egg Market, Fish Market & RDF activity indicate higher levels.

Odourous activity (ambient air)	Odour Unit (olfactometer data) OU_E/M^3 (Field olfactometer)	
	Pre monsoon	Post-monsoon
Chicken & Egg Market (Main Gate) (Amb.Air)	1318	1412
Fish Market (Main Gate) (Amb.Air)	660	620
BW-W near RDF plant (Amb.Air)	555	741
BW-SW near RDF plant (Amb.Air)	501	524
Slaughter House (Boiler Room/Utility)(Amb.Air)	199	173

- iv. The active dump cells contribute maximum odour to ambient air

ACTIVE DUMP site (ambient air)	Odour Unit (olfactometer data) OU_E/M^3 (Field olfactometer)	
	Pre monsoon	Post-monsoon
Active Dump Cell A (Amb.Air)	3273	3531
Active Dump Cell (B) Towards RDF Plant (Amb.Air)	2766	3133

- v. Upwind impact stations : Impact of odour at the upwind locations (surrounding the MSW landfill) : The post monsoon data is higher than pre-monsoon in majority of the cases indicating significant odour

UPWIND STATIONS (ambient air)	Odour Unit (olfactometer data) OU_E/M^3 (Field olfactometer)	
	Pre monsoon	Post-monsoon
Up-Wind AC-B/500 Meter/ODC- UW (A, B)/GC-UW/LC-UW (Nr. Shive Dharam Kata/Nr. Ghazipur Dairy Farm) (Amb.Air)	238	325
Active Dump Cell A Up-Wind/500 Meter (Nr. Metro Station/Ghazipur Dairy Farm) (Amb.Air)	60	96
Fish/SH/PH-Up Wind (Entry Gate EDMC) (Amb.Air)	79	77

vi. Downwind impact stations : Impact of odour at the downwind locations (surrounding the MSW landfill) - The post monsoon data is higher than pre-monsoon in majority of the cases

DOWN-WIND STATIONS (Ambient air)	Odour Unit (olfactometer data) OU_E/M^3 (Field olfactometer)	
	Pre monsoon	Post-monsoon
i. AC-DW1 (B)/500 Meter/ODC-DW1 (A,B)/GC-DW1/LC-DW1 (Nr. Ambedkar Bhawan, Rajveer Colony) (Amb.Air)	239	312
ii. AC-DW-2 (B)/500 meter/ODC-DW-2 (A,B)/GC-DW2/LC-DW 2 (Nr. Police Station, Mulla Colony)(Amb.Air)	275	367
iii. ADC-A-DW 2 (Nr. Police Thana) (Amb.Air)	229	301
iv. ADC-A-DW 1 (Mulla Colony) (Amb.Air)	281	382
v. SH/PH/FM DW 1 (Back Side Police Thana)	71	128
vi. SH/PH/FM DW 2 (Nr.Ajay Paper Cop.,Plot No. 375, Pocket-C, Nr. Khoda Colony)	59	50

vii. Impact of odour at the upwind & downwind locations (surrounding the MSW landfill) is perceptible and influenced by distance from the source, wind direction & period of the day (time). Odour at upwind is less than downwind

Odour monitoring locations	Range Odour Unit (olfactometer data) OUE/M^3		Remarks
	Pre monsoon	Post monsoon	
For upwind locations	60 - 238	77-235	Odour concentrations influenced by distance from the source, wind direction & period of the day (time).
Six downwind locations	59-289	50- 382	

- viii. Odour at 500 m and 1000m impact locations: With increase in distances the odour concentration decreases (refer two Tables below) for odour impacts stations at 1000m and 500m respectively.

IMPACT STATIONS 500 m DOWN-WIND STATIONS (Ambient air)	Odour Unit (olfactometer data) OU_E/M³ (Field olfactometer)	
	Pre monsoon	Post-monsoon
i. AC-DW1 (B)/500 Meter/ODC-DW1 (A,B)/GC-DW1/LC-DW1 (Nr. Ambedkar Bhawan, Rajveer Colony) (Amb.Air)	239	312
ii. AC-DW-2 (B)/500meter/ODC-DW-2 (A,B)/GC-DW2/LC-DW 2 (Nr. Police Station, Mulla Colony)(Amb.Air)	275	367

IMPACT STATIONS 1000m	Odour Unit (olfactometer data) OU_E/M³ (Field olfactometer)	
	Pre monsoon	Post-monsoon
1000 Meter North Direction (Amb.Air)	36	31
1000 Meter East Direction (Amb.Air)	63	71
1000 Meter West Direction (Amb.Air)	36	47
1000 Meter South Direction (Amb.Air)	24	29

- ix. Influences of wind directions:

The Table below indicates that odour at monitoring stations located near boundary wall (BW) are higher than those that are located farther away besides the wind direction influences dispersion of odour significantly

Concentration direction wise (ambient air) BW- boundary wall	Odour Unit (olfactometer data) OU_E/M³ (Field olfactometer)	
	Pre monsoon	Post-monsoon
BW-S (Amb.Air)	146	149
BW-N (Nr. LC/GC) (Amb.Air)	188	276
BW-E (Amb.Air)	380	478
BW-W near RDF plant (Amb.Air)	555	741
BW-SW near RDF plant (Amb.Air)	501	524
BW-NW (Amb.Air)	436	312
BW-NE near Old Site GAIL (Amb.Air)	102	128
BW-SE (Amb.Air)	162	211
1000 Meter North Direction (Amb.Air)	36	31
1000 Meter East Direction (Amb.Air)	63	71
1000 Meter West Direction (Amb.Air)	36	47
1000 Meter South Direction (Amb.Air)	24	29

x. Odourants at 1000m and in downwind locations in ambient air (impact locations) :

The information provided in the TWO Tables indicates that though most of the odourant values are BDL (below detection limit) it also highlights that concentration values depend on the minimum detection threshold of the analytical instrument. Similar observations observed as for the odourants at the downwind impact locations. In both the above cases it was observed that the odourants are at low concentration and the detectable ones are Methane, VOCs and ammonia. Also refer to section discussing '**Odour Detection Threshold of odourants**'

Table: Post-monsoon odourants (ambient) in MSW Ghazipur (at 1000 m distance)

Odourous compound monitoring stations	PARAMETERS ($\mu\text{g}/\text{m}^3$)							
	Dimethyl Sulphide	Ethyl Mercaptan	Methyl Mercaptan	Methane (ppm)	Butyric Acid ($\mu\text{g}/\text{m}^3$)	Hydrogen Sulphide	Ammonia	VOC,s (ppb)
1000 Meter North Direction (Amb.Air)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	1.91	BDL (DL:1.0)	BDL (DL:6.0)	12.5	15.4
1000 Meter East Direction (Amb.Air)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	1.76	BDL (DL:1.0)	BDL (DL:6.0)	14.2	20.3
1000 Meter West Direction (Amb.Air)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	1.80	BDL (DL:1.0)	BDL (DL:6.0)	10.9	18.6
1000 Meter South Direction (Amb.Air)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	1.83	BDL (DL:1.0)	BDL (DL:6.0)	16.8	17.2

Table: Post-monsoon odourants (ambient) in MSW Ghazipur (downwind locations ambient)

Odourous compound monitoring stations	PARAMETERS ($\mu\text{g}/\text{m}^3$)							
	Dimethyl Sulphide	Ethyl Mercaptan	Methyl Mercaptan	Methane (ppm)	Butyric Acid ($\mu\text{g}/\text{m}^3$)	Hydrogen Sulphide	Ammonia	VOC,s (ppb)
AC-DW1 (B)/500 Meter/ODC-DW1 (A,B)/GC-DW1/LC-DW1 (Nr. Ambedkar Bhawan, Rajveer Colony) (Amb.Air)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	2.9	BDL (DL:1.0)	BDL (DL:6.0)	29.3	32.1
AC-DW-2 (B)/500 meter/ODC-DW-2 (A,B)/GC-DW2/LC-DW 2 (Nr. Police Station, Mulla Colony)(Amb.Air)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	3.3	BDL (DL:1.0)	BDL (DL:6.0)	36.2	36.4
ADC-A-DW 2	BDL	BDL	BDL	2.9	BDL	BDL	33.8	24.7

Odorous compound monitoring stations	PARAMETERS ($\mu\text{g}/\text{m}^3$)							
	Dimethyl Sulphide	Ethyl Mercaptan	Methyl Mercaptan	Methane (ppm)	Butyric Acid ($\mu\text{g}/\text{m}^3$)	Hydrogen Sulphide	Ammonia	VOC,s (ppb)
(Nr. Police Thana) (Amb.Air)	(DL:1.0)	(DL:1.0)	(DL:1.0)		(DL:1.0)	(DL:6.0)		
ADC-A-DW 1 (Mulla Colony) (Amb.Air)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	3.0	BDL (DL:1.0)	BDL (DL:6.0)	29.6	28.7
SH/PH/FM DW 1 (Back Side Police Thana) (Amb.Air)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	1.9	BDL (DL:1.0)	BDL (DL:6.0)	24.8	9.2
SH/PH/FM DW 2 (Nr.Ajay Paper Cop.,Plot No. 375, Pocket-C, Nr. Khoda Colony) (Amb.Air)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	2.1	BDL (DL:1.0)	BDL (DL:6.0)	29.0	7.8

Odour analyses at MSW Ghazipur landfill – at source

Key findings

1. Odour during post monsoon was generally higher than pre-monsoon
2. RDF : Odour monitored at source locations at Refuse derived fuel (RDF) , Odour Unit (olfactometer data) OU_E/M^3 (Field olfactometer) for pre monsoon range between 2691 to 2971 and for post monsoon the range is between 3273 to 3388.

Odour monitoring – SOURCE station RDF	Odour Unit (olfactometer data) OU_E/M^3 (Field olfactometer)	
	Pre monsoon	Post-monsoon
RDF Gate No. 3 (Source)	2851	3273
RDF Gate No. 4 (Source)	2971	3388
RDF Gate No. 2 (Source)	2691	2760

3. Old dumpsites – the post-monsoon data is higher than pre-monsoon , indicating that trapped heat within the waste heap has catalysed decomposition of the organic wastes

Odour monitoring – SOURCE station Old dumpsites	Odour Unit (olfactometer data) OU_E/M^3 (Field olfactometer)	
	Pre monsoon	Post-monsoon
Old Dump Cell –A1 (Source)	237	260
Old Dump Cell –A2 (Source)	257	312
Old Dump Cell –A3 (Source)	346	457
Old Dump Cell –B4 (Source)	380	367
Old Dump Cell –B5 (Source)	223	312
Old Dump Cell –B6 (Source)	309	382

4. Active dumpsite: Active dumpsites are highly odorous compared to old dumpsites. The post monsoon values higher than pre monsoon, indicating that the summer heat was rapidly decomposing the biodegradable (organic) matter of the MSW – mainly surface phenomena.

The pre-monsoon values ranged between 2754 to 3630 while post monsoon values were in the range between 2951 to 4897.

Odour monitoring – SOURCE station Active dumpsite	Odour Unit (olfactometer data) OU _E /M ³ (Field olfactometer)	
	Pre monsoon	Post-monsoon
Active Dump Cell –A1 (Source)	3311	4395
Active Dump Cell –A2 (Source)	3630	4897
Active Dump Cell –A3 (Source)	3054	4178
Active Dump Cell –B4 (Source)	3388	3981
Active Dump Cell –B5 (Source)	3715	2951
Active Dump Cell –B6 (Source)	2754	4623

5. Leachate : This is the MOST odorous of all sources , the pre-monsoon values were in the range of 4897 to 5248 and post-monsoon in the range of 5495 to 5888

Odour monitoring – SOURCE station Leachate	Odour Unit (olfactometer data) OU _E /M ³ (Field olfactometer)	
	Pre monsoon	Post-monsoon
Leachate Collection-1 (Source)	5188	5888
Leachate Collection-2 (Source)	4897	5495
Leachate Collection-3 (Source)	5248	5559

6. Odourants at source locations post-monsoon (Table below)-
Odourants: The odourants reported are hydrogen sulphide, methane, VOC,s and ammonia. The Table below shows that though most of the odourant values are BDL (below detection limit) it also highlights that concentration values depend on the minimum detection threshold of the analytical instrument. Also refer to section discussing ‘**Odour Detection Threshold of odourants**’

Table: Odourants at source (Active dumpsite) locations post-monsoon MSW Ghazipur

Odorous compound monitoring stations	PARAMETERS (µg/m ³)							
	Dimethyl Sulphide (µg/m ³)	Ethyl Mercaptan (µg/m ³)	Methyl Mercaptan (µg/m ³)	Methane (ppm)	Butyric Acid (µg/m ³)	Hydrogen Sulphide (µg/m ³)	Ammonia (µg/m ³)	VOC,s (ppb)
Active Dump Cell –A1 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	532.0	BDL (DL:1.0)	68.2	518.0	6587.0

Odorous compound monitoring stations	PARAMETERS ($\mu\text{g}/\text{m}^3$)							
	Dimethyl Sulphide ($\mu\text{g}/\text{m}^3$)	Ethyl Mercaptan ($\mu\text{g}/\text{m}^3$)	Methyl Mercaptan ($\mu\text{g}/\text{m}^3$)	Methane (ppm)	Butyric Acid ($\mu\text{g}/\text{m}^3$)	Hydrogen Sulphide ($\mu\text{g}/\text{m}^3$)	Ammonia ($\mu\text{g}/\text{m}^3$)	VOC,s (ppb)
Active Dump Cell -A2 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	462.0	BDL (DL:1.0)	74.9	687.0	5629.0
Active Dump Cell -A3 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	528.0	BDL (DL:1.0)	70.1	509.0	5874.0
Active Dump Cell -B4 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	615.0	BDL (DL:1.0)	63.2	547.0	6985.0
Active Dump Cell -B5 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	523.0	BDL (DL:1.0)	59.6	489.7	6478.0
Active Dump Cell -B6 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	340.0	BDL (DL:1.0)	67.4	714.0	7524.0

Table: Odourants at source locations post-monsoon MSW Ghazipur

Odorous compound monitoring stations	Dimethyl Sulphide ($\mu\text{g}/\text{m}^3$)	Ethyl Mercaptan ($\mu\text{g}/\text{m}^3$)	Methyl Mercaptan ($\mu\text{g}/\text{m}^3$)	Methane (ppm)	Butyric Acid ($\mu\text{g}/\text{m}^3$)	Hydrogen Sulphide ($\mu\text{g}/\text{m}^3$)	Ammonia ($\mu\text{g}/\text{m}^3$)	VOC,s (ppb)
RDF Gate No. 3 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	578	BDL (DL:1.0)	36.2	758.0	3021.0
RDF Gate No. 4 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	642	BDL (DL:1.0)	30.6	697.0	3314.0
RDF Gate No. 2 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	619	BDL (DL:1.0)	34.1	786.0	2925.0

Odorous compound monitoring stations	Dimethyl Sulphide (µg/m³)	Ethyl Mercaptan (µg/m³)	Methyl Mercaptan (µg/m³)	Methane (ppm)	Butyric Acid (µg/m³)	Hydrogen Sulphide (µg/m³)	Ammonia (µg/m³)	VOC,s (ppb)
GC-1 (G-16 Bore well) (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	51.8 % (v/v)	BDL (DL:1.0)	24.3	326.5	546.0
GC-2 (G-15 Bore well) (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	44.6 % (v/v)	BDL (DL:1.0)	19.6	370.2	625.00
GC-3 (D-11 Bore well) (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	49.4 % (v/v)	BDL (DL:1.0)	21.3	416.0	487.00
Old Dump Cell -A1 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	42.3	BDL (DL:1.0)	6.3	26.9	34.2
Old Dump Cell -A2 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	30.2	BDL (DL:1.0)	6.8	16.8	36.5
Old Dump Cell -A3 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	33.4	BDL (DL:1.0)	7.2	19.3	39.4
Old Dump Cell -B4 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	50.2	BDL (DL:1.0)	6.2	25.4	40.6
Old Dump Cell -B5 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	24.3	BDL (DL:1.0)	6.1	28.1	29.3
Old Dump Cell -B6 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	37.1	BDL (DL:1.0)	6.9	24.7	45.2
Leachate Collection-1 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	489.0	BDL (DL:1.0)	69.2	1025.0	578.0
Leachate Collection-2 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	466.0	BDL (DL:1.0)	75.6	987.6	526.0

Odorous compound monitoring stations	Dimethyl Sulphide ($\mu\text{g}/\text{m}^3$)	Ethyl Mercaptan ($\mu\text{g}/\text{m}^3$)	Methyl Mercaptan ($\mu\text{g}/\text{m}^3$)	Methane (ppm)	Butyric Acid ($\mu\text{g}/\text{m}^3$)	Hydrogen Sulphide ($\mu\text{g}/\text{m}^3$)	Ammonia ($\mu\text{g}/\text{m}^3$)	VOC,s (ppb)
Leachate Collection-3 (Source)	BDL (DL:1.0)	BDL (DL:1.0)	BDL (DL:1.0)	517.0	BDL (DL:1.0)	72.1	1074.0	556.00

Comparison of analytical results with simulated data (AERMOD)

Refer to report 'Odour Dispersion Modelling - MSW Landfill Site, Ghazipur, Delhi'. Two classes of dispersion models are currently being used for odour dispersion (for regulatory purpose):

- Gauss Models
- Lagrange models.

Both model classes belong to the so-called non-CFD (computational fluid dynamics) models. Non-CFD models do not explicitly resolve fluid-dynamics equations but physical processes are parameterized.

Numerous modelling approach has been applied to simulate the impact of odour generated from various sources. Most popular models are Gaussian steady state plume models (e.g., AERMOD, ISCST3, ADMS-Urban) , *the Gaussian dispersion models is found to be the most frequently used for simulation of odour dispersion with satisfactory performance.* After detailed review of odour dispersion modelling study for different sources, it is found the AERMOD and CALPUFF can satisfactorily predict the odour concentration emitting from a landfill site. Out of Gaussian dispersion models, AERMOD and Austrian odour dispersion model (AODM) are the most common in the steady state plume category. However for shorter prediction range model like AERMOD prediction are much closer to the observed data when compared to CALPUFF.

In the present study, **AERMOD** (UESPA, 2005; CPCB, 2016) has been adopted to simulate the dispersion of odour concentration emitted from the Ghazipur MSW Landfill site in Delhi. To evaluate the maximum probable distance for odour concentration of $5.0 \text{ OU}/\text{m}^3$ cut-off, the modelling domain was extended up to $50 \text{ km} \times 50 \text{ km}$ with receptor grid cell size of $1 \text{ km} \times 1 \text{ km}$. The results of

simulation to evaluate maximum probable distance for 5.0 OU/m³ cut-off for pre & post monsoon is shown in Table below.

Table Predicted Odour concentration w.r.t. downwind distance (AERMOD)

Distance from boundary of Old Dump (km)	24 hr. average downwind side Odour concentration [OU/m ³]	
	Pre-monsoon (Summer)	Post-monsoon
0	112	43.3
0.25	82.5	36.2
0.5	69.8	34.1
<u>1</u>	<u>63.3</u>	<u>29.4</u>
2	32.6	17.4
3	19.1	20.2
5	10.8	12.1
10	8.01	9.01
15	6.26	6.55
20	4.88	4.99

Table : Comparison of analytical results with simulated data (AERMOD) at ONE KM distance

1. The field data of odour concentration at a distance of ONE KM (1000 m) and the simulated data through modelling are found very close which validate the use of AERMOD model even for Odour dispersion (refer Table (top) below)
2. The decrease in post monsoon model output may directly be attributed to hindrance in dispersion processes assuming the same source situated at 1000 m distance due prevailing meteorological conditions (high humidity) . However the field data has captured impact of odour generated in the intermediate stretch also. (Table (bottom) below)

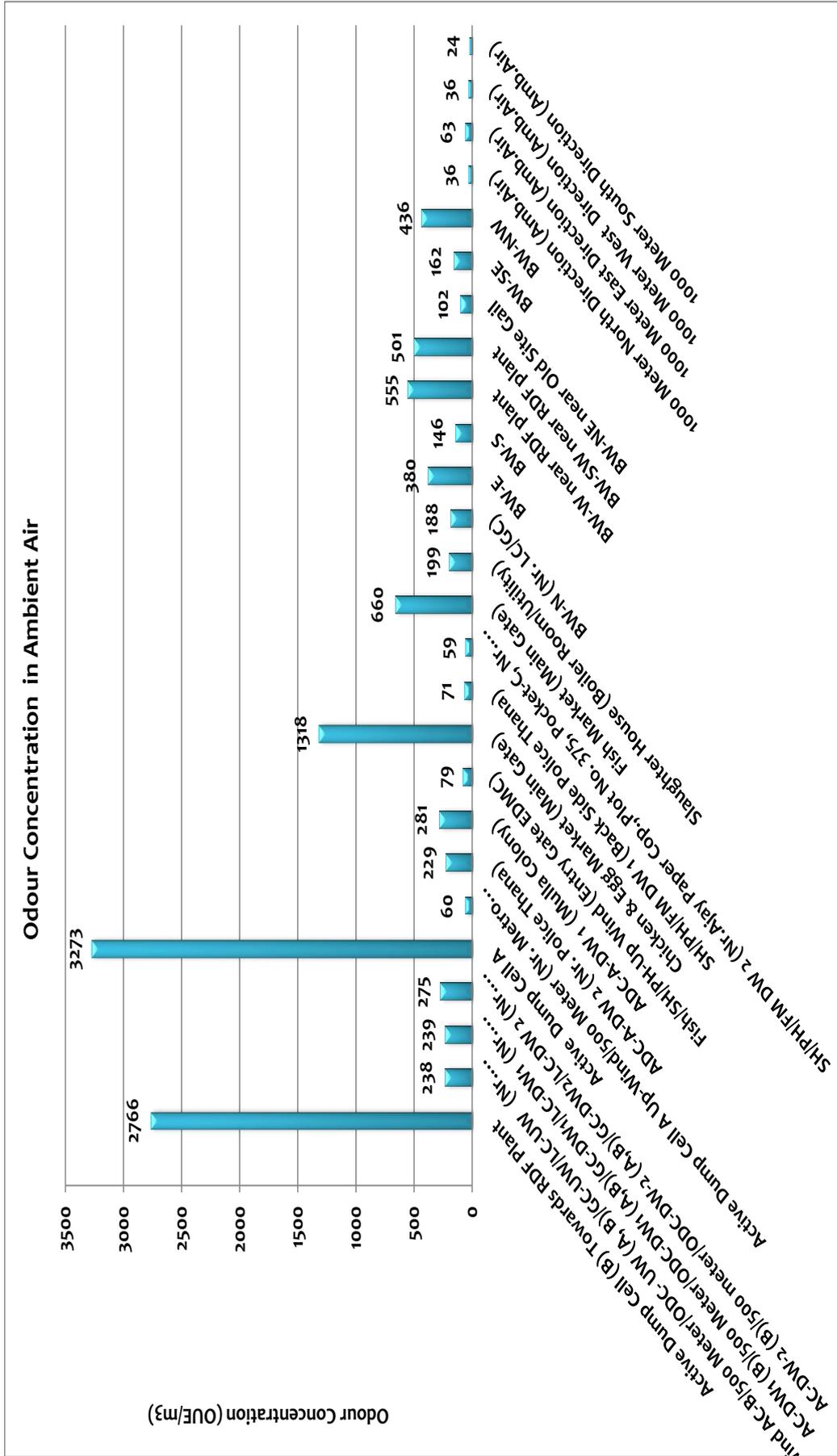
Tool	Pre-monsoon (OU /M³)	Post monsoon (OU /M³)
Downwind locations using Field olfactometry	24-63 Average - 40	29-71 Average - 45
AERMOD : The simulation results downwind predicted odour concentration	63.3 OU/m³	29.4 OU/m³

AERMOD : simulation results	Distance to detect odour concentration 5.0 OU/m³.	
	Pre-monsoon	Post monsoon
The simulation results indicate from the boundary of landfill site, the downwind predicted odour concentration:	at distance of 24 km	at distance of 22.5 km

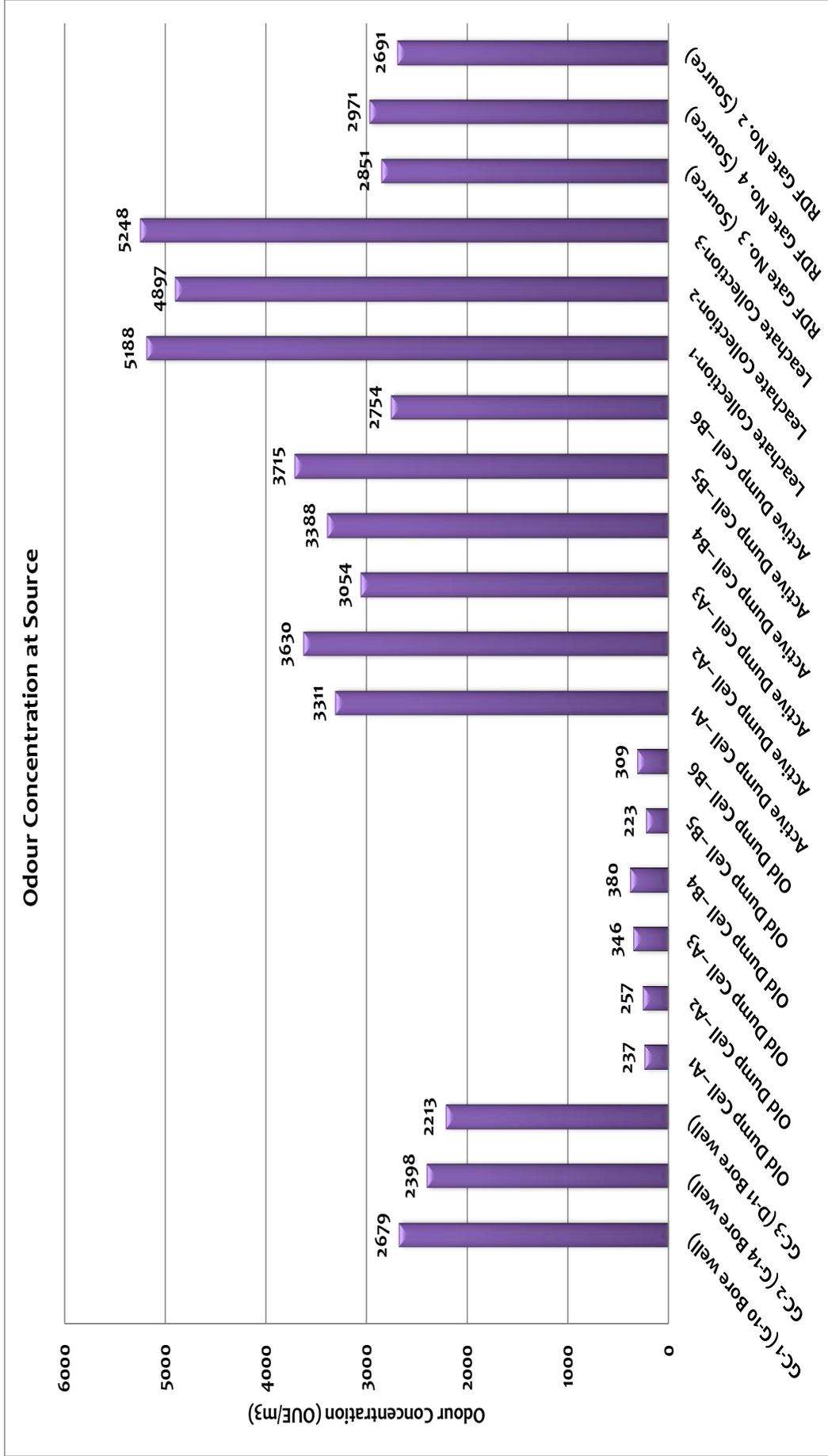
GRAPHICAL REPRESENTATION OF RESULTS

The graphical representation of results is given below.

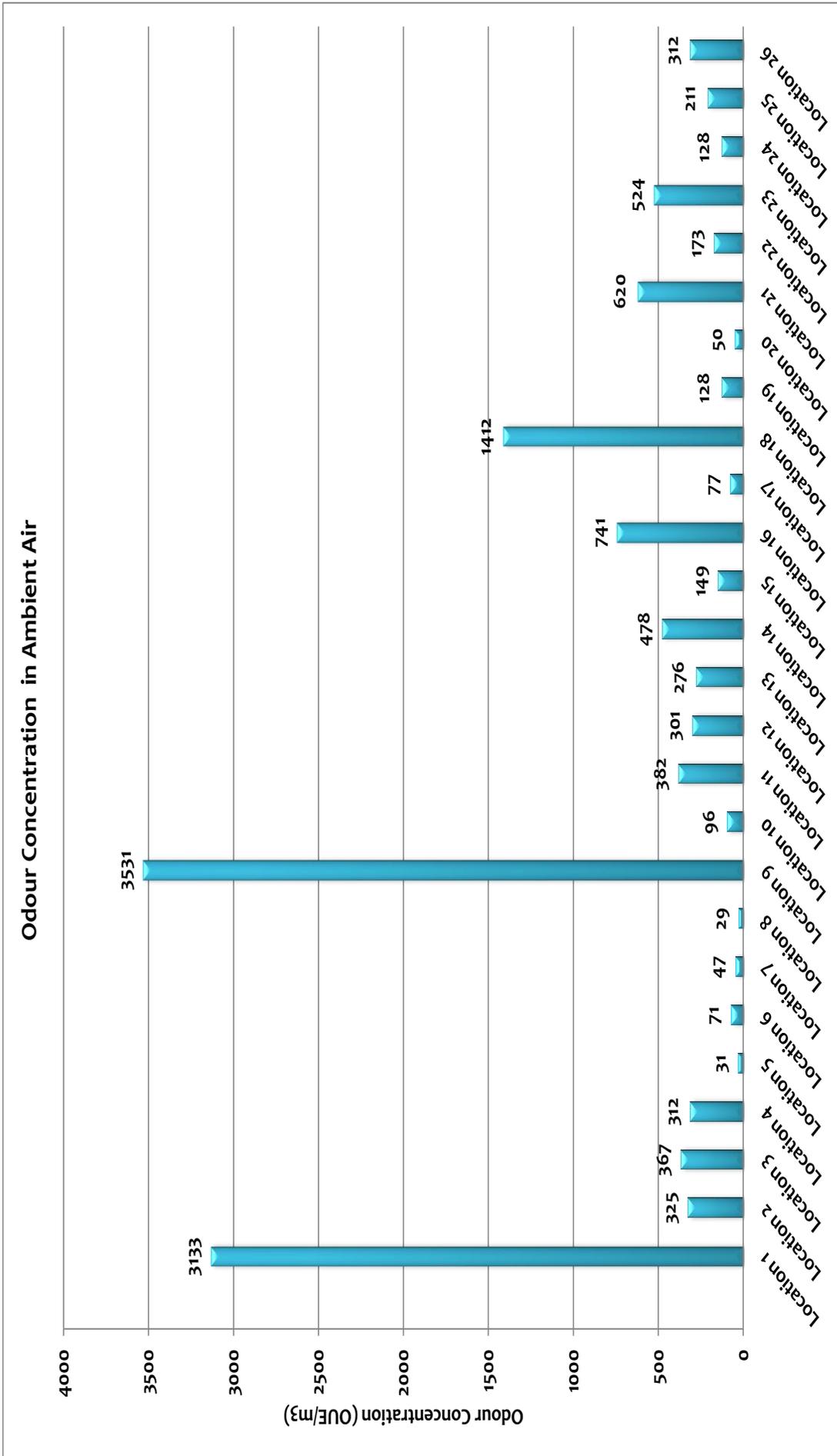
A. Odour Concentration or Level in Ambient Air pre monsoon:-



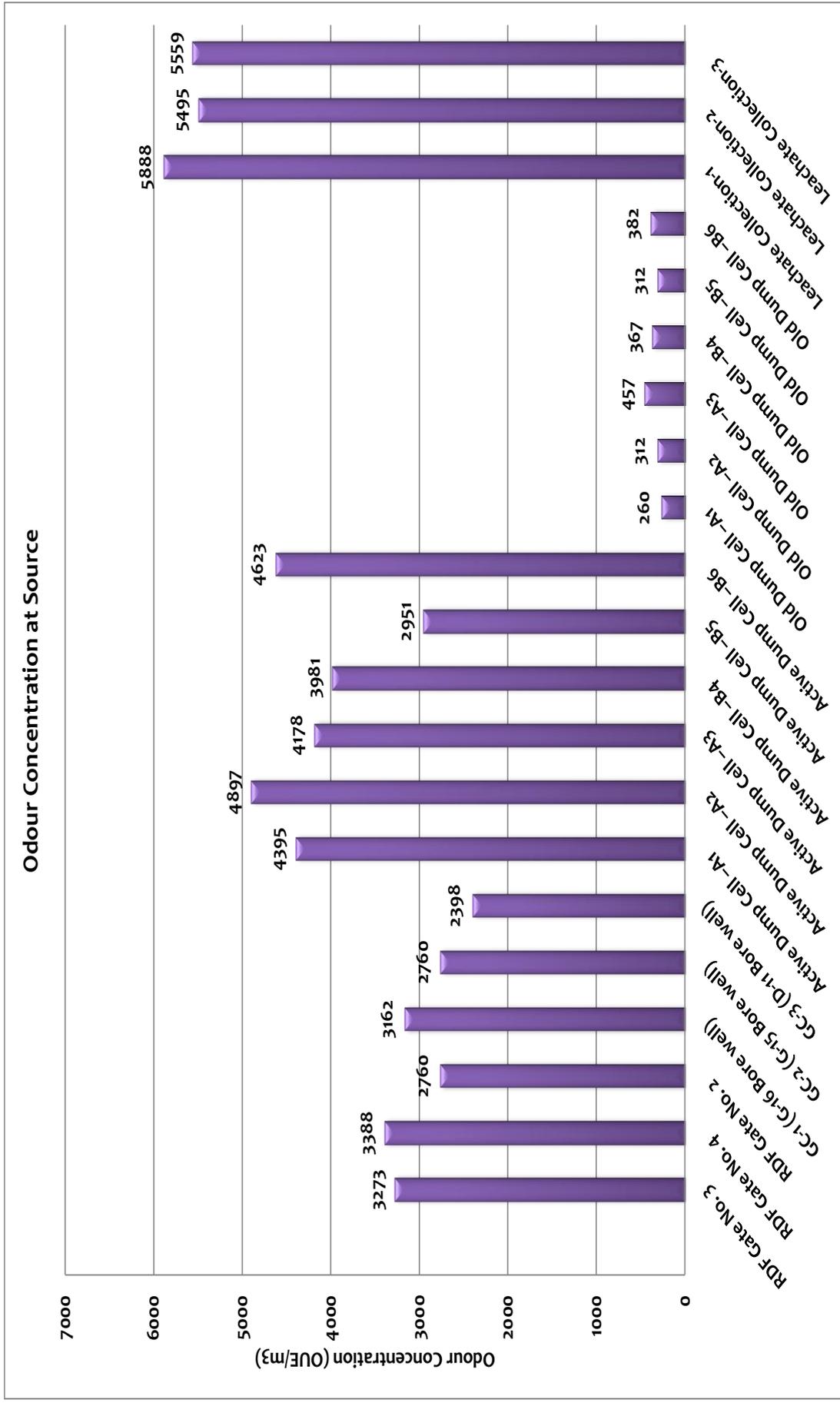
B. Odour Concentration or Level at Source pre monsoon:-



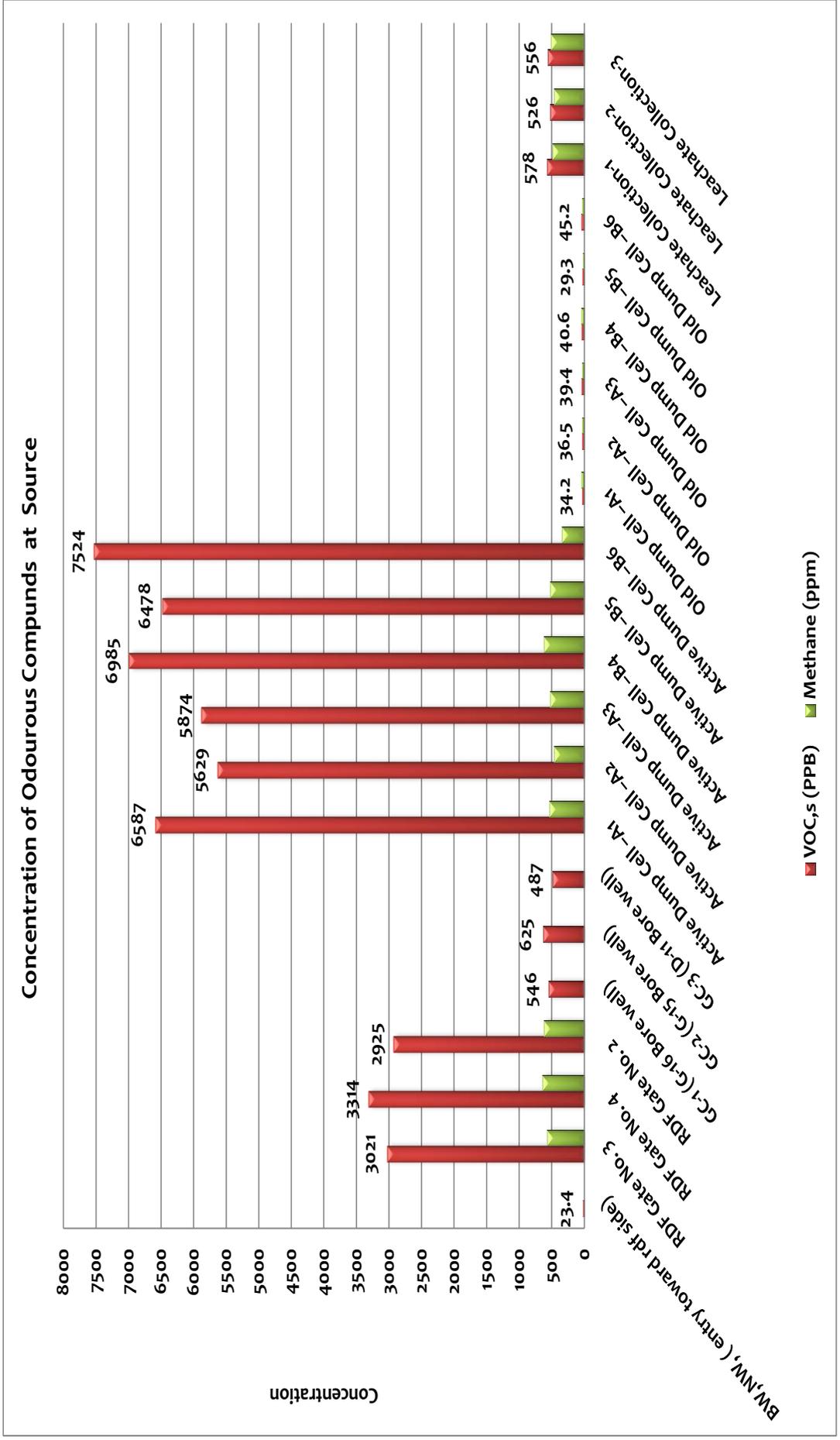
G. Odour Concentration or Level in Ambient Air post monsoon:-



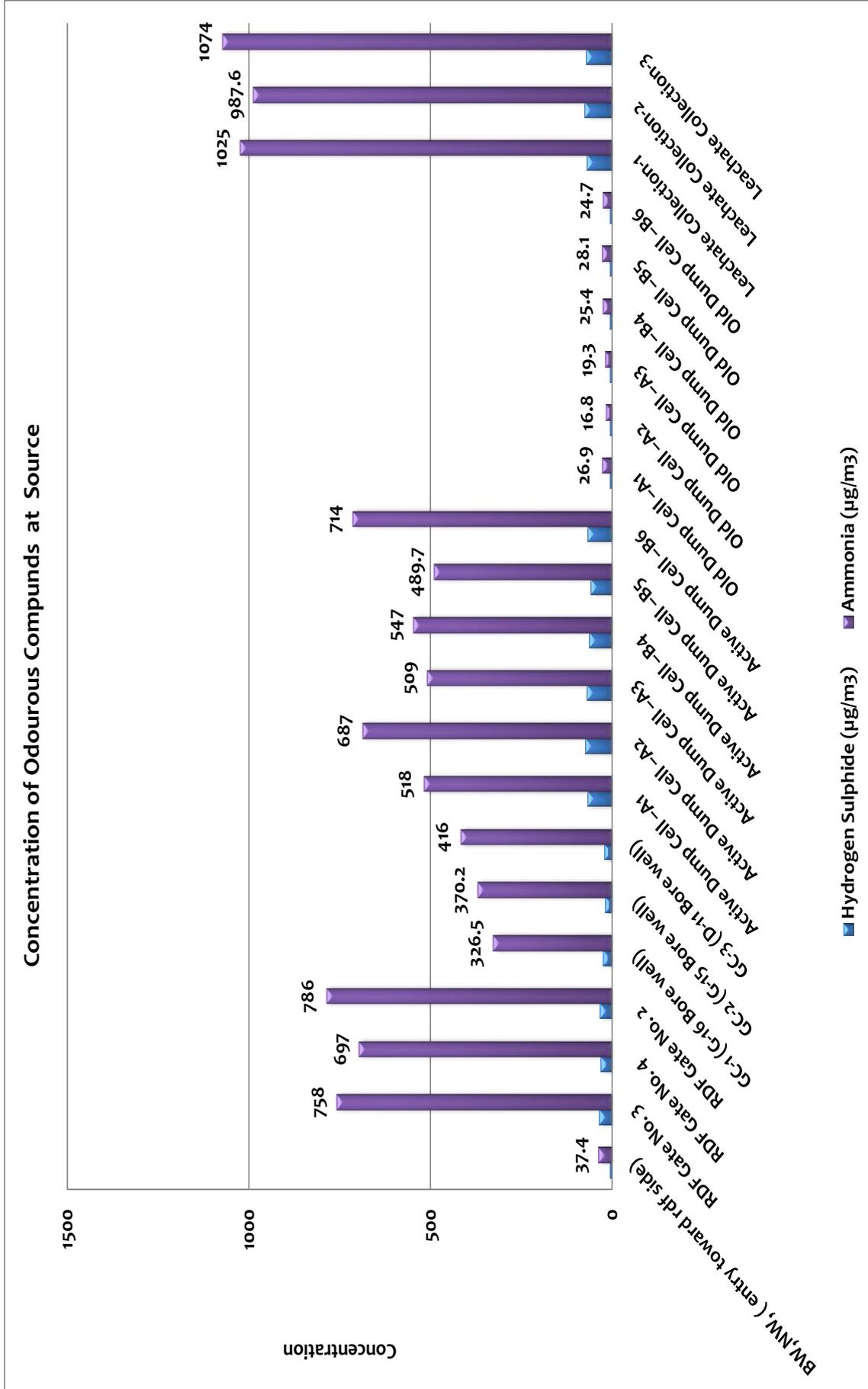
H. Odour Concentration or Level at source Emission post monsoon



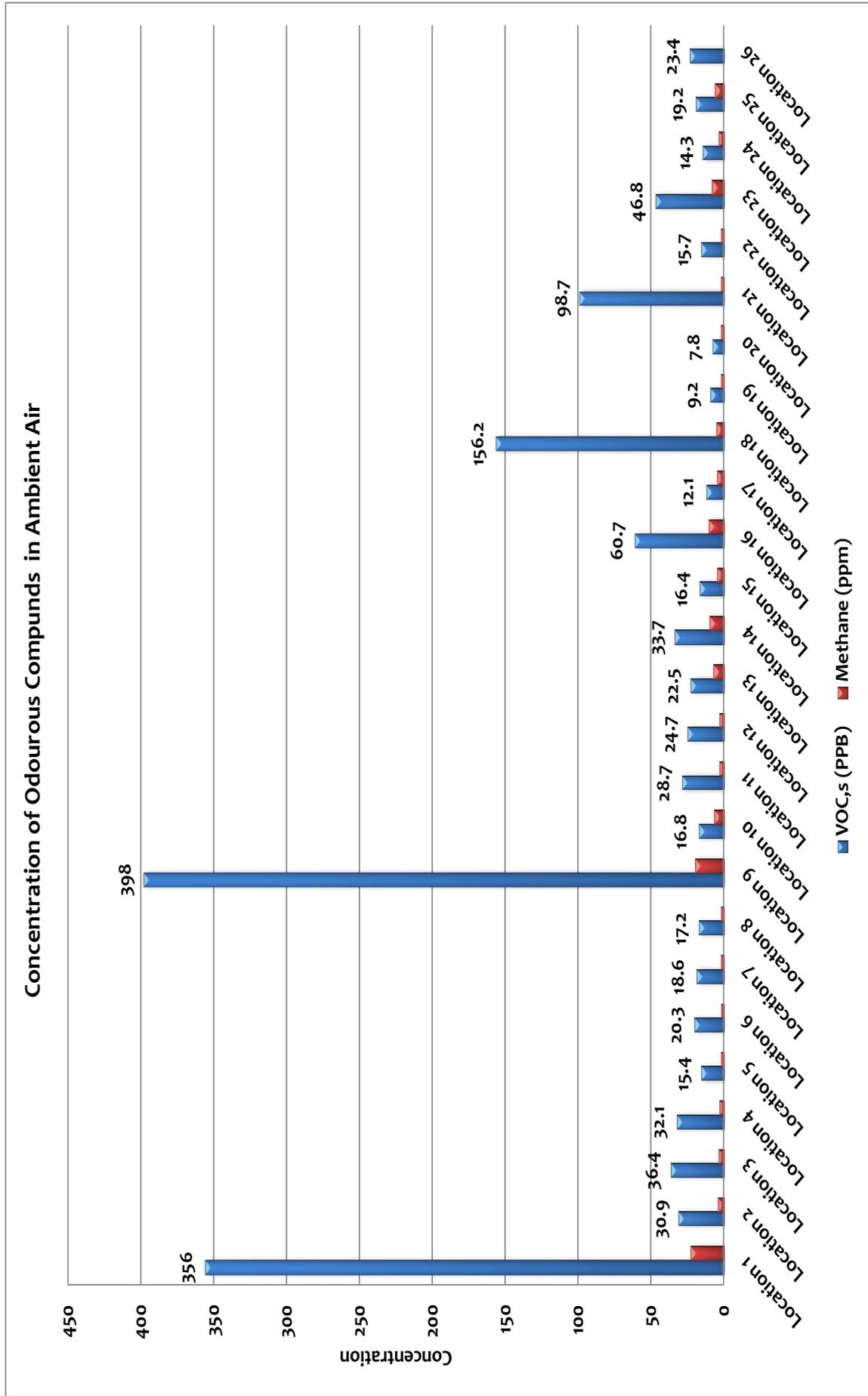
I. Concentration of odourous compound at source:- VOC and Methane post monsoon



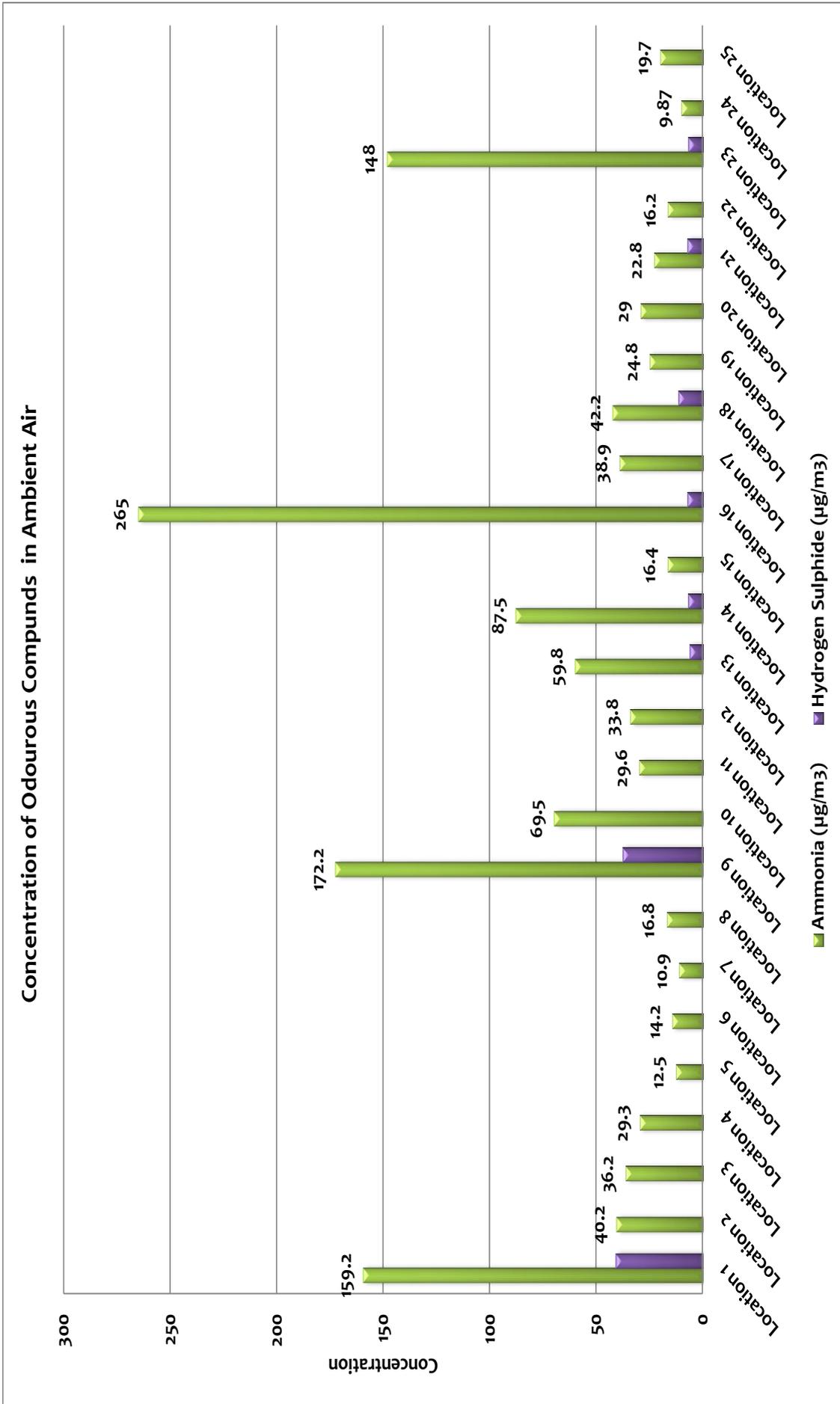
J. Concentration of odorous compound at source:- Hydrogen Sulphide & Ammonia post monsoon



K. Concentration of odorous compound in Ambient Air:- VOC & Methane post monsoon

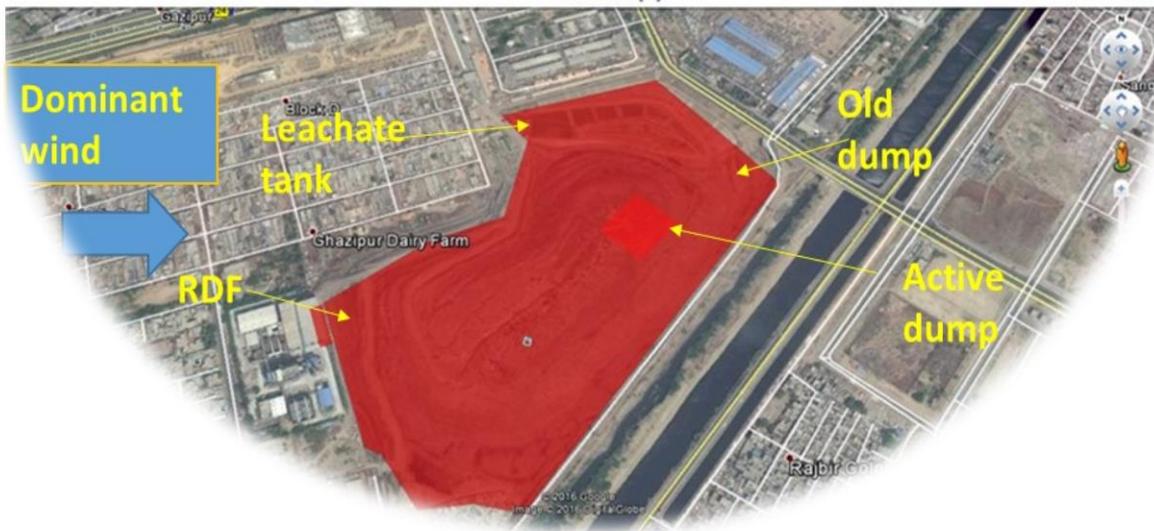
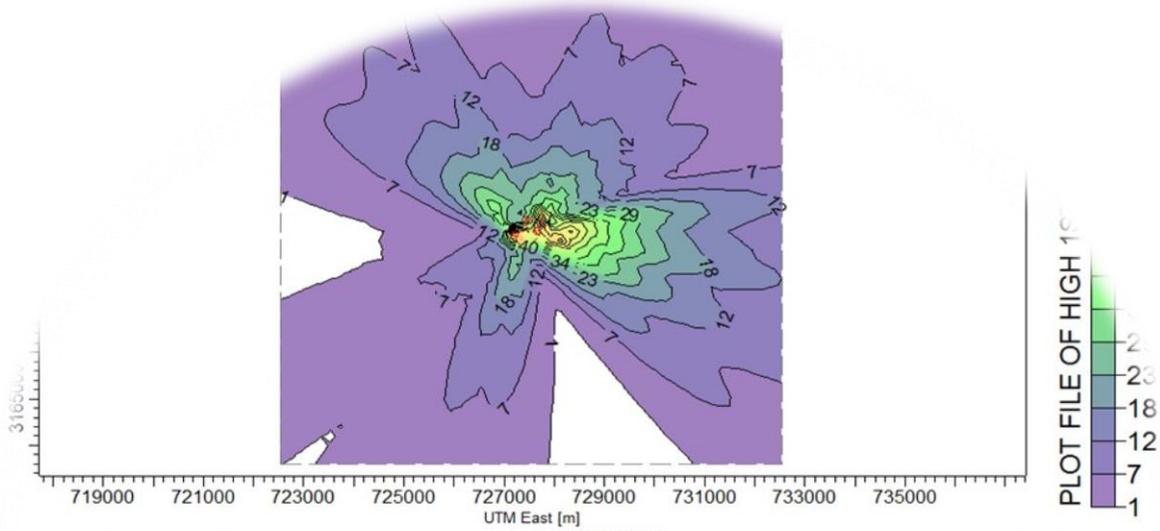


L. Concentration of odorous compound in Ambient Air:- Hydrogen Sulphide & Ammonia post monsoon



Part 3

Odour Dispersion modeling & mapping Ghazipur MSW Landfill, Delhi



Report :

Odour Dispersion modeling & mapping - Ghazipur MSW Landfill , Delhi

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1. Dispersion Modeling Method – an introduction

Odour perception is a biological reaction which can be expected if the concentration lies above the odour concentration threshold. Therefore odour sensation cannot be expressed by the concentration itself; instead, a biologically-effective parameter, the odour intensity, has to be used. This approach is similar as for many other biological reactions (e.g. brightness, loudness). In many cases the odour sensation is expressed in terms of odour intensity which is described by the relationship between the magnitude of a physical stimulus (odour concentration) and its perceived odour intensity. The sensation of odour is an instantaneous reaction to a certain odour concentration. With the known odour emission flow rate and the necessary meteorological information, the ambient odour concentration can be calculated by dispersion models. Annoyance caused by environmental odour can only be assessed by including the temporal dimension. From this it follows that the ambient odour concentration has to be known at least on a 1-h basis over a one year period (Yu et al., 2009). Dispersion models provide the ambient odour concentration for each time step (mainly half-hour or 1-h mean values of the ambient concentration). Evaluating time series of ambient odour concentrations, the probability of annoyance can be assessed.

Two classes of dispersion models are currently used for (regulatory) odour dispersion,

- Gauss Models
- Lagrange models.

Both model classes belong to the so-called non-CFD (computational fluid dynamics) models. Non-CFD models do not explicitly resolve fluid-dynamics equations but physical processes are parameterized.

2. Odour Dispersion Modelling and Mapping of Landfill Site – literature survey

The gaseous compounds emitted from landfills have various impacts on their surroundings and act on different scales. In addition to having impacts over a large spatial scale, gaseous emissions also act on different time scales. Hence the task to evaluate the spatial and temporal dispersion of odour level around the landfill sites. The climate condition of any landfill site governs the physical, chemical and biological activities occurring within the dump as well as outer surface of the dump landfill. Unpleasant odours have become an important environmental issue and it is considered as atmospheric contaminants, due to the growing environmental awareness of the population. There is a need to provide a legal framework about odour impacts entails the definition of specific

methods for odour measurement. Regulations of different countries propose air dispersion modelling as a method for odour impact assessment and this is currently the most frequently used approach (Capelli et al., 2013). It was found that internationally, several studies have already demonstrated the capability of air dispersion models to estimate odour impact from various sources (Busini et al., 2012; Chemel et al., 2012; Mantovani et al., 2010).

Numerous modelling approach has been applied to simulate the impact of odour generated from various sources. Most popular models are Gaussian steady state plume models (e.g., AERMOD, ISCST3, ADMS-Urban), Gaussian non-steady state puff models (e.g. CALPUFF), Fluid dynamic models, i.e. CFD models and Lagrangian particle models (Capelli et al., 2013). Out of them, the Gaussian dispersion models is found to be the most frequently used for simulation of odour dispersion with satisfactory performance.

Out of Gaussian dispersion models, AERMOD and Austrian odour dispersion model (AODM) are the most common in the steady state plume category and CALPUFF in the non-steady state puff one (Wang et al. 2006; Dourado et al. 2014; Capelli et al., 2013). Wang et al. (2006) highlighted that CALPUFF model could fairly well predict average downwind odour concentrations even though failed to predict peak odour concentrations using a constant average emission rate. In particular, Drew et al. (2007) conducted simulations of odour dispersion from a landfill site through a Gaussian steady state model, using two different averaging times (hourly and short). The simulations highlighted that the short period ones were in accordance with odour incidents recorded in the community monitoring database, while the hourly averaging times underestimated odour concentration peaks. In one of the studies, Barnéoud et al. (2012) evaluated the performances of two Gaussian steady state plume model for odour impact assessment around an urban composting plant and found that in both models an increase of the distance from the source resulted in an underestimation of the output concentrations, while a good performance of the models was observed with short distances from the source. Busini et al. (2012) showed a good agreement between AERMOD and CALPUFF results in prediction of odour concentration generated from point source, except for stable atmospheric condition. Recently, Dourado et al. (2014) found that the Gaussian steady state model correctly predicted mean odour concentrations, but underestimated concentrations in the near-wake recirculation region of the obstacle. The details of different models used of odour dispersion are described below:

Type of Model	Name of the model	Reference
Gaussian Steady State	AERMOD	Busini et al., 2012
	Austrian odour dispersion model (AODM)	Piringer et al., 2007
	ISCST3	Wang et al., 2006
Gaussian Non-Steady State/ Gaussian Advanced	CALPUFF	Busini et al., 2012
	ADMS	Capelli et al., 2013
Fluid Dynamic	FLUENT	Maïzi et al., 2010
Lagrangian Particle	AUSTAL 2000	Piringer et al., 2015

3. Models odour concentration prediction from a landfill site

After detailed review of odour dispersion modelling study for different sources, it is found the AERMOD and CALPUFF can satisfactorily predict the odour concentration emitting from a landfill site. However, dispersion of odour is very prompt and does not travel far from sources, hence shorter prediction range model like AERMOD prediction are much closer to the observed data when compared to CALPUFF. The gaussian based steady state dispersion model (such as AERMOD) is more satisfactorily for nearby sources (<50 km) while CALPUFF is a long range transport and non-steady state dispersion model and more appropriate for far distance sources in range of 50-300 km (USEPA, 2005). Additionally, AERMOD is simple and userfriendly in operation compared to CALPUFF. Therefore, in the present study, AERMOD (USEPA, 2005; CPCB, 2016) has been adopted to simulate the dispersion of odour concentration emitted from the Ghazipur MSW Landfill site in Delhi.

4. Air Quality Dispersion Model: The AERMOD

AERMOD is a steady-state plume model developed by a working group of AMS/EPA Regulatory Model Improvement Committee, AERMIC, (USEPA, 2005). In the stable boundary layer (SBL), it assumes the concentration distribution to be Gaussian in both, vertical and horizontal fields. In the CBL, the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function. AERMOD is applicable to rural and urban areas, flat and complex terrain, surface and elevated releases and multiple sources including, point, area and volume. AERMOD removes need for defining complex terrain regimes because all terrains are handled in a consistent and continuous manner in stably stratified conditions. AERMOD constructs vertical profiles of required meteorological variables based on measurements and extrapolations of those measurements using similarity (scaling) relationships. Vertical profiles of wind speed, wind

direction, turbulence and temperature gradient are estimated using all available meteorological observations. AERMOD requires surface measurement of wind speed, wind direction and ambient temperature, solar radiations, cloud cover, relative humidity and atmospheric pressure. A full morning upper air sounding is required in order to calculate the convective mixing height throughout the day. Surface characteristics (surface roughness, Bowen ratio, and albedo) are also needed in order to construct similarity profiles of the relevant PBL parameters. Surface characteristics in the form of albedo, surface roughness and Bowen ratio and standard meteorological observations (wind speed, wind direction, temperature, and cloud cover) are input to AERMET which calculates the PBL parameters. The AERMAP, terrain pre-processor uses gridded terrain data to calculate a representative terrain-influence height (h_c) also referred to as the terrain height scale which is uniquely defined for each receptor location.

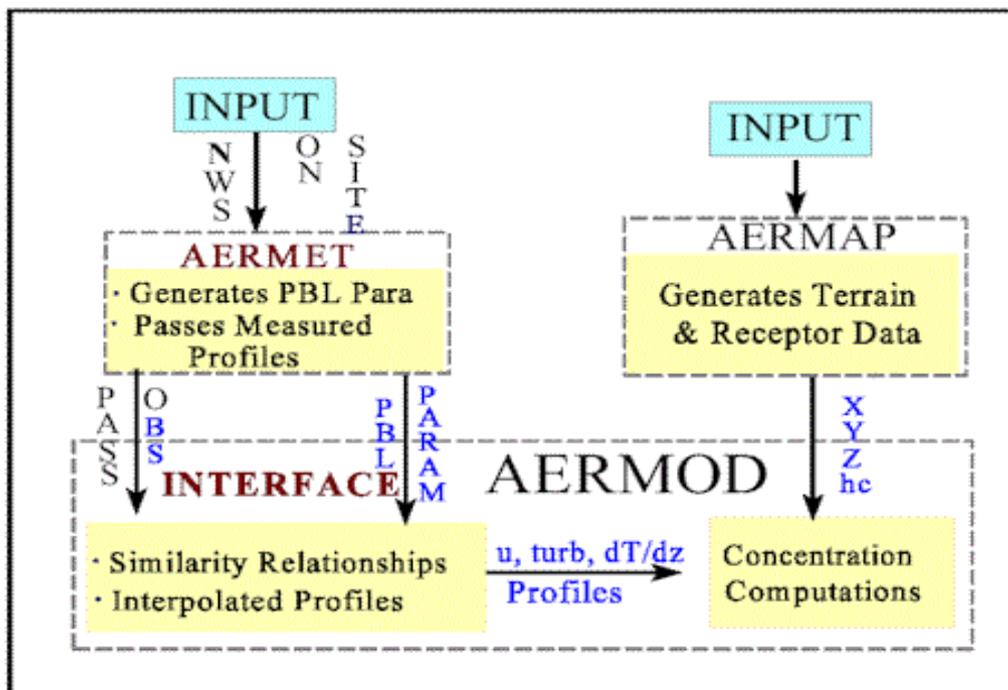


Figure 1: Data processing flow chart of AERMOD

5. Data Requirement for Odour Dispersion Modelling

In general, for the application of an atmospheric dispersion model, at least three different kinds of input data are needed: meteorological, emission and topographical.

1. Meteorological data :The acquisition and pre-processing of meteorological data is of crucial importance for atmospheric dispersion modelling purposes. In general, the meteorological data required for dispersion modelling include wind speed, wind direction, and information about the atmospheric stability conditions which can be derived from other meteorological parameters, such as humidity, temperature and wind speed profiles, as well as cloud covering or solar radiation (global or net).

Older dispersion models, i.e. simple Gaussian plume models, are based on the use of the Pasquill-Gifford-Turner stability classes for the characterization of the vertical and lateral dispersion (EPA, 1995). Instead, the new generation of short-range dispersion models, including more complex Gaussian plume models such as ISC3, AERMOD and ADMS, use Monin-Obukhov similarity to describe the mean and turbulence structure in the surface boundary layer. The ground-level concentration is generally expressed in terms of specific variables, such as the surface friction velocity and the Monin-Obukhov length, which contain information on the turbulence and the mean wind that govern dispersion (Vankatram, 2004).

In the present study, site specific meteorological data is used for summer (pre-monsoon) and post monsoon season. In AERMOD, both surface and upper air meteorological parameter are required to generate the vertical profile of the wind field. The surface meteorological parameters used in the AERMAP are wind speed (m/s), wind direction (degree), ambient temperature ($^{\circ}\text{C}$) relative humidity (%), cloud cover (Tenth), precipitation (mm), atmospheric pressure (mbar) and Solar radiation (W/m^2). The upper air meteorological data were not available for the study site. Therefore, upper air estimator is used to generate the vertical profile of the wind field. An upper air estimator, in the AERMET based on the well referred algorithms (Thomson, 1992) has been used to estimate the convective mixing height using surface meteorological data (The, 2011).

Figure 4 shows the windrose diagram of the study period in summer season. The data collected from site specific meteorological station which is located at an height of 3.5 meter from the ground level. It is observed that the dominant wind direction were blowing from the West side and followed by Northwest direction. The wind were 12% of the times were calm, 13 % of the times were blowing with wind speed in range of 0.5-1.0 m/s, 51 % of the times in range of 1-2 m/s, 18.6 % of the times in range of 2-3 m/s and 5.5 % of the times in range of 3-7 m/s.

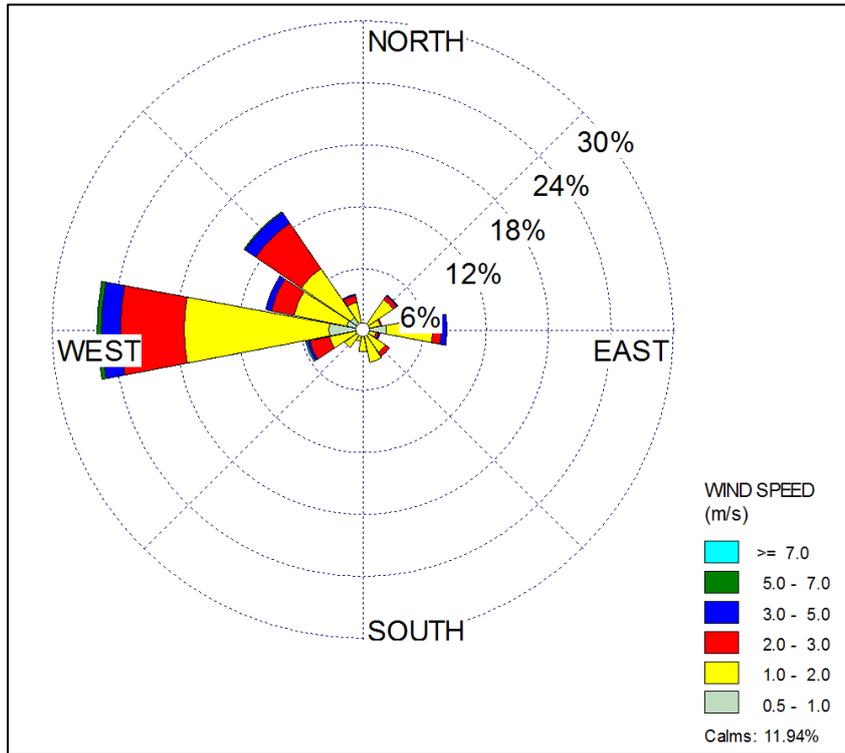


Figure 2: Windrose diagram summer period (1-30 June 2016)

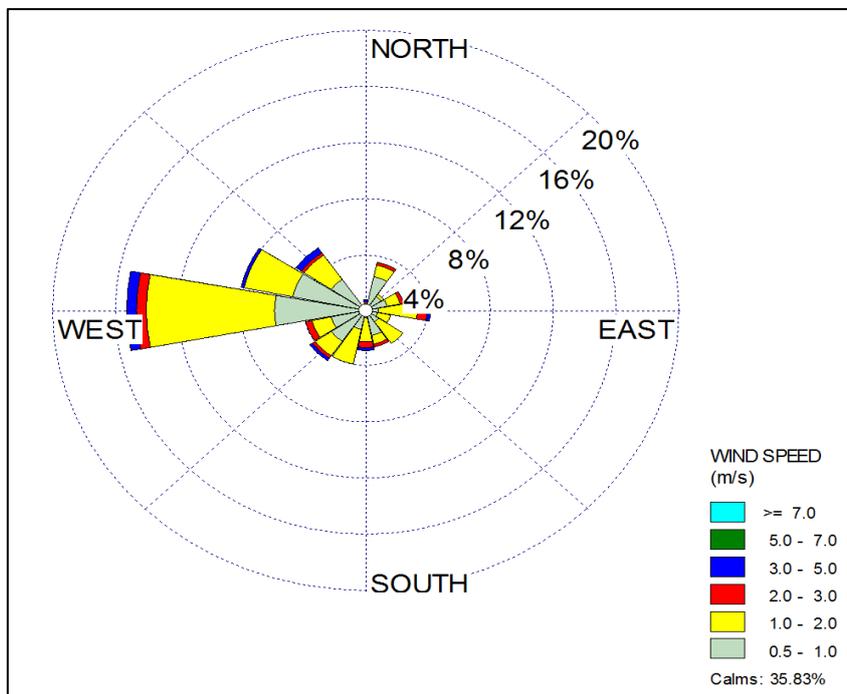


Figure 3: Windrose postmonsoon period (26 Sept.- 15th Oct., 2016)

It was observed that the dominant wind direction were blowing from the West side and followed by West-Northwest direction. The wind were 35.8% of the times were calm, 30.7 % of the times were blowing with wind speed in

range of 0.5-1.0 m/s, 28% of the times in range of 1-2 m/s and 5.4 % of the times in range of 2-5 m/s.

b. Emission Rate Estimation

In the case of odour, the parameter to be considered for dispersion modelling purposes is the Odour Emission Rate (OER), which is expressed in odour units per second ($OU_E s^{-1}$) and is obtained as the product of the odour concentration and the air flow associated with the source (EN 13725, Capelli et al., 2013) . The emitted air flow can be calculated by measuring the air velocity and the duct transversal section, and then the OER is obtained as follows:

$$OER = Q_{air} \times C_{od}$$

where OER= Odour Emission Rate ($OU_E s^{-1}$)

Q_{air} = Effluent volumetric air flow ($m^3 s^{-1}$)

C_{od} = measured odour concentration ($OU_E m^3$)

In the case of area sources, where emissions typically come from extended solid or liquid surfaces, it is first necessary to distinguish between: active sources, which have an out coming air flow (e.g., bio filters or aerated heaps), and passive sources, where there is no out coming air flow and the mass flow from the surface to the air (volatilization) is due to phenomena such as equilibrium or convection. The estimation of the OER requires the calculation of another significant parameter, i.e. the Specific Odour Emission Rate (SOER), expressed in odour units emitted per surface and time unit ($OU_E m^{-2} s^{-1}$), according to the following equation:

$$SOER = (Q_{air} \times C_{od}) / A_{base}$$

Where SOER = Specific odour Emission Rate ($OU_E m^{-2} s^{-1}$)

Q_{air} = air flow rate inside the hood ($m^3 s^{-1}$)

C_{od} = measured odour concentration ($OU_E m^{-3}$)

A_{base} = base area of the hood (m^2).

Table 1 : Emission rate at four different sources at Ghazipur Landfill site during summer period (pre – monsoon) and post monsoon

Sl.	Sampling Location	Pre-monsoon			Post monsoon		
		A	B	C	A	B	C
1.	RDF	922.00	5	353.61	922.00	5	549.32
2.	Old Dump Cell	225200.00	27	33.4	6000.00	27	735.76
3.	Active Dump Cell	6000.00	47	658.96	225200.00	47	40.05
4.	Leachate Collection Tank	10.82	0	635.84	10.82	0	957.55

Note: A=Source Area (m²) ; B=Height from Ground (m) ; C = Specific Odour Emission Rate (SOER) in OU/m²/sec. ; The odour emission rate of the particular area is arrived by taking Geometric mean of monitored odour concentration at different location

c. Topographical parameters :

The spatial domain of the simulation has been setup as per actual mean sea level including all the emission sources to be studied, as well as the receptors that are believed to be impacted by the emitted odours, and their geographical coordinates, i.e. latitude and longitude in the UTM-WGS84 (Universal Transverse of Mercator - World Geodetic System 1984). The terrain is varying from 180 m to 220 m at 5 km area from the centre of the radius (**Figure 6**).

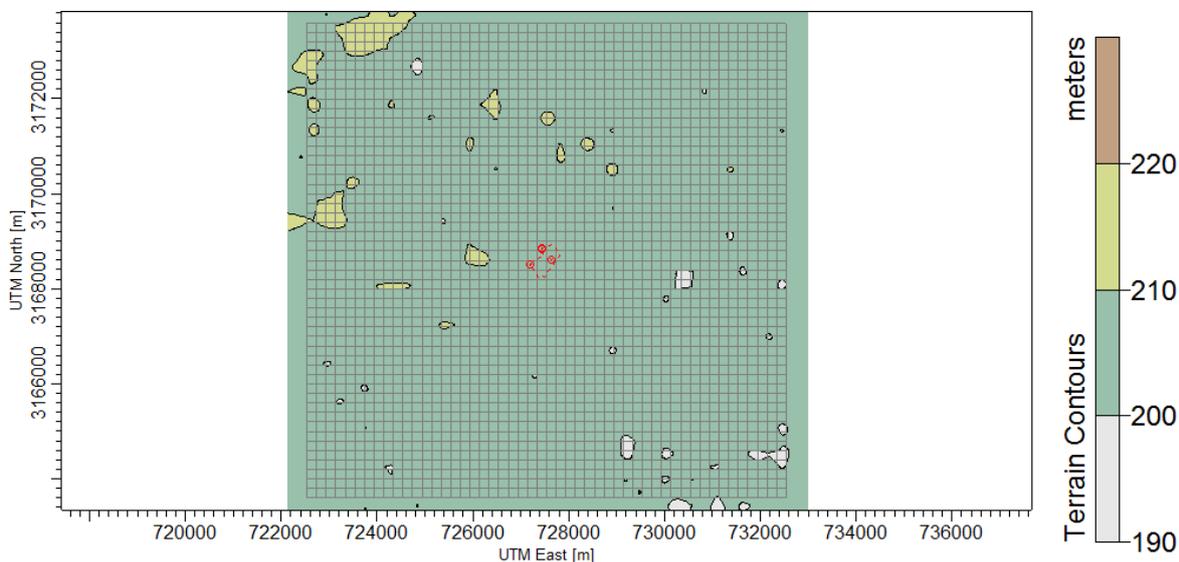


Figure 4: Terrain feature of the study area around 5 km from centre of the Landfill

6. Receptor Points

Two types of receptors are defined in the model, one discrete receptor points and second grid receptor. The discrete receptor points are those location where ambient odour monitoring are carried out. These monitoring data at these receptor points are compared with predicted model data to validate the model result. The details of discrete locations are given in **Tables 4** and **5** for summer and postmonsoon, respectively. The receptor grid of size 10 km x 10 km area around the centre of the landfill site with each grid cell size of 200 m. The model domain has been setup using UTM coordinates with four major sources i.e. Active Dump, Old Dump, Refuse Drived Fuel and Leachate Tank. **Figure 7** shows the screen shot of AERMOD and Goggle veiw showing the areas source defined in the model.

Table 2: Receptor locations during Summer Season (pre – monsoon)

Date	Receptor Code	Receptor Locations	Concentration OU/m ³
13.06.2016	R1	Up-Wind AC-B,500 Meter, ODC- UW (A, B),GC-UW LC-UW (Nr. Shive Dharam Kata/Nr. Ghazipur Dairy Farm)	238
	R2	AC-DW1 (B),500 Meter, ODC-DW1 (A,B),GC-DW1,LC-DW1 (Nr. Ambedkar Bhawan, Rajveer Colony)	239
	R3	AC-DW-2 (B),500 meter,ODC-DW-2 (A,B),GC-DW2,LC-DW 2 (Nr. Police Station, Mulla Colony)	275
14.06.2016	R4	Active Dump Cell A Up-Wind 500 Meter (Nr. Metro Station/Ghazipur Dairy Farm)	60
	R5	ADC-A-DW 2 (Nr. Police Thana)	229
	R6	ADC-A-DW 1 (Mulla Colony)	281
15.06.2016	R7	Fish/SH/PH-Up Wind (Entry Gate EDMC)	79
	R8	SH/PH/FM DW 1 (Back Side Police Thana)	71
	R9	SH/PH/FM DW 2 (Nr.Ajay Paper Cop.,Plot No. 375, Pocket-C, Nr. Khoda Colony)	59
	R10	Fish Market (Main Gate)	660
	R11	Slaughter House (Boiler Room/Utility)	199
16.06.2016	R12	BW-N (Nr. LC/GC)	188
	R13	BW-E	380
	R14	BW-S	146
	R15	BW-W near RDF plant (just Near)	555
17.06.2016	R16	BW-SW near RDF plant	501
	R27	BW-NE near Old dump Site Gail	102
	R18	BW-SE	162
	R19	BW-NW (Entry toward RDF side)	436
18.06.2016	R20	1000 Meter North Direction	36
	R21	1000 Meter East Direction	63
	R22	1000 Meter West Direction	36
	R23	1000 Meter South Direction	24

Table 3: Receptor locations during Post-monsoon Season

Date	Receptor Code	Receptor Locations	Concentration OU/m ³
27.09.2016	R1	AC- DW-2(B)/500 Meter/ODC-DW2 (A,B) / GC-DW2/LC-DW2, (Nr. Ambedkar Bhawan, Rajveer Colony)	367
27.09.2016	R2	AC- DW-1 (B)/500 Meter/ODC-DW-1(A,B)/GC-DW1/LC-DW1, (Nr. Police Station, Mulla Colony)	312
28.09.2016	R3	1000 Meter North Direction	31
28.09.2016	R4	1000 Meter East Direction	71
28.09.2016	R5	1000 Meter West Direction	47
28.09.2016	R6	1000 Meter South Direction	29
29.09.2016	R7	AC- Up-Wind (A)/500 METER, (Nr. Metro Station/Ghazipur Dairy Farm)	96
29.09.2016	R8	AC- DW-1 (A), (Mulla Colony)	382
29.09.2016	R9	AC- DW-2 (A), (Nr. Police Thana)	301
30.09.2016	R10	Bowndary wallW-1, N, (Nr. LC/GC)	276
30.09.2016	R11	BW-2, W, (near RDF plant)	741
30.09.2016	R12	BW-3, E	478
30.09.2016	R13	BW-4, S	149
01.10.2016	R14	Fish/SH/PH-Up Wind (Entry Gate EDMC)	77
01.10.2016	R15	Fish Market (Main Gate)	620
01.10.2016	R16	Slaughter House (Boiler Room/Utility)	173
03.10.2016	R17	BW-5, NW, (entry toward rdf side)	312
03.10.2016	R18	BW-6, NE, near Old dump Site Gail	128
03.10.2016	R19	BW-7, SE	211
03.10.2016	R20	BW-8, SW near RDF plant	524

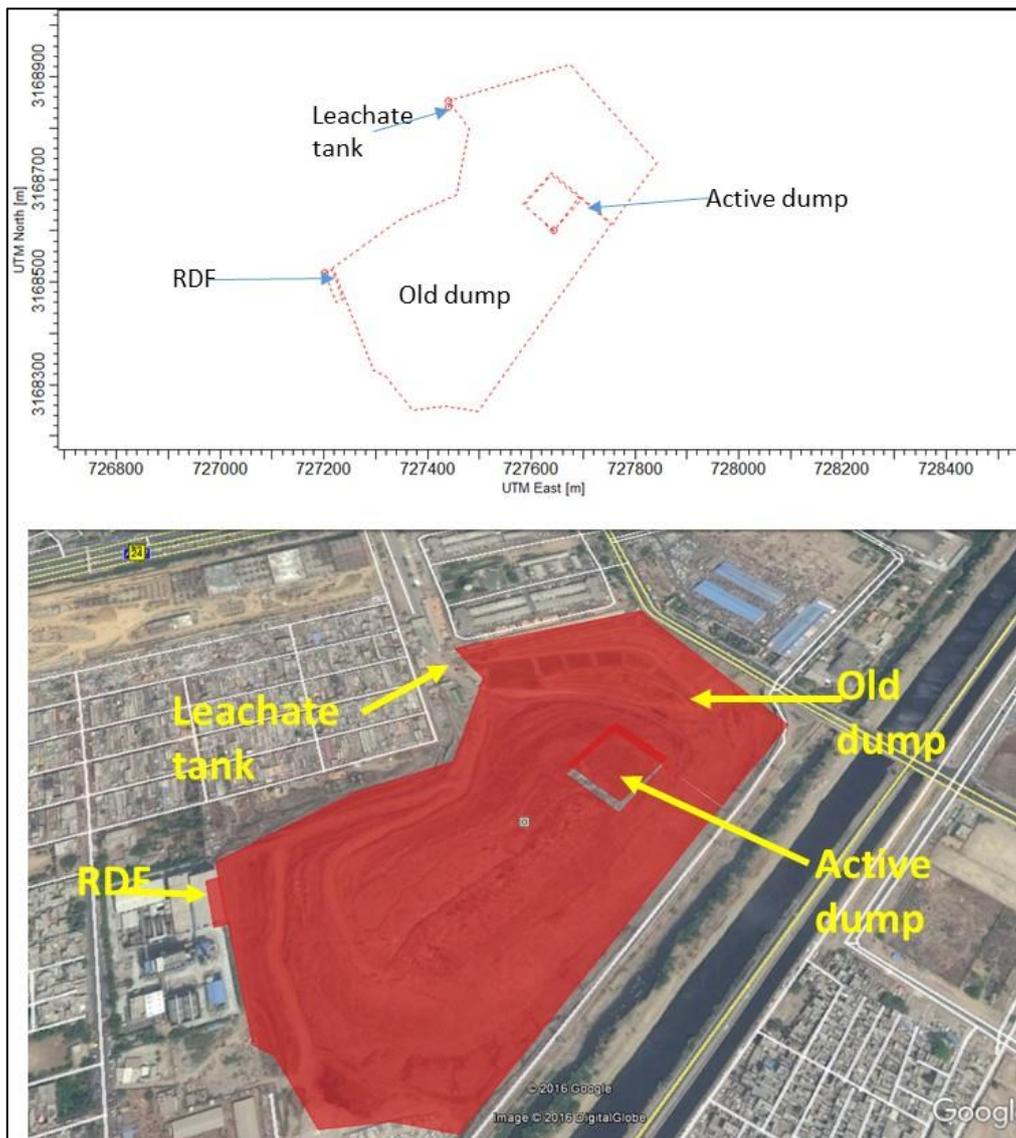


Figure 5: Area sources of Ghazipur Landfill site

7. Model Validation

In addition to the above input parameters, the following options were also considered in the AERMOD model.

- Dispersion option: Regulatory default,
- Pollutant averaging: 1 hours, 24 hours,
- Pollutant Type: Odour
- Emission rate unit: OU/m²/sec
- Dispersion coefficient: Urban
- Terrain Type: Elevated + Flat
- Source Type: Area
- Source location (X, Y): UTM Coordinates

- Terrain Feature: Digital Elevation Model (DEM) file
- Receptor locations: Discrete and Grid receptor

a. Index of Agreement (d)

The value **d** determines the extent to which magnitudes and signs of the observed values about \bar{O} (mean) are related to the predicted deviations about \bar{O} , and allows for sensitivity toward differences in O and P as well as proportionality changes (Willmott, 1981). It is a standardized measure of the degree of model prediction error and varies between 0 and 1. Therefore, it is a measure of how well model estimates depart from observed mean matches the observation departure from observed mean. It represent following equation.

$$d = 1 - \frac{\sum_{i=1}^n (P_i - O_i)^2}{\sum_{i=1}^n (|P_i - \bar{O}| + |O_i - \bar{O}|)^2}$$

P_i = predicted value
 O_i = observed value
 \bar{O} = observed mean

b. Fractional Bias

Fractional bias is a non-linear operator which is used to represent the relative difference between modelled and observed concentration in a bounded range (Cooper, 1999). It is convenient to compare results with different levels of concentration since it is symmetrical and dimensionless number.

$$FB = 2(\bar{O} - P_{\text{mean}}) / (\bar{O} + P_{\text{mean}}).$$

P_{mean} = Average of predicted concentration
 \bar{O} = Average of observed concentration

10. Results – Pre monsoon (summer season)

a. Summer Season - Model validation for Summer season (pre mnsoon)

The predicted and observed odour concentration are compared using different statistical descriptors and line diagram between predicted and observed concentrations. **Table 6** shows the statistical descriptor values calculated using predicted and observed odour concentration at different receptor locations. The result indicate the AERMOD predict odour concentration statistafactorily having d values of 0.41. The value of FB is also found at boundary of the ideal range. **Figure 8** shows the line diagram between predicted odour concentration by AERMOD and obserbved concentration at different locations arround the landfill site. It is found the predicted concentration values are close to the observed odour concentration. However, slight variations are noticed between AERMOD and monitoring result which might be due to the influence of

other nearby sources such as fish market (in North direction), Chicken market (in North east), Slaughter house (In east direction) and Ghazipur dairy (in Northwest direction). These source may emit huge odour which increase the baseline/background concentration of the study area. The background concentration is an important parameter for any air quality modelling study. In the present study, the odour concentration at 1000 m in the upwind direction during summer season is used as baseline/background concentration.

Table 4: Statistical descriptors for Summer season

Sr. No.	Parameters	Values	Ideal Range
1	Index of Agreement (d)	0.41	0.4 to 1.0
2	Fractional Bias (FB)	0.55	-0.5 to 0.5

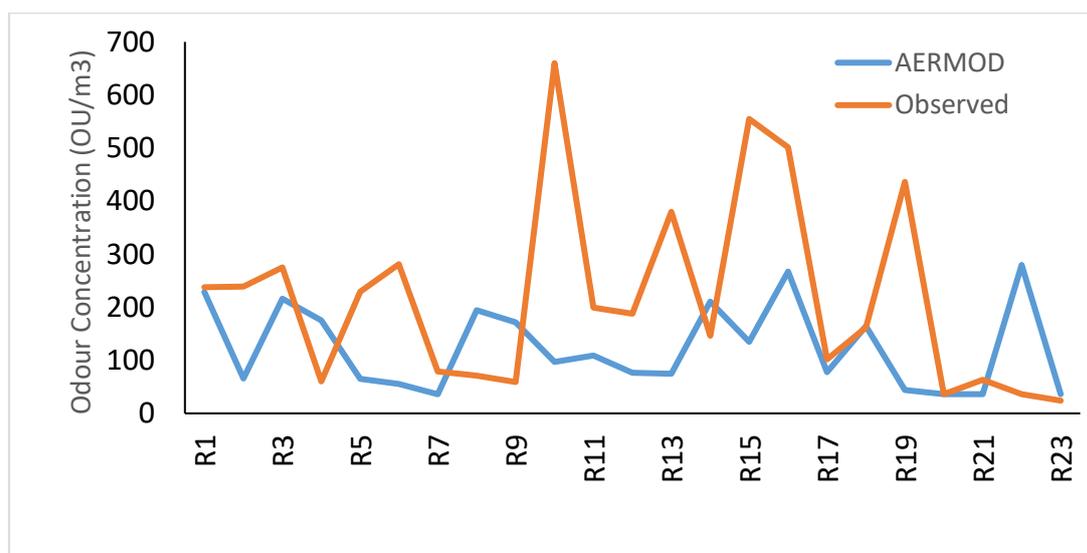


Figure 6: Line diagram of AERMOD Predicted and Observed Concentration during Summer season

b. Odour Pollution Map for Summer season

The odour pollution map are prepared around Ghazipur landfill site for an area of 10 km x 10 km with grid cell size of 200 m each. The pollution maps are prepared separately for hourly (**Figure 9**) and 24 hourly (**Figure 10**) average odour concentration. The background concentration does not added in these map. The maximum ground level concentration (GLC) of odour emitted from Landfill site is 712 OU/m³ at locations within the boundary of the landfill site. The 24 hour average odour pollution map clearly shows the higher concentration in the down wind direction of the landfill (East direction). The maximum GLC are found to be 155 OU/ m³ at

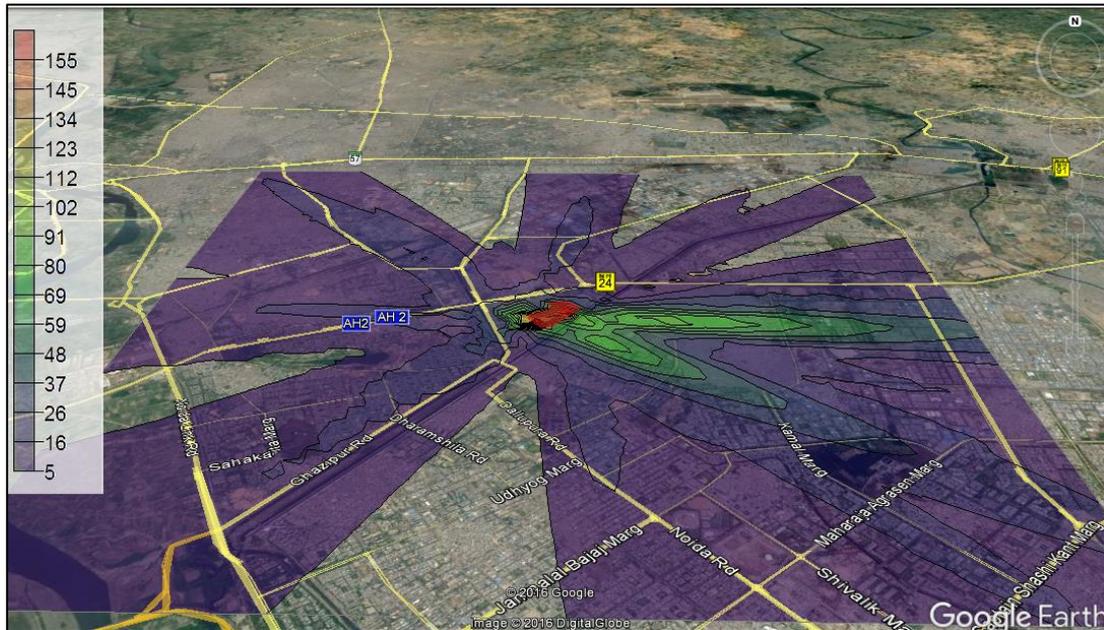


Figure 9: 24-Hour average odour concentration around landfill 10 km x 10 km area on Google view

c. Scenario analysis for Summer season

A separate analysis has been carried out to predict the contribution of each source (out of four landfill source) on the odour concentration at receptor location. Further, simulation has been carried out for different combination of sources (**Table 7**). The simulation results indicate that out of all four sources, the old dump contributed maximally followed by RDF and active dump (**Figure 12**). However, Active Dump Cell, Old Dump Cell and Leachate Collection Tank combined altogether, contribute odour concentration of 104 OU/m³ while Active Dump Cell and Old Dump Cell also contribute similar concentration level.

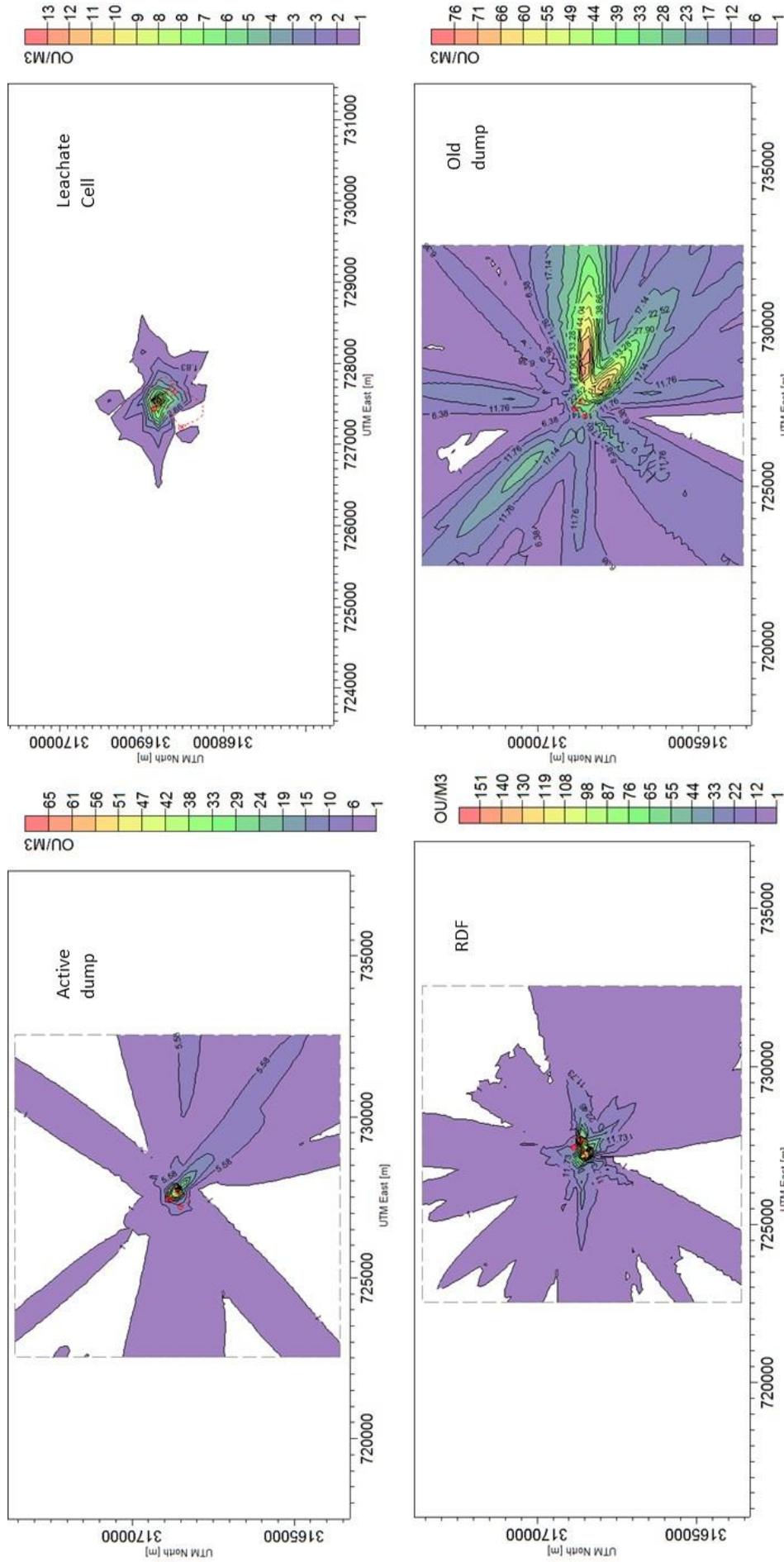


Figure 10: Contribution of respective sources towards 24-Hour average odour concentration around landfill 10 km x 10 km area

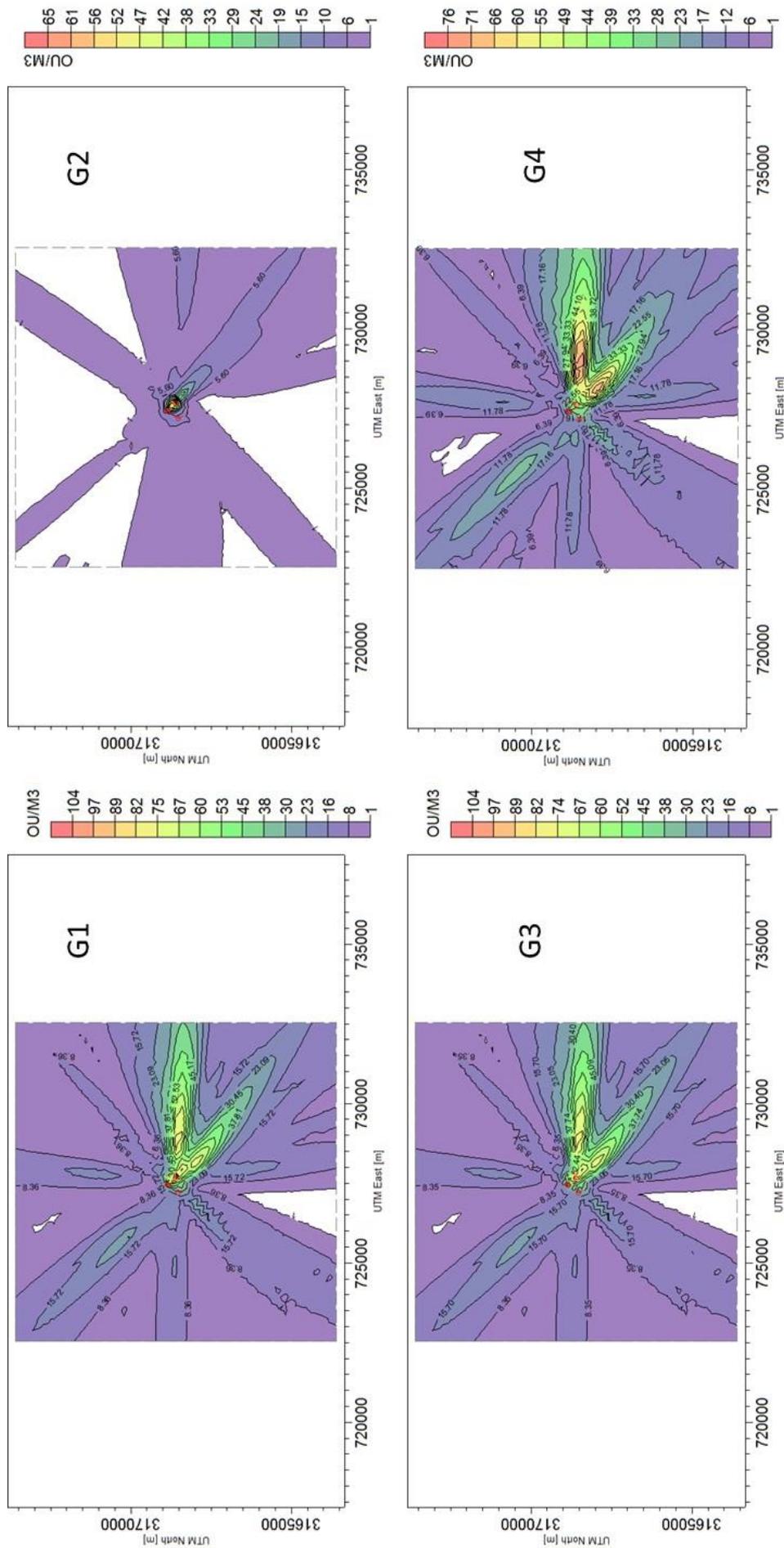


Figure 11: Contribution of respective sources towards 24-Hour average odour concentration around landfill 10 km x 10 km area

d. Impact of odour emission reduction from landfill site

If the odour control practices implemented at the landfill are done efficiently, then it may reduce the emission of odour up to 25%. Further, the odour dispersion simulation has been carried assuming reduction in odour emission by 75%, 50% and 25%. **Table 8** and **Figure 14** show the impact of odour reduction from landfill site at the surrounding region.

Table 5: Landfill Sources Gropus for Post monsoon

Group	Sources
G1	Active Dump Cell, Old Dump Cell, Leachate Collection Tank
G2	Active Dump Cell, Leachate Collection Tank
G3	Active Dump Cell, Old Dump Cell
G4	Old Dump Cell, Leachate Collection Tank

Table 6: Impact of odour emission reduction from landfill site

Sr. No.	Reduction in Odour emission	Max GLC (OU/m ³)	GLC at 5 km downwind direction (OU/m ³)
1	75%	39	9.1
2	50%	78	17.44
3	25%	117	25

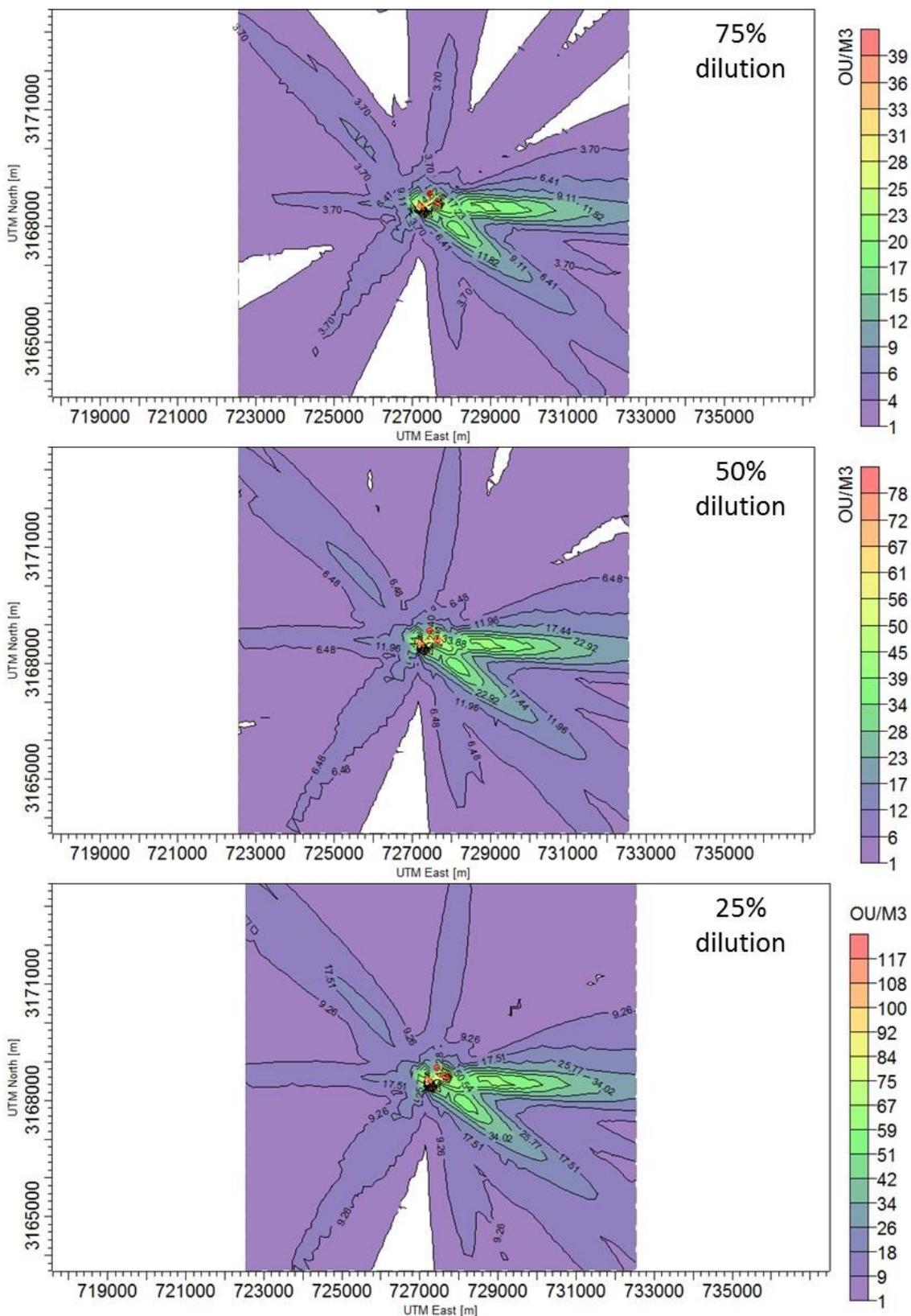


Figure 12: Odour concentration isopleth with different emission reduction from landfill

e. Simulation to evaluate maximum probable distance for 5.0 OU/m³ cut-off for Summer

To evaluate the maximum probable distance for odour concentration of 5.0 OU/m³ cut-off, the modelling domain has been extended up to 50 km x 50 km with receptor grid cell size of 1 km x 1 km. The simulation results indicate that at distance of 24 km from the boundary of landfill site, the downwind predicted odour concentration is 5.0 OU/m³. The details are given in **Table 9** and **Figure 15**.

Table 7. Predicted Odour concentration wrt downwind distance (pre monsoon)

Distance from boundary of Old Dump	24 hr. average odour Concentration [OU/m ³] downwind side
0	112
0.25	82.5
0.5	69.8
1	63.3
2	32.6
3	19.1
5	10.8
10	8.01
15	6.26
20	4.88

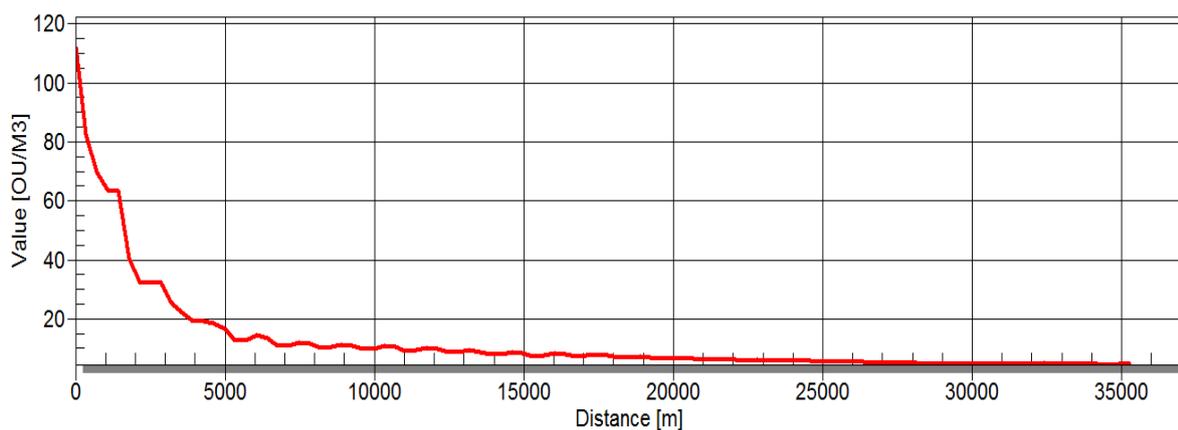


Figure 13: Predicted 24 hr average Odour concentration wrt downwind distance (pre monsoon)

11. Results – Post - monsoon season

a. Model validation for Post monsoon

Table 10 shows the statistical descriptor values calculated using predicted and observed odour concentration at different receptor locations. The result indicate the AERMOD predict odour concentration statistifactorily having d values of 0.7. The value of FB is also at the boundary of the ideal range which indicate slight under prediction by the AERMOD. The predicted concentration values are close to the observed odour concentration (**Figure 16**). However, slight variations are noticed between AERMOD and monitoring result which might be due to the influence of other nearby sources such as fish market (in North direction), Chicken market (in North east), Slaughter house (In east direction) and Ghazipur dairy (in Northwest direction). These source may emit huge odour which increase the baseline/background concentration of the study area. The background concentration is an important parameter for any air quality modelling study. In the present study, the odour concentration at 1000 m in the upwind direction during post monsoon season is used as baseline/background concentration. Barnéoud et al. (2012) have found similar results when compared two Gaussian steady state plume model for odour impact assessment arround an urban composting plant.

Table 8: Statistical descriptors for Post monsoon season

Sr. No.	Parameters	Values	Ideal Range
1	Index of Agreement (d)	0.71	0.4 to 1.0
2	Fractional Bias (FB)	0.68	-0.5 to 0.5

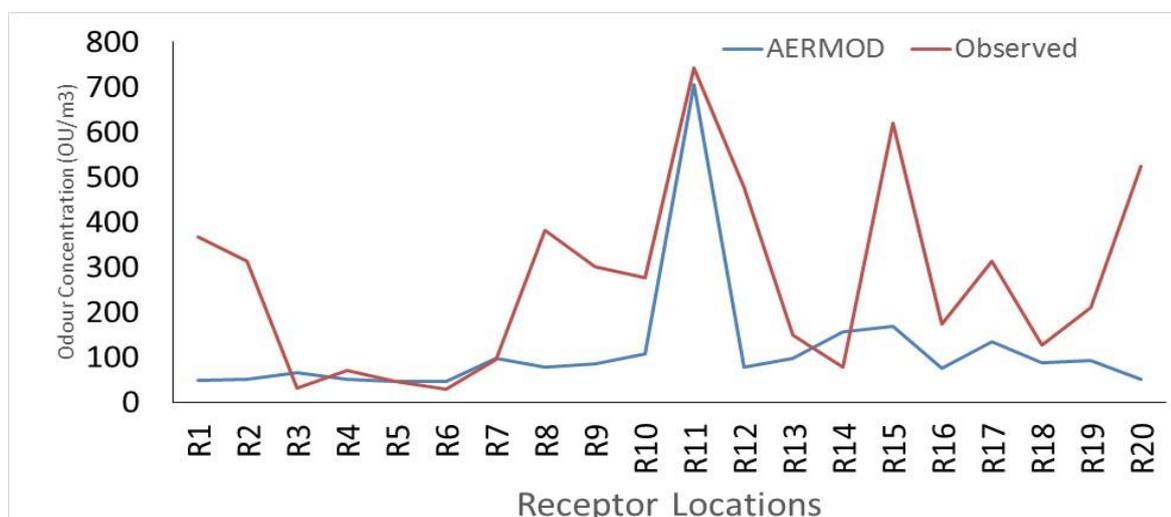


Figure 14: Line diagram of AERMOD predicted and Observed Concentration during Post monsoon season

b. Odour Pollution Map for Post monsoon

The pollution maps are prepared separately for hourly (**Figure 17**) and 24 hourly (**Figure 18**) average odour concentration. The background concentration does not added in these map. The maximum hourly GLC of odour emitted from Landfill site is 336 OU/m³ at location within the boundary of the landfill site. The 24 hour average odour pollution map clearly shows the higher concentration in the down wind direction of the landfill (East direction). The maximum GLC is found to be 80 OU/ m³ at boundary of the landfill site in the down wind direction. **Figure 19** shows the odour dispersion map of 24 hour average concentration on google map.

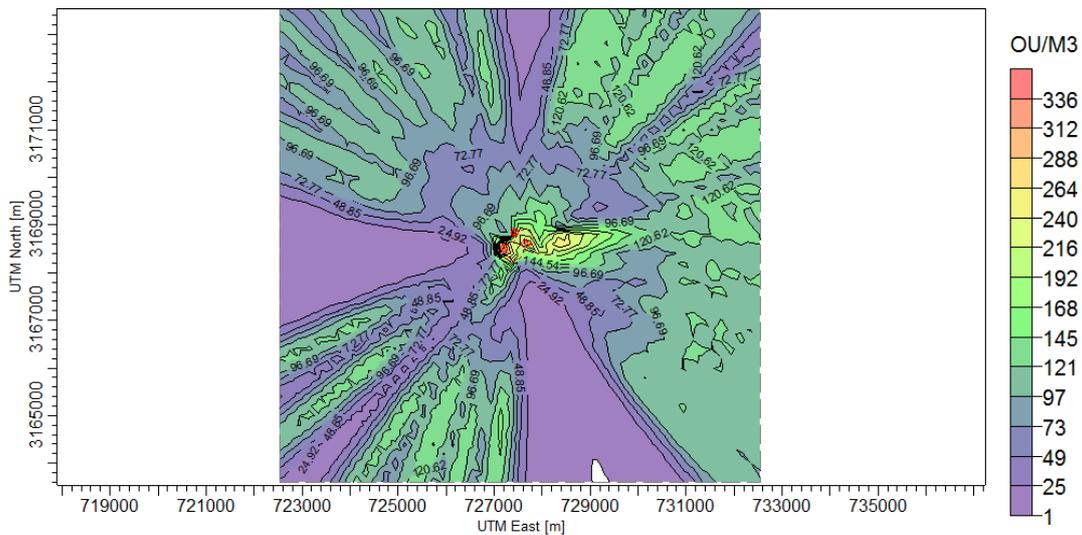


Figure 15: Hourly average odour concentration around landfill 10 km x 10 km area during post monsoon

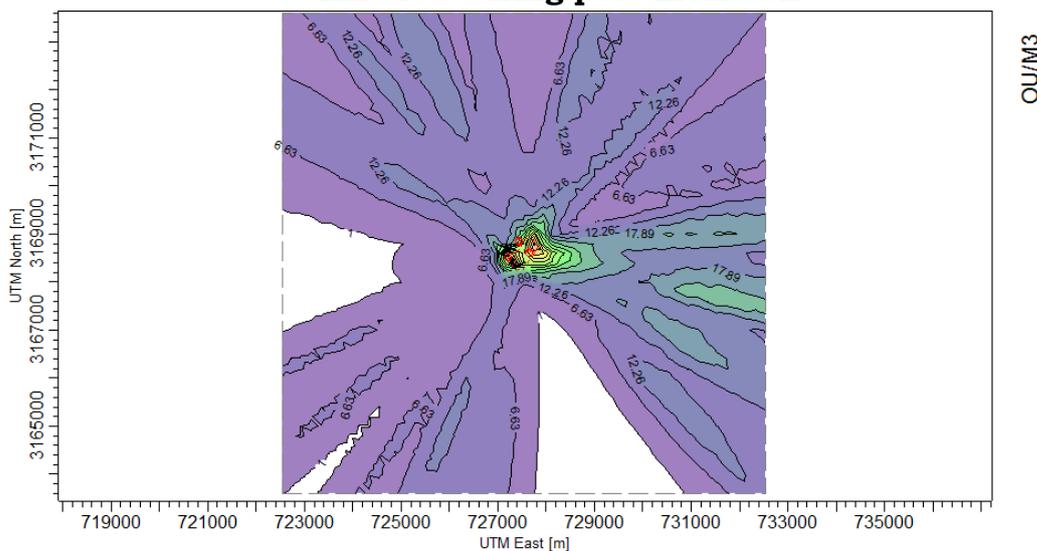


Figure 16: 24-Hour average odour concentration around landfill 10 km x 10 km area during post monsoon



Figure 17: 24-Hour average odour concentration around landfill 10 km x 10 km area on Google view during post monsoon

c. Scenario analysis for Post monsoon season

Similar to Summer season, simulation has been carried out for different scenarios such as contribution of each source (out of four landfill sources) on the odour concentration at receptor locations. **Figure 20** shows that RDF contributed maximally followed by Old dump and active dump. Further, simulation has also been carried out for different combinations of sources (Table 7). The simulation results indicate that out of all four sources, the old dump contributed maximally followed by RDF and active dump (**Figure 21**). However, Active Dump Cell, Old Dump Cell and Leachate Collection Tank combinedly contribute an odour concentration of 71 OU/m³ while Active Dump Cell and Old Dump Cell also contribute a similar concentration level.

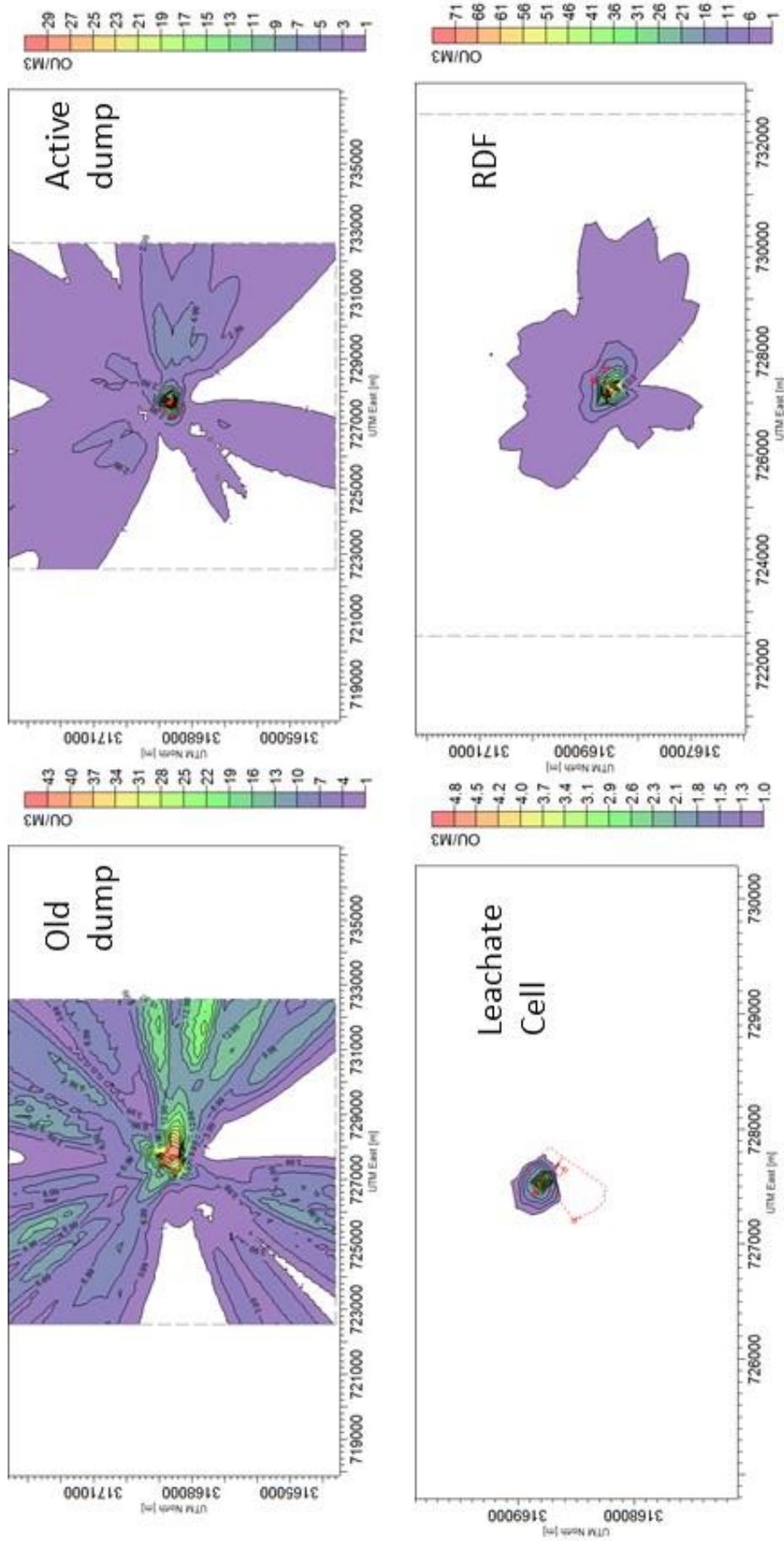


Figure 18: Contribution of respective sources towards 24-Hour average odour concentration around landfill 10 km x 10 km area

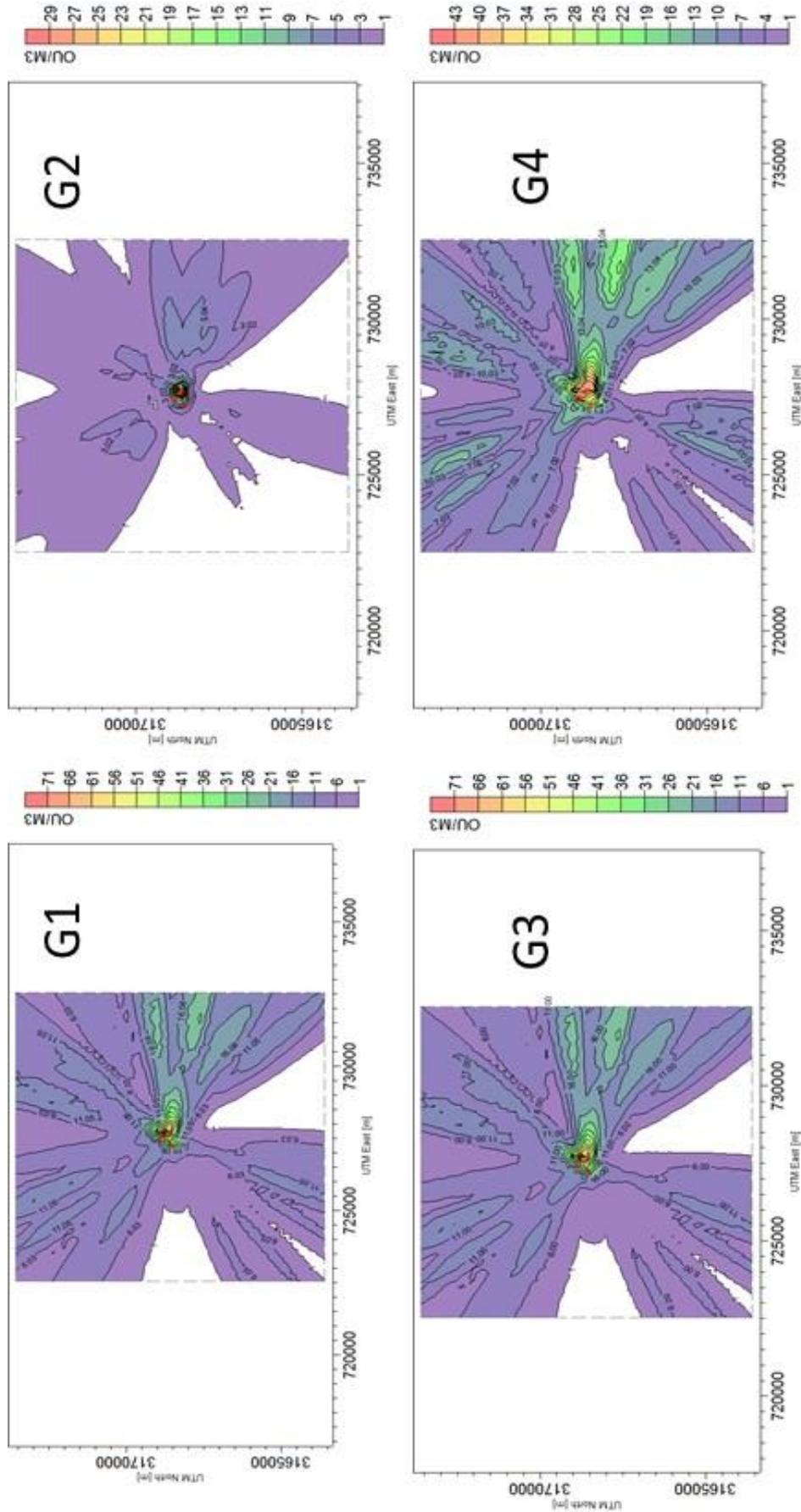


Figure 19: Contribution of respective sources towards 24-Hour average odour concentration around landfill 10 km x 10 km area

The odour dispersion simulation has been carried assuming reduction in odour emission by 75%, 50% and 25%. **Table 11** and **Figure 22** show the impact of odour reduction from landfill site at the surrounding region.

Table 9: Impact of odour emission reduction from landfill site

Sr. No.	Reduction in Odour emission	Max GLC (OU/m ³)	GLC at 5 km downwind direction (OU/m ³)
1	75%	20	3.7
2	50%	40	6.5
3	25%	60	9.4

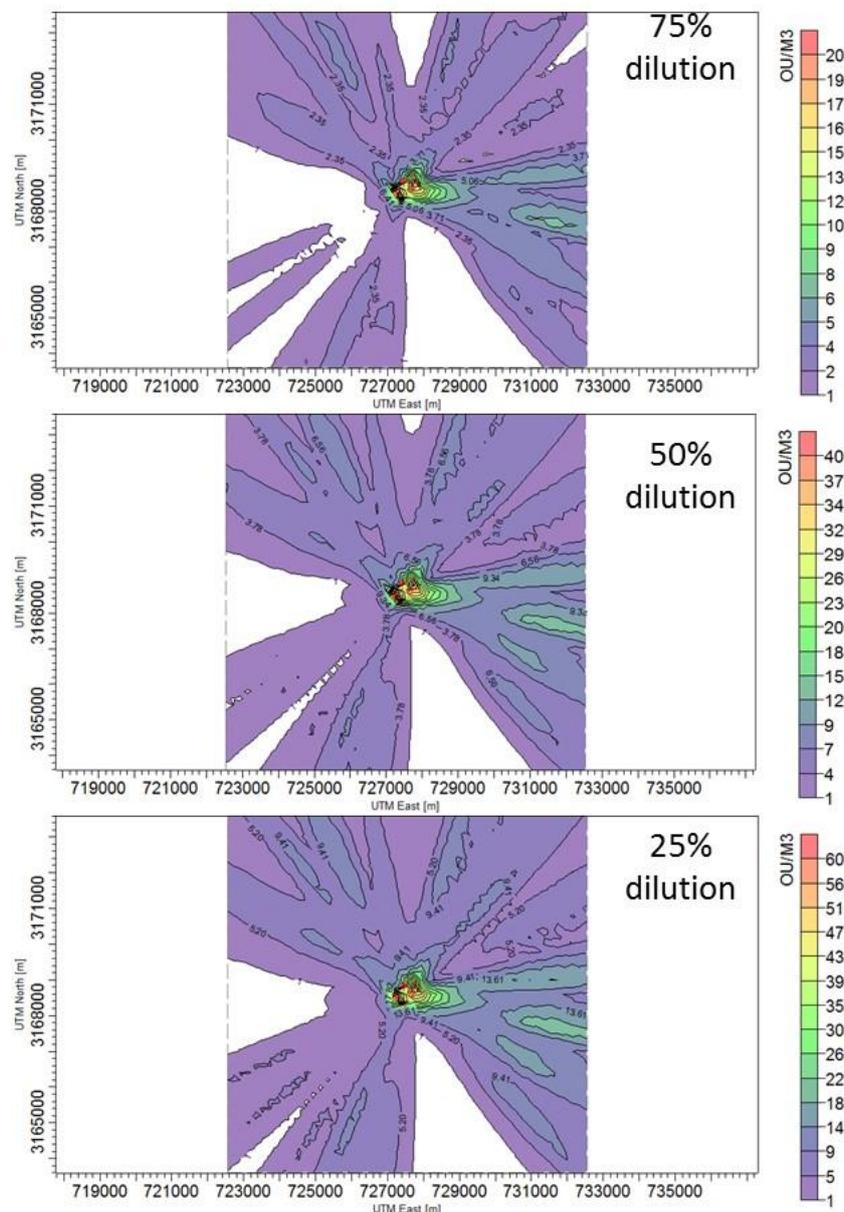


Figure 20: Odour concentration isopleth with different emission reduction from landfill

Simulation to evaluate maximum probable distance for 5.0 OU/m³ cut-off for post monsoon season

Similar to summer season, the maximum probable distance for odour concentration of 5.0 OU/m³ cut-off has been evaluated for post monsoon season. The modelling domain has been extended up to 50 km x 50 km with receptor grid cell size of 1 km x 1 km. The simulation results indicate that at distance of 22.5 km from the boundary of landfill site, the odour predicted odour concentration is 5.0 OU/m³ in downwind side. The details are given in **Table 12** and **Figure 23**.

Table 10: Predicted Odour concentration wrt downwind distance

Distance from boundary of Old Dump	24 hr. average odour Concentration [OU/m ³] downwind side
0	43.3
0.25	36.2
0.5	34.1
1	29.4
2	17.4
5	20.2
10	12.1
15	9.01
20	6.55
22.5	4.99

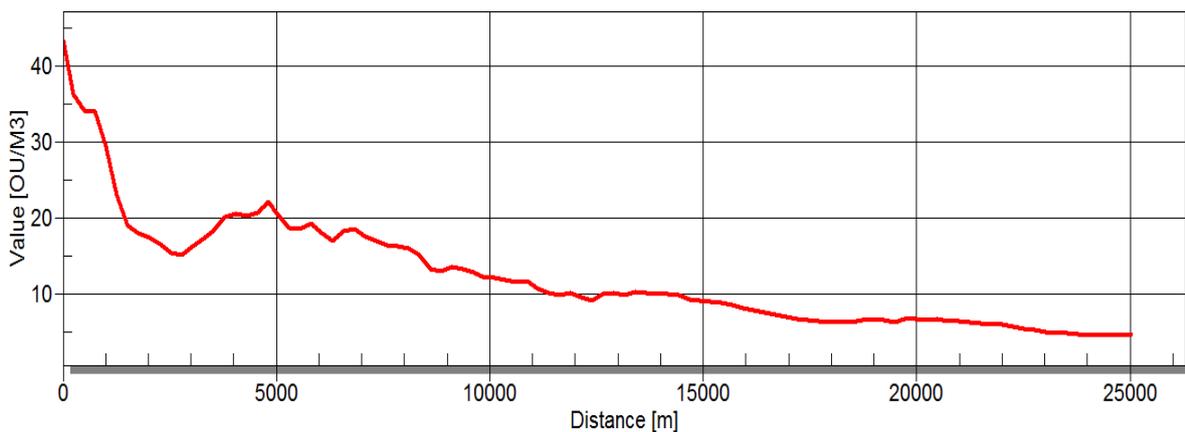


Figure 21: Predicted 24 hr average Odour concentration wrt downwind distance

12. Conclusion and Recommendations

The present study evaluated the dispersion of the odour concentration emitted from the MSW landfill site in Delhi i.e., Ghazipur MSW Landfill site. The Landfill site receives approximately 2000- 2200 metric tons of municipal solid waste per day. The landfill site emits odour from four-different activity/sources such as Refuse Derived Fuel (RDF), Active dump area, Leachate tank and old dump area which are located at different heights from the ground. The dispersion modelling is carried out by considering all these four sources for summer and Post-monsoon season. The results of the study conclude and recommends the following:

1. AERMOD performed satisfactorily during summer ($d= 0.41$) and Post monsoon ($d= 0.70$) seasons. It also inferred that AERMOD is slightly under predicted the odour concentration in both the seasons with satisfactory range.
2. Further, simulations are carried using different combination of sources and found that old dump (largest area) contribute maximum at the receptor location even its emission rate is lowest compared to other three sources.
3. The simulation results indicate that the predicted odour concentration of 5.0 OU/m^3 in downwind side are estimated at 24 and 22.5 km from the boundary of the landfill during summer and post monsoon period, respectively.
4. *The under prediction of the AERMOD may be due to the presence of other odour emitting sources in the nearby regions such as fish market (in North direction), Chicken market (in North east), Slaughter house (in east direction) and Ghazipur dairy (in Northwest direction) which emit huge odour. These sources may increase the background/baseline odour concentration. It is suggested that any odour dispersion modelling of landfill should be carried out including all the nearby sources and later find out the contribution of each sources at receptor location using air quality model.*
5. This study provides a *Standard Protocol/Methodology* for odour dispersion emitting from a Landfill site. This modelling approach can be used to evaluate the odour dispersion of any landfill site using respective site specific odour emission, meteorology and topographic data including all the nearby influencing sources other than investing sources.

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Part 4

Guidelines on Odour Monitoring in Urban MSW Landfills



**Guidelines on Odour Monitoring in
Urban MSW Landfills**

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ODOUR IS A PUBLIC NUISANCE

Growing awareness on odour

Increasing awareness on odorous emissions from effluent , sewage & solid wastes due to lack of adequate scientific tools to assess odour levels. Besides increasing public complaints due to odorous emissions from above sources.

Table : Some Common sensory perceptions

Sensory tool	Sensory Perception
RAINBOW (eyes)	the seven key colors - VIBGYOR
MUSIC (ear)	Seven key notes : sa-re-ga-ma-pa-dha-ni or do-re-me-fa-so-la-ti
TASTE (tongue) (range bitter to sweet)	Five key tastes : sweet, sour, bitter, salty, and umami (Japanese flavour).
ODOUR (nose) Science of smell—olfaction— was too complex for experts to group neatly into categories. Now researchers from Bates College and the University of Pittsburgh have used a mathematical algorithm to bring hundreds of standard smells down to their basic essence	Odours fall into combination of following NINE basic categories of smell: (1) Fragrant (2) woody/resinous (3) Fruity (citrus) (4) chemical (5) minty/peppermint (6) sweet (7) popcorn (8) pungent (9) decayed/ rotten

Odour perception by the human brain

Odour is defined as perception of smell , it may be range from being unpleasant (rotten smell of garbage) to pleasant (ex fragrance) and is generally caused by one or more volatilized chemical compounds, generally at a very low concentration, that humans are able to perceive by the sense of olfaction. Odour sensing mechanism is unique in man & animals. Due to the complex nature of odour perception, the level of sensitivity (response) to odour within a population may vary from person to person. An impulse of smell is conveyed by two main nerves:

- Olfactory nerve (first cranial nerve) : these nerves process the perception of chemical.

- Trigeminal nerve (Fifth cranial nerve): process the irritation or pungency (sensation of chemical)

All the olfactory signals meet in the olfactory bulb from where the information is distributed to two different parts of the brain. One of the major pathways of information is to the limbic system which processes emotions and memory response of the body. The second major pathway involves frontal cortex, where the conscious sensations take place, as the information is processed with other sensations, it is then compared with accumulated life experiences (memory) of individuals to explore possibility to recognise the odour and make the necessary decision. This entire activity from sensation in nostrils to signal in the brain is completed within 500 milli seconds.

Odour affects quality of life – a public nuisance

Presence of any air pollutants or odour at undesirable levels affects air quality thereby affecting normal life of citizens. Odour, in scientific terms is an organoleptic attribute perceptible by the olfactory organ on sniffing certain volatile substances. The odour sensation is induced by inhaling airborne volatile organics or inorganics, which may or may not have toxic effects. Partial putrefaction of the waste produces obnoxious odorous volatile organic and inorganic substances disturbs the aesthetic environment.

Odour emissions affects quality of life leading to psychological stress and symptoms such as insomnia, loss of appetite and irrational behavior. Odour emissions originate principally due to release various compounds in the atmosphere formed by the biological and chemical decomposition of the waste (mainly domestic solid waste), hence complaints on odour are increasingly on the rise more often in thickly populated areas particularly w.r.t. municipal waste disposal practices. The odour sources may be numerous (drains, stagnant water bodies, fish & meat markets) however (municipal) solid waste disposal sites attract maximum complaints from nearby localities in the near vicinity.

Since odour is a perception, it is difficult to measure by any instrument or chemical method. However, conversion of equivalent sensory signal into a measured value is the basic concept of odour measurement and is termed “OLFACTOMETRY”. As Odour sensing is directly link to transmission of signals through one of the cranial nerves (olfactory) to the brain, the odour attributes may affect memory.

Health impacts due exposure to odour

The imbalance between existing infrastructure and increasing quantum of waste generation coupled with improper management of MSW increases the

vulnerability to increasing odour problems, communities residing near MSW disposal sites largely experience unpleasant odour problems. Exposure to an offensive high intensity odour may cause behaviour impact on human beings depending on the if the type of odour & its concentration (above the threshold limit) , in some cases odourants may impact health due to their toxic nature. Some of the health impacts are described as under :

- Vomiting, Headaches, Nausea
- Stress, anxiety, frustration
- Social embarrassment to host
- Restricting outdoor activities in children due to bad odour
- Sleep disruption
- Discomfort

There are several types of smell disorders depending on how the sense of smell is affected. People who have smell disorders experience either a loss in their ability to smell or changes in the way they perceive odours.



Figure : Odour Public nuisance (Improper garbage dumping & open drain discharge)

Odour – WHO’s nuisance threshold level

Health is a state of complete physical, mental and social well being and not merely the absence of disease or infirmity.

- Odours is one of the pollution perception vectors with dust and noise as the other (URBAN issue).
- Odor annoyance affects the quality of life, therefore the social well being dimension of the health;

There are several types of smell disorders depending on how the sense of smell is affected. People who have smell disorders experience either a loss in their ability to smell or changes in the way they perceive odours.

As per WHO the nuisance threshold level is defined as the concentration at which not more than a small proportion of the population (less than 5%) experiences annoyance for a small part of the time (less than 2%).

Some typical odour perceptions

Some typical odour perceptions are listed below :

- i. Substance of similar or dissimilar chemical constitution may have similar odour, nature and strength of odour may change on dilution.
- ii. Sometime odourants having strong intensity (like mercaptans) may mask the weak odourants irrespective of their concentration. Odour of same strength blends to produce a combination in which one or both may be unrecognizable.
- iii. Constant intensity of odour causes as individual to quickly diminishes perception of the sensation and only detected when it varies in intensity.
- iv. Fatigue for one odour may not affect the perception of dissimilar odour but will interfere with the perception of similar odour.
- v. An unfamiliar odour is more likely to cause complaint than a familiar one.
- vi. Two or more odourous substance may neutralize the smell of each other.
- vii. Odour travels downwind.



Figure : Poorly maintained public toilets & typical cess pool in cities

Terminologies associated with Odour

Odour analysis involves simultaneous chemical and sensory analysis. AROMAGRAM is generated by trained human panelist scoring the aroma character, duration, intensity and (un)pleasantness . When reading reports on odour related issues some new terminologies arise REFER to GLOSSARY

Figure : Odour is a fugitive emission



OVERVIEW OF CPCB's PROJECT ON ODOUR IN MSW LANDFILLS

Guidelines on ambient odour – Europe

In the United States and throughout Europe in the 1970's and 1980's there was a significant increase in public concern for odors from industrial, agricultural, and waste water treatment facilities. Many of the regulations required the measurement of odors through olfactometry, either to prove compliance or to measure and monitor odors. Olfactometry has been used throughout the 20th century in the medical research community. However, there has existed variability of results due to differences in olfactometer design and operating performance as well as the lack of consistency in odor testing methods used. Ambient Odour guidelines in some European countries is given below.

Table : Odour guidelines in some European countries

Country	Odour guidelines
Germany	Here odour limit values w.r.t. odour hours ; In residential areas odour frequency should be <10% 'odour hours' ; in industrial areas < 15% 'odour hours'. The method VDI 3940, (1993) <i>Determination of Odorants in Ambient Air by Field Inspections</i> is applied to determine licensing applications. (Odournet 2011).
Switzerland	The minimum distance setbacks for various types of animal farm ; no numeric standard (Bokowa 2010).
Austria	The guideline for general odour is 1 ou _E /m ³ at 8 % of total time and 3 ou _E /m ³ at 3 % of total time. Minimum distance setbacks for various types of animal farms. (Bokowa 2010).
Belgium	The concept of 'sniffing units' is applied , it is similar in use to odour units, but they are measured in the field rather than in the laboratory, using stack samples, as is done for odour units. (Odournet 2011). 0.5 sniffing units means very slight odour and 2 sniffing units means clear odour. The for 'no effect level' set to <u>three</u> types of odour sources. <ul style="list-style-type: none"> • 'No effect level' for <u>slaughter houses</u> is 0.5 sniffing units for 2% of total time • for <u>paint spraying</u> facilities 2 sniffing units for 2% of total time • for <u>wastewater</u> treatment plants 0.5 sniffing units for 2% of total time. The determination techniques rely on dispersion modelling of odour emissions or on field panels.
Denmark	The exposure criterion states that the ground level concentration (GLC) should not exceed 5 to 10 ou _E /m ³ , depending on the location (residential or non-residential), at a 99-percentile, with an averaging time of 1 minute. (Odournet 2011).
Poland	Has a statutory odour nuisance legislation for odour nuisance prevention guidelines. From year 2009, the guideline used is 1

	<p>ou_E/m³ at 92-percentile as a 1 hour average. From year 2013 the guideline is 1 ou_E/m³ at 97-percentile as a 1h average. (Kośmider 2010). Odour frequencies and intensities are be modelled or olfactory used in surveys surveyed.</p>
The Netherlands	<p>The objectives for odour annoyance formulated in year 1995 state that by year 2000 no more than 12% of the Dutch population would experience odour annoyance and by year 2010 Dutch people are no longer subject to 'serious annoyance' of odour. These objectives relate to odour annoyance from <u>industry, agriculture and road traffic</u>. (Lagas 2010)</p> <p>For new environmental permits dispersion modelling using 99-percentile and one hourly calculation are used in most of the cases to estimate possible odour nuisance risk (Odournet 2011).</p>
Latvia	<p>The regulations stipulate that for outline odour target values that may not be exceeded for more than 7 days a year:</p> <ol style="list-style-type: none"> 10 ou_E/m³ polluting activities of category A, B, C; 8 ou_E/m³ in agricultural lands; and 5 ou_E/m³ elsewhere in the ambient air with no regular activity. <p>Categories A, B and C are under environmental permissions excluding e.g. railroads, port or road transport hubs and waste processing warehouses. (Plāte 2005).</p>
Italy	<p>Odour regulations exist in Lombardia region. All requirements are for 2% of total time on yearly basis and hedonic tone of the odour allows authorities to raise the limits. The acceptability criteria relevant to new activities are (Cusano et al. 2010):</p> <ul style="list-style-type: none"> - 2 ou_E/m³ at the first receptor in residential area - 3 ou_E/m³ at the first receptor or at 500 m from the plant boundary in commercial areas - 4 ou_E/m³ at the first receptor or at 500 m from the plant boundary in agricultural or industrial areas <p>The acceptability criteria relevant to existing activities are:</p> <ul style="list-style-type: none"> - 1-3 ou_E/m³ depending on distance (> 500 m to < 200 m) at the first receptor in residential area - 2-4 ou_E/m³ depending on distance (> 500 m to < 200 m) at the first receptor in commercial areas - 3-5 ou_E/m³ depending on distance (> 500 m to < 200 m) at the first receptor in agricultural or industrial areas.
United Kingdom	<p>Has no specific guidelines for odours.</p> <p>However, in <u>Scotland</u> region there are indicative criteria of significant pollution which can be used in dispersion modelling when applying environmental permit for plants. Indicative criteria depend on the hedonic tone of odour. Industry types and indicative criteria (SEPA 2010)</p>
Overview of global Odour monitoring methods	<p>Besides the standards adopted are given below:</p> <ol style="list-style-type: none"> The <u>EN 13725:2003</u> - Air quality determination of odour concentration by Dynamic Olfactometry is adopted by 18 countries (Austria, Belgium, Denmark, Finland, France, Greece, Germany, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and UK).

	ii) EN 13725 has been adopted by Australia & New Zealand as AS/NZS 4323:2001. iii) ASTM E679-91 : Though there is no odour policy in US at Federal level, however most of the Universities adopt EN 13725. The European Odor Testing standard, prEN 13725 is becoming the standard of practice in the U.S. and Canada. It is being implemented in university and other research laboratories throughout North America. iv) Proposals of European Field Investigation methods include : a. prEN 264086:2011, Part 1 - Grid measurement and b. prEN 264086:2011, Part 2 - Plume measurement
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‘Odour’ nuisance recognized National regulations

Some commonly familiar odorous sources are :

- MSW - Rotting garbage
- Industry bases - Pulp & Paper , tanneries, pharmaceuticals, pesticides distilleries , beverages , paints, organic chemicals

‘Odour’ nuisance is recognized under National regulations under Environment Protection Rules 1986 including under Solid Waste Management Rules 2016 which is discussed separately.

**Table : ‘Odour’ recognized as a NUISANCE in INDUSTRIES)
(Under Schedule I , Environment Protection Rules 1986)**

Industry	Compliance norms for ODOUR
Petroleum Refinery	Standards for eqpts leaks : Any component observed to be leaking by sight , sound , <u>smell</u> regardless of concentration or presence of bubbles using soap solution should be considered as a leak
Fermentation industry (distilleries , maltries & breweries)	All efforts should be made to remove <u>Odour</u>
Natural rubber industry	Odour should be absent
Large pulp & paper mill	Hydrogen sulphide (odourous) : 10 mg/ cub.m
Coffee processing	No compliance norms , however public complaints are received.
Cashew seed processing industry	No compliance norms , however public complaints are received.
Petrochemicals (basic & intermd.)	No compliance norms , however public complaints are received.

Pesticide manufacturing & formulation	No specific compliance norms , however public complaints are received ; Hydrogen sulphide (odorous) : 5 mg/ cub.m
Tanneries	No compliance norms , however public complaints are received ;
Slaughter house – meat & sea food	No compliance norms , however public complaints are received ;
Food & fruit processing	No unpleasant odour ; however specific compliance norms
Pharmaceutical (manufacturing & formulation)	No compliance norms , however public complaints are received ;

Table : ‘Odour’ recognized as a NUISANCE in water (Under Schedule I , Environment Protection Rules 1986)

Water type	Compliance norms for ODOUR
Water quality standards for <u>coastal waters & marine outfalls</u>	No noticeable offensive odour
Primary water quality <u>criteria for Bathing</u>	DO > = 5 mg/l ; ensure reasonable freedom from oxygen consuming organic pollution immediately upstream which is necessary for preventing production of anaerobic gases (<u>obnoxious gases</u>) from sediment

Table : General standards for Discharge of Environmental Pollutants Under Schedule VI , Environment Protection Rules 1986

Recipient body	Standards
Inland surface water	No unpleasant odour
Public sewers	-do -
Land for irrigation	-do -
Marine coastal areas	-do -
Industry	Compliance norms for ODOUR

ODOUR nuisance - Solid Waste Management Rules 2016

Human response to ODOUR is highly subjective besides ODOUR is the most complex of all the air pollutants. Odour is acknowledged as a public nuisance and is also highlighted under various sections under Solid Waste Management Rules 2016 (previous version MSW Management Rules 2000) , in the Rules definitions ‘*anaerobic digestion*’ , *biodegradable substances*’ & *biomethanation*’ indicate the putrescible nature of the MSW which is being

generated & disposed on a DAILY basis hence the focus has always been on efficient collection , segregation before final disposal. The courts – Hon’ble NGT has expressed concerns regarding management of MSW by the local bodies. Some salient features regarding ODOUR under the Solid Waste Management Rules 2016 is highlighted below.

Subrule	Definitions
Subrule 40. "SANITARY LAND FILLING:"	means the final and safe disposal of residual solid waste and inert wastes on land in a facility designed with protective measures against pollution of ground water, surface water and fugitive air dust, wind-blown litter, BAD ODOUR, fire hazard, animal menace, bird menace, pests or rodents, greenhouse gas emissions, persistent organic pollutants slope instability and erosion;
Subrule 52. "TRANSPORTATION"	means conveyance of solid waste, either treated, partly treated or untreated from a location to another location in an environmentally sound manner through specially designed and covered transport system so as to prevent the FOUL ODOUR, littering and unsightly conditions;

Under Duties and responsibilities_of local authorities and VILLAGE PANCHAYATS OF CENSUS TOWNS AND URBAN AGGLOMERATIONS subrule :

‘ (t) involve communities in waste management and promotion of home composting, bio-gas generation, de-centralised processing of waste at community level subject to CONTROL OF ODOUR and maintenance of hygienic conditions around the facility;’

Under SCHEDULE I (F) Criteria for ambient air quality monitoring- Sub section *‘(i) Landfill gas control system including gas collection system shall be installed at landfill site to MINIMIZE ODOUR, prevent off-site migration of gases, to protect vegetation planted on the rehabilitated landfill surface. For enhancing landfill gas recovery, use of geo membranes in cover systems along with gas collection wells should be considered.’*



Figure : Odour from Area Sources’ ex. STPs and ,MSW landfills .

GoI prioritises MSW management in national program

Swachh Bharat Mission under MoUD the key objective is of processing 100% solid waste generated in cities/towns by **2nd October 2019**. The earlier Central Government incorporated solid waste management as one of the components in the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) programme.

CPCB’s past association on ‘Odour’ issue

An MoU (2011) was signed between CPCB & VTT Technical Research Centre of Finland on ”*Capacity Building for Emission Measurement in India*” , one of focus areas was *Improved capacities in ODOUR measurement technologies*.

The areas covered under the program were :

- a. Olfactometric Odour Concentration Method
- b. Field Investigation Method

Photographs below are from the project report ’ *Improved Capacities in Odour Measurements Technologies*’ under the bilateral project.

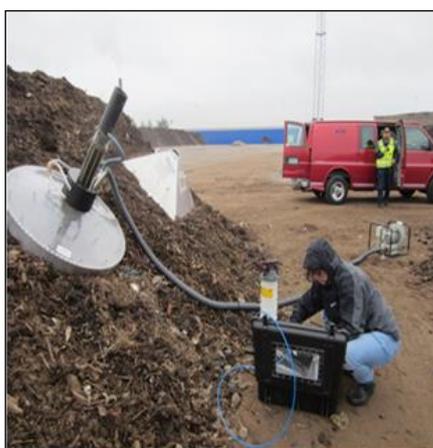


Figure : Demonstration of Odour monitoring at source in Finland on segregated biodegradable waste__ (left-wind tunnel method & right static hood method)



Figure : Demonstration of n-butanol test in odour measurement

CPCB's reports on 'Odour'

Reports dealing with Odour brought by CPCB are listed below :

- a. Parivesh Newsletter : Odour Pollution & its Control (2002)
- b. Status of methane emission from Municipal Solid Waste Disposal Sites (MSW) (CUPS/63/2005 – 06)
- c. Guidelines for Odour Pollution & its Control PROBES/121/2008 (CPCB's (Information based on literature survey, no pilot study undertaken)
- d. Improved Capacities in Odour Measurements Technologies' a deliverable under bilateral project with VTT Finland (May 2014)

Odour Monitoring in Urban MSW Landfill - The Guidelines

Landfill is a large area of land specifically designed and built to receive wastes particularly municipal solid wastes (MSW). MSW is the widely known urban wastes that gets disposed in landfills, the waste attracts rodents, insects, birds (vultures) and emit unpleasant odours due to decaying organic component of the MSW. The MSW landfill in urban areas draw attention as the holding capacity of the existing landfills in cities are inadequate to receive the growing quantum of wastes generated due to rapid increase in population density (urbanization). The unpleasant odours emitted from these landfills impact significantly on a spatial & temporal and widely influenced by the the prevailing regional meteorological parameters like temperature, wind speed, wind direction, relative humidity and rain fall i.e. climatic influence which are region specific.

Central Pollution Control Board (CPCB) launched the project “*Development of National Guidelines on Odour Monitoring & Management of Urban Municipal Solid Waste (MSW) Landfill Site*” in September 2015. The sampling & analysis

protocols were prepared for determining odour emission from MSW Landfill site, based on this document the pilot study on Odour monitoring was conducted at the MSW landfill located at Ghazipur in East Delhi. In India Odour is a NEW area, hence the need to familiarize on the subject and to explore economically feasible and adaptable monitoring methods to create mass awareness. For CPCB's pilot study on Odour monitoring use Field Olfactometry was accepted. Odour Dispersion modeling & mapping was done by IIT Delhi. The above exercises assisted in preparing the Guidelines on Odour Monitoring in MSW Landfills which recognizes the diverse climatic zones of our vast country, hence odour surveys at MSW landfill sites cannot be generalized but to be assessed on a case to case basis taking into account the unique regional – temporal & spatial influences of each MSW landfill site.

The entire study on ODOUR has been brought out in FOUR parts in the chronological order that they were prepared for a better understanding as follows:

1. **Sampling & analysis protocols for determining odour emission from MSW Landfill site**
2. **Case study – Pilot Study on Odour Monitoring at Municipal Solid Waste (MSW) Landfill Site, Ghazipur, East Delhi in year 2016 .**
3. **Dispersion modeling & mapping of Odour in Ghazipur MSW Landfill site in East Delhi**
4. **Guidelines on Odour Monitoring in Urban MSW Landfill**

Overview of MSW landfill at Ghazipur , Delhi

The MSW landfill at Ghazipur located in east Delhi was identified for pilot study on odour monitoring for several reasons mainly due to its unique location features – it is not only the oldest dumpsite in Delhi but has several odourous activities at the periphery such as fish market (in North direction), chicken market (in North east), slaughter house (in east direction) and the Ghazipur dairy (in Northwest direction) all emit significant odour. Besides there is a Refuse Derived Fuel (RDF), active dump areas, leachate tank and old dump area which are located at different heights from the ground besides the landfill has exceeded its holding capacity.

Table : Features of MSW Ghazipur landfill sites in Delhi

Item	Ghazipur
MSW (MT) in March'14	76975
% dumping in March '14	28.5%
Dumping w.e.f.	1984
Area (ha)	29.62

The project on development of ‘Guidelines for Odour Monitoring in Urban MSW landfills’ covered TWO seasons viz.

- a. Pre Monsoon Season Monitoring (field work 13 to 22 June 2016)
- b. Post Monsoon Season Monitoring (field work Sep. 27 to Oct. 15, 2016)

Odourants surveyed at from MSW Ghazipur landfill site is given in Table below.

Table : Odourants surveyed in MSW Ghazipur Landfill

Odourant (compound name)	Description of Offensive Odour
1. Ammonia	Pungent, Irritating
2. Hydrogen Sulphide	Rotten eggs
3. Butyric Acid	Rancid butter
4. Ethyl Mercaptan	Decayed Cabbage
5. Methyl Mercaptan	Rotten Cabbage
6. Dimethyl sulphide	Decayed Cabbage
7. Methane	Odourless
8. VOCs (total)	Odour influenced by the dominating compound

India is unique compared to other European countries that it gets abundant sunlight throughout the year besides there are also regions which experience cooler climates (hilly terrains). As odour is a menace in MSW landfill sites in the country, this pilot study is important as it has offered opportunities to explore monitoring odour in other activities (industries , sewage) besides



Fig. : Ambient Air Monitoring near boundary wall of MSW Ghazipur landfill

MSW landfills. The Guidelines were prepared based on the experience gained during the pilot study conducted in the field MSW landfill site at Ghazipur, East Delhi besides extensive literature survey and odour management practices globally. Though MSW landfill sites are unique by their regional climatic conditions these Guidelines offer a direction to be adopted in abatement of odour.

Project team

The project development of ‘National Guidelines on Odour Monitoring & Management in Urban Municipal Solid Waste Landfill Site’ was awarded to Project Consultant M/s. J.M. EnviroNet Pvt. Ltd. Gurugram, Haryana, India in September 2015. Odour is a NEW AREA, being multi-disciplinary, feedback was taken from



Fig.: Odourous compounds monitored at Old Dump site with Dragger Tube at MSW Ghazipur landfill

various organizations including CDAC-Kolkata, CSIR - National Physical Laboratory (NPL), CSIR -

NEERI Nagpur and IIT - Delhi. Besides literature survey, several consultations were held with experts from different disciplines on areas regarding sampling & analytical experts, odour panelists, instrumentation experts, odour dispersion modeling (IIT Delhi was associated) and experienced engineers & scientists to evaluate and review the field reports being delivered during project execution. CPCB’s in-house Project Monitoring team had officers from Urban Pollution Control Division (UPCD) and Air Laboratory led by the Member Secretary CPCB. The field surveys at the MSW landfill site were possible because of the support extended by the staff of East Delhi Municipal Corporation (EDMC). The entire report has been formatted by Sh. Prem Raj, Sr. IT Assistant, CPCB ENVIS Centre.

IMPORTANCE OF ODOUR MONITORING IN URBAN MSW LANDFILL SITES

‘WASTES’ included & excluded under the Solid Waste Rules 2016

The following wastes are defined under the Solid Waste Rules 2016 :

- i. solid waste
- ii. non-biodegradable waste
- iii. biodegradable waste
- iv. combustible waste
- v. domestic hazardous waste
- vi. dry waste
- vii. inerts
- viii. residual solid waste
- ix. sanitary waste

The wastes excluded under Solid Waste Rules 2016 :

- a) The revised wastes Rules excludes industrial waste, bio-medical waste and e-waste, battery waste, radio-active waste generated in the area under the local authorities
- b) Also entities mentioned in Rule 2 i.e. industrial waste, hazardous waste, hazardous chemicals, bio medical wastes, e-waste, lead acid batteries and radio-active waste, that are covered under separate rules framed under the Environment (Protection) Act, 1986.

Characteristics of ‘WASTES’ under the Solid Waste Rules 2016 - Definitions

In supersession of the Municipal Solid Waste (Management and Handling) Rules, 2000 the Solid Waste Management Rules, 2016 was notified by MoEF&CC on 8th April, 2016 , the following wastes are defined under the Solid Waste Rules 2016 under Rule #3 :

- i. Under subrule 46. "**solid waste**" means and *includes solid or semi-solid domestic waste, sanitary waste, commercial waste, institutional waste, catering and market waste and other non residential wastes, street sweepings, silt removed or collected from the surface drains, horticulture waste, agriculture and dairy waste, treated bio-medical waste*
- ii. subrule 32. "**non-biodegradable waste**" means *any waste that cannot be degraded by micro organisms into simpler stable compounds;*

- iii. sub rule 4. **“biodegradable waste ”** means *any organic material that can be degraded by micro-organisms into simpler stable compounds;*
- iv. sub rule 11. **“combustible waste”** means *non-biodegradable, non-recyclable, non-reusable, non hazardous solid waste having minimum calorific value exceeding 1500 kcal/kg and excluding chlorinated materials like plastic, wood pulp, etc;*
- v. subrule 17. **“domestic hazardous waste”** means *discarded paint drums, pesticide cans, CFL bulbs, tube lights, expired medicines, broken mercury thermometers, used batteries, used needles and syringes and contaminated gauge, etc., generated at the household level;*
- vi. subrule 19. **“dry waste”** means *waste other than bio-degradable waste and inert street sweepings and includes recyclable and non recyclable waste, combustible waste and sanitary napkin and diapers, etc;*
- vii. subrule 26. **“inerts”** means *wastes which are not bio-degradable, recyclable or combustible street sweeping or dust and silt removed from the surface drains;*
- viii. subrule 39. **“residual solid waste”** means *and includes the waste and rejects from the solid waste processing facilities which are not suitable for recycling or further processing;*
- ix. Subrule 41. **“sanitary waste”** means *wastes comprising of used diapers, sanitary towels or napkins, tampons, condoms, incontinence sheets and any other similar waste;*

Importance of waste management hierarchy in odour abatement

The Importance of waste management hierarchy highlighted under the Solid Waste Management Rules, 2016 indicates the potential to reduce odour. For guidance the activities definitions under Rule #3 is given below :

- a) Under subrule 57. **“waste hierarchy”** means *the priority order in which the solid waste is to should be managed by giving emphasis to prevention, reduction, reuse, recycling, recovery and disposal, with prevention being the most preferred option and the disposal at the landfill being the least;*
- b) Under subrule 53. **“treatment”** means *the method, technique or process designed to modify physical, chemical or biological characteristics or composition of any waste so as to reduce its volume and potential to cause harm;*
- c) Under subrule 36. **“recycling”** means *the process of transforming segregated non-biodegradable solid waste into new material or product or as raw material for producing new products which may or may not be similar to the original products;*
- d) Under subrule 16. **“disposal”** means *the final and safe disposal of post processed residual solid waste and inert street sweepings and silt from surface drains on land as specified in Schedule I to prevent contamination*

of ground water, surface water, ambient air and attraction of animals or birds;

Municipal solid waste hierarchy ranks in different ways in which MSW can be treated and disposed off sustainably, thus obtaining relative environmental benefits. For final disposal, landfill is often the largest component in MSW waste management pyramid and this indirectly affects odour management. The waste hierarchy if applied is an environmentally sound waste management strategy to minimize and reduce odour w.r.t. holding capacity of the landfill. The familiar hierarchy of waste management pyramid is depicted below.

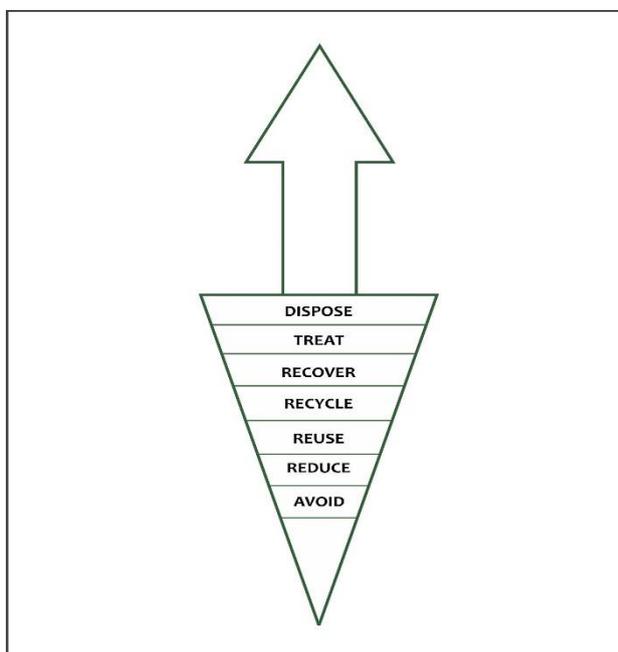


Figure 6: Waste management hierarchy

Appropriate handling & management measures reduces odour

There is potential to reduce odour at all levels in MSW handling & management as can be noted from the definitions under Rule #3 of the Solid Waste Management Rules 2016 as given hereunder :

- i. Under subrule 25. **“handling”** includes all activities relating to sorting, segregation, material recovery, collection, secondary storage, shredding, baling, crushing, loading, unloading, transportation, processing and disposal of solid wastes;
- ii. Under subrule 44. **“segregation”** means sorting and separate storage of various components of solid waste namely biodegradable wastes including agriculture and dairy waste, non biodegradable wastes including recyclable waste, non-recyclable combustible waste, sanitary waste and non recyclable inert waste, domestic hazardous wastes, and construction and demolition wastes;
- iii. Under subrule 47. **“sorting”** means separating various components and categories of recyclables such as paper, plastic, cardboards, metal, glass, etc., from mixed waste as may be appropriate to facilitate recycling;
- iv. Under subrule 48. **“stabilising”** means the biological decomposition of biodegradable wastes to a stable state where it generates no leachate or

offensive odours and is fit for application to farm land ,soil erosion control and soil remediation;

- v. Under subrule 52. "**transportation**" means conveyance of solid waste, either treated, partly treated or untreated from a location to another location in an environmentally sound manner through specially designed and covered transport system so as to prevent the foul odour, littering and unsightly conditions;
- vi. Under subrule 53. "**treatment**" means the method, technique or process designed to modify physical, chemical or biological characteristics or composition of any waste so as to reduce its volume and potential to cause harm;
- vii. Under subrule 36. "**recycling**" means the process of transforming segregated non-biodegradable solid waste into new material or product or as raw material for producing new products which may or may not be similar to the original products;
- viii. Under subrule 16. "**disposal**" means the final and safe disposal of post processed residual solid waste and inert street sweepings and silt from surface drains on land as specified in Schedule I to prevent contamination of ground water, surface water, ambient air and attraction of animals or birds;

Odour management concerns in urban MSW landfill sites in India

In India due to unplanned cities , increase in urban population and land scarcity in cities for waste management the residential areas located downwind MSW landfills may be subjected to unpleasant odour depending on prevailing meteorological conditions. Other factors responsible for this situation include lack of awareness on waste (collection & segregation) at source & at disposal site i.e. Inefficient management of MSW. Key factors responsible an odourous environment around MSW landfills are listed below:

- i. Lack of segregation in to solid waste into biodegradable, non-biodegradable and inert waste at point of generation (at source) ;
- ii. Non-biodegradable waste such as plastics, E- waste, hazardous waste, construction and demolition waste are not efficiently segregated at the source thereby adding to MSW load.
- iii. The area earmarked for MSW disposal is inadequate to handle to the growing quantum of MSW generation
- iv. Inadequate collection facilities at the community level by the local bodies.
- v. Inadequate number of vehicles deployed for the collection of the MSW.
- vi. The vehicles deployed for collection and transportation of MSW are not properly designed , operated and maintained.

- vii. With urban sprawl (includes unregulated encroachments) the once 'distant' MSW landfill site have habitation near it due to improper land-use planning thereby non-complying with landuse palns / buffer zone restrictions.
- viii. Lack of awareness on waste (collection & segregation) at source & at disposal site
- ix. Need to promote de-centralised MSW treatment ex. composting at source;



Figure : Unscientific designed landfill site

Health impacts Vs odour - from MSW landfills

There is lack of data in the country regarding health impacts from odorous substances in MSW landfills. As per available literature the following odourants from MSW handling & management facilities (landfill) may cause health hazards :

- a) **Mercaptans:** These are characterized by a particularly unpleasant odour even in very low concentration that provokes intolerable gastric effects even with low exposure times. With longer exposure times, these compounds can also interfere with blood haemoglobin and consequently with the oxygen transport process, causing temporary cyanosis.
- b) **Hydrogen sulphide:** Effects of exposure range from irritation of the eyes and respiratory tract, for concentrations between 10 and 20 ppm, up to immediate loss of consciousness and death (1000–2000 ppm). The particular and hazardous nature of this compound resides in the

fact that, at particularly dangerous concentrations (700 ppm), it loses its malodorous compound characteristics giving rise to an almost pleasant odour.

- c) **Ammonia:** Its exposure causes irritation of the bronchi and lungs, while prolonged exposure to at low concentrations can provoke chronic bronchitis or emphysema.
- d) **Amines:** Irritant effects have been encountered on the mucus of the primary respiratory tract, though possible irritation of the eyes with subsequent corneal damage cannot be ruled out.
- e) **Organic acids:** Although these do not lead to any pathogenic effects at low concentrations, prolonged exposure can cause irritation of the respiratory tract.

It may be noted that the abovementioned impacts depend not only on the duration of exposure but also on the concentration of the odourant during period of exposure – meteorology plays an important role in dispersion in ambient air.

Table : Odour Detection Threshold of odourous compounds

Sl.	Compound Name Formula	Odour Detection Threshold in $\mu\text{g}/\text{m}^3$
1	Ammonia NH_3	11820
2	Hydrogen Sulphide H_2S	0.70
3	Butyric Acid $\text{CH}_3\text{CH}_2\text{CH}_2\text{CO OH}$	432
4	Ethyl Mercaptan $\text{C}_2\text{H}_5\text{SH}$	0.76
5	Methyl Mercaptan CH_3SH	0.98
6	Dimethyl sulphide $(\text{CH}_3)_2\text{S}$	2.6

Processes generating Odour from MSW landfills

Odour and related complaints are being received from workers within the MSW landfill and affected localities particularly in the downwind directions. The complex nature of the many substances and emissions from waste disposal facilities result in an 'odour impact'. Odour (unpleasant odour) have become a priority concern for waste facility operators, engineers and urban planners dealing with waste management (ex. MSW landfills, STPs, open drains). The extent of



impacts depends on a variety of factors, most notably location of waste management facility, age of waste, weather conditions and the subjectivity of each individual's perception of a smell. Monitoring odour at MSW landfills is critical as assessing odour annoyance generated from these areas raise several challenges due to the fugitive, diffuse and multiple nature of the odour generating sources.

In MSW landfills, odour is generated by the following processes :

- i. Volatilization
- ii. Biodegradation
- iii. Photo-Decomposition
- iv. Hydrolysis
- v. Combustion

Centralized Vs De-centralized MSW management - Odour abatement measure

There is potential to reduce odour at all levels in MSW handling & management the following two definitions under Rule #3 of the Solid Waste Management Rules 2016 indicate that the Rules recognize the major constraint in identifying LAND for waste management in cities, in the coming times there will be a gradual shift from 'centralized' waste processing. Under Rule 3 :

- subrule 15. "de-centralised processing" means establishment of dispersed facilities for maximizing the processing of biodegradable waste and recovery of recyclables closest to the source of generation so as to minimize transportation of waste for processing or disposal;

From the above it may be noted that management of odour is important feature MSW management both – at landfill (centralized facility) and at community levels (de-centralized faculty) – waste segregation at source has been given importance under the Rules.

'Waste PROCESSING' technologies - potential to minimize odour at MSW landfill

In supersession of the Municipal Solid Waste (Management and Handling) Rules, 2000 the Solid Waste Management Rules, 2016 were notified by MoEF&CC, the 'Waste PROCESSING' technologies highlight the potential to minimize odour at MSW landfill (integrated waste management approach) key definitions under Rule #3 :

1. Processing of wastes :

a. subrule 35. (Rule 3) "**processing**" means *any scientific process by which segregated solid waste is handled for the purpose of reuse, recycling or transformation into new products;*

2. **Composting** (Rule 3)

- i. Sub rule (1) "**aerobic composting**" means a controlled process involving microbial decomposition of organic matter in the presence of oxygen;
- ii. Sub rule 12. "**composting**" means a controlled process involving microbial decomposition of organic matter;
- iii. Subrule 55. "**vermi composting**" means the process of conversion of biodegradable waste into compost using earth worms;
- iv. Sub rule 2. "**anaerobic digestion**" means a controlled process involving microbial decomposition of organic matter in absence of oxygen;
- v. Subrule 48. "**stabilising**" means the biological decomposition of biodegradable wastes to a stable state where it generates no leachate or offensive odours and is fit for application to farm land ,soil erosion control and soil remediation;

3. **Bio-Methanation** (Rule 3)

Sub rule 5. "**bio-methanation**" means a process which entails enzymatic decomposition of the organic matter by microbial action to produce methane rich biogas;

4. Incineration (Rule 3)

Subrule 27. "**incineration**" means an engineered process involving burning or combustion of solid waste to thermally degrade waste materials at high temperatures;

5. Co-processing (Rule 3)

Subrule 14. "**co-processing**" means use of non-biodegradable and non recyclable solid waste having calorific value exceeding 1500k/cal as raw material or as a source of energy or both to replace or supplement the natural mineral resources and fossil fuels in industrial processes;

6. Refused Derived Fuel (RDF) – waste to energy (Rule 3)

Subrule 38. "**refused derived fuel**"(RDF) means fuel derived from combustible waste fraction of solid waste like plastic, wood, pulp or organic waste, other than chlorinated materials, in the form of pellets or fluff produced by drying, shredding, dehydrating and compacting of solid waste ;

Chemical characteristics & beneficial utilization of MSW

Knowledge of chemical characteristics is essential in selecting and designing the waste processing and disposal facilities, they :

- a. Chemical characteristics include pH, Nitrogen, Phosphorus and Potassium (N-P-K), total Carbon, C/N ratio, *etc.* – ex for composting
- b. Bio-Chemical characteristics include carbohydrates, proteins, natural fibre, and biodegradable factor, *etc.* ex for composting & waste to energy projects
- c. Toxicity characteristics include heavy metals, pesticides, insecticides, toxicity test for Leachates (TCLP), *etc.*

The efficiency of abovementioned solid waste technologies depends largely on the efficiency of MSW ‘SEGREGATION’. Technologies adopted for beneficial utilisation of wastes are briefed below.

1. Compositing of biodegradable MSW waste

Composting of MSW is carried out using different approaches to produce organic manure. The organic manure can be utilized in horticulture / agriculture sector for improving soil texture for achieving better crop productivity. The utilization of horticulture waste in compositing minimizes the waste load at MSW land fill site.

2. Energy production from MSW

- a) Green briquettes: The biodegradable part of MSW after segregation is mixed with other biodegradable mass to produce the briquettes size up to 20 mm with a moisture content of less than 10%. Such briquettes are called green briquettes or bio-coal with a calorific value of approx 4000 Kcal/kg – a source of alternative fuel. This process helps partial disposal of MSW for energy recovery.
- b) Refused Derived Fuel (RDF): Similarly sorted MSW may be treated with hot dried air to produce RDF which also has a high calorific value – an alternate energy source from waste.
- c) Methane and Hydrogen Production: **Other sources for energy generation include** viz. biological and chemical processes. For biodegradable content of MSW (30 to 40%) be converted to generate biogas with methane content of 50 to 60%. The biogas can be enriched with methane up to 80% by removing CO₂ and traces of odorous sulphurous constituents, by adopting pre-emptive desulphurization process.

3. Recyclable materials and its composites from MSW

Upon proper sorting of MSW, 10-20% of the recyclable materials such as paper, plastics and metals can be extracted by an active informal sector & different products can be made from the sorted materials of the MSW. This will reduce waste load to the landfill.

4. Land filling for inerts

The inert part of the MSW may be utilized in land filling for construction, mines and other purposes.

Thus conversion of waste to energy not only gives economical benefits but also helps in waste minimization and odour minimization. Similarly compost can be marketed to meet urban horticulture needs.

Different options for beneficial utilization of MSW are depicted in **Figure. 5**

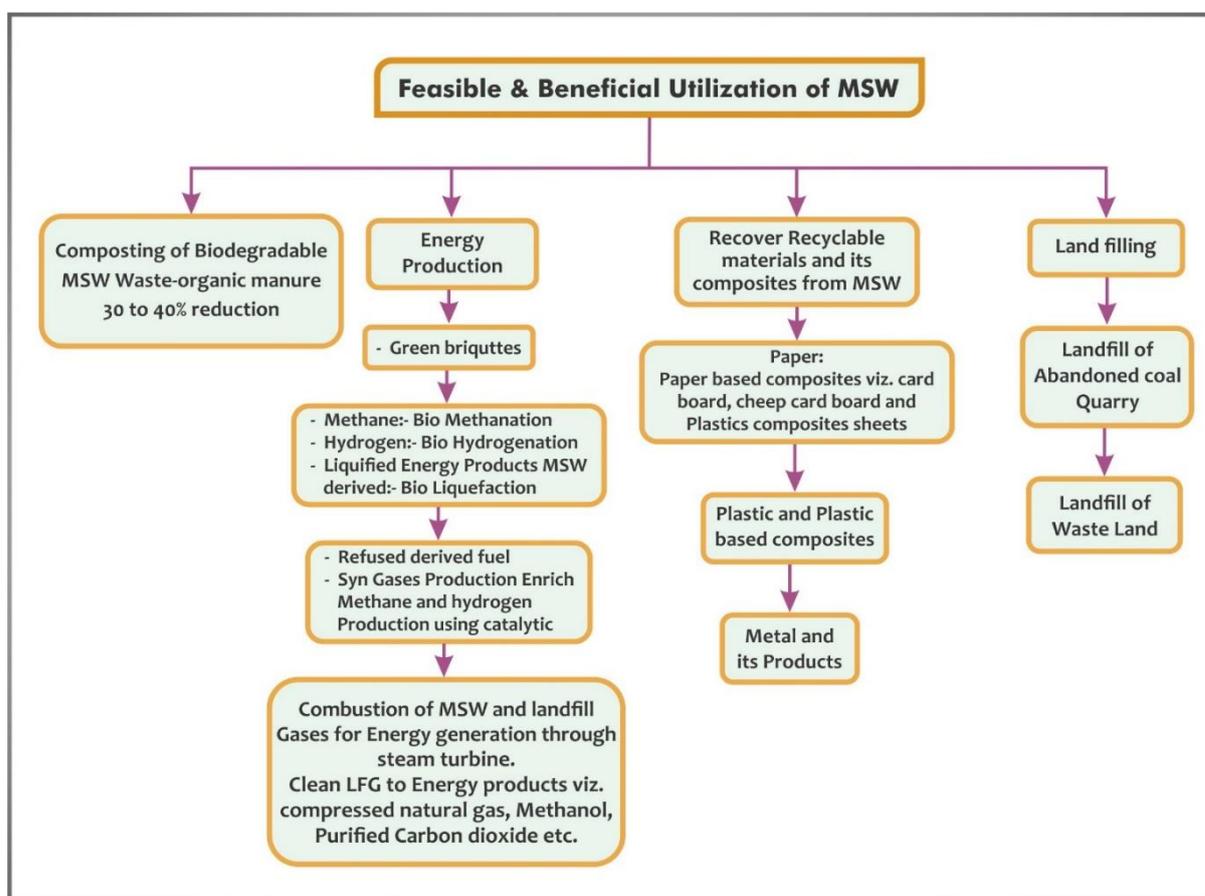


Figure : Feasible & Beneficial utilization of MSW

Limitations in implementing odour abatement goals

The global odour abatement goals are desirable however in the Indian context there are various factors that challenge their direct adoption, key issues being rising quantum of MSW waste due to rapid urbanization which are straining

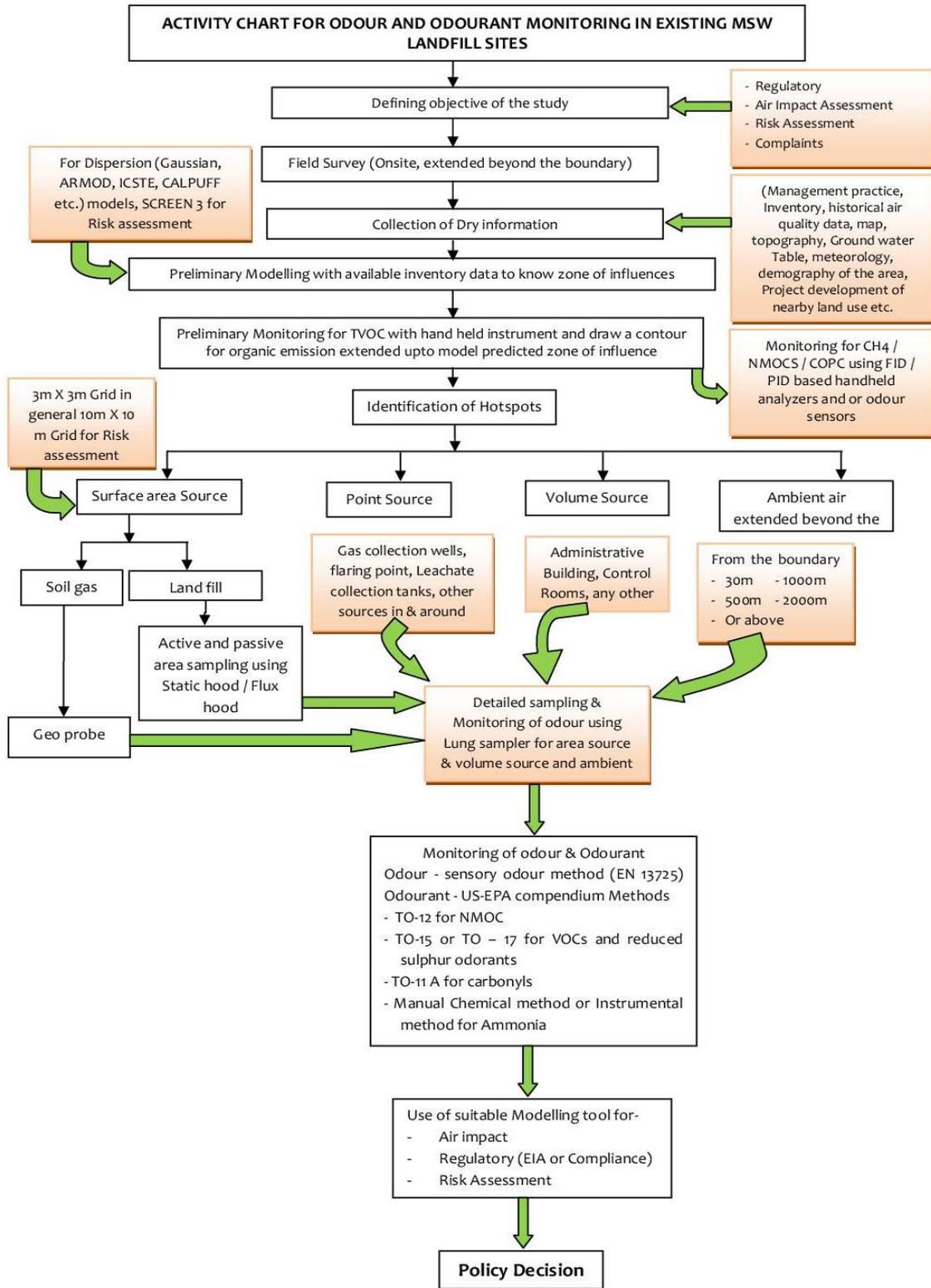
the existing waste management infrastructure besides low awareness on odour minimization.

Some goals that need to be targeted to raise awareness :

- a. Improve public awareness on odour management
- b. Odour adds to aesthetics – citizens to support initiatives by the urban local bodies
- c. Dissemination of information on odour monitoring methods & strategies
- d. Affected (impact) area
 - i. At source : Premises involved in odour generating activities to examine critical stages where odour minimization measures can be applied includes safety of workers
 - ii. Downwind areas : Needs of communities affected downwind due to meteorological conditions from distant odorous activities to be minimised

Proposed activity chart - Odour monitoring in existing MSW landfill site

India due to its typical topography has a wide range of climatic conditions, hence adopting a common plan for odour management for MSW landfills across the country is not possible , however these Guidelines offer a path for addressing regional odour management (abatement & minimization) plans after consultation with local urban bodies and other stakeholders. An activity chart detailing the outline for conducting odour monitoring in an existing MSW landfill is shown below.



PREVENTIVE MEASURES - ODOUR ABATEMENT AT MSW LANDFILLS

Physical & chemical characteristics of MSW influence odour levels

Key 'physical' characteristics of MSW include the specific weight, moisture content, size of the waste constituents:

- i. Specific weight is defined as the weight of a material per unit volume (e.g. kg/m³), it indicates the degree 'compactness' of waste and depends on region being surveyed, the season and holding capacity of the storage area (ex landfill). It is an important measure which is used to define all the elements of the solid waste management system such as storage, transportation and disposal facilities required. Compaction of waste increases or assists in accommodating larger quantities of waste within the available (storage) area.

Typical specific weight values:

- Loose MSW, with poor or compaction - 90-150
- Compact (baled) MSW - 710-825
- MSW in a compacted landfill (without cover) - 440-740

- ii. Moisture content of solid wastes is usually expressed as the weight of moisture per unit weight of wet material. Moisture increases the weight of solid waste, thereby increasing the cost of collection and transportation. Therefore moisture content is a critical component in the economic feasibility of waste treatment and processing methods . Typical range of moisture content (in %) in wastes is given below :

- Food wastes (mixed) 50 - 80
- Paper 4 - 10
- Industrial Chemical sludge (wet) 75 - 99
- Mixed Agricultural waste 40 - 80 50
- Manure (wet) dung 75 - 96

The total amount of moisture that can be retained in a waste sample subject to the pressure applied from above layers of wastes and the level of decomposition of wastes, this is critical in determining the volume of leachate generation in MSW landfills

- iii. Size of waste constituents is important for the recovery of materials, especially when mechanical means are used, such as screens , separators , shredders and magnetic separators.

- iv. Calorific value is the amount of heat generated from combustion of a unit weight of a substance, expressed as kcal/kg calorific value indicates its suitability energy generation.

The production of ODOURS are related to the putrescible nature of the organic content of the waste (MSW). The 'biodegradability' depends on the characteristic of the organic content, which gets converted to gases and inert organic and inorganic solids.. Typical chemical transformations of solid waste is a change of phase - solid to liquid, liquid to gas or solid to gas. The organic waste content within MSW may be categorized as

- rapidly decomposable and
- slowly decomposable

Odour generation results from the anaerobic decomposition of the readily decomposable organic content in MSW, generally odors arise when wet MSW waste is stored for long periods of time on-site between collections or at transfer stations or in landfills, the odours are significant in warm climates.

Quantification of MSW (estimations & forecasting)

Over the last decade the rapid urbanization in India has shown the a massive increase of in the quantum of waste (MSW) generation in most cities, particularly cities with million plus population. By the year 2021, the urban population is expected to represent 41% of the overall population. Some statistics are given below :

1. Forecasting of MSW generation:

Study conducted by the CPCB on management of MSW in the country estimates that waste generation from the present 48 million tones (MT) per year is expected to increase to 300 MT per year, by the year 2047 (490 g per capita to 945 g per capita). MSW generation is highly co-related with the economic growth i.e. Gross Domestic Product per Capita (GDP per Capita). The key reason for increase waste generation are firstly increase in consumption pattern (lifestyle) and movement of the people from rural area to urban areas for better employment prospects.

The mathematical calculation for forecasting of municipal solid waste generation is a tedious process beginning with the estimation of future population based on the present trend and then calculate the future quantum of MSW generation (Weber, 2004 of studied countries.

- Future population = Initial population (1 + % growth rate/100) years
Future amount of municipal solid waste generation= (Predicted population) x (Waste generation rate) x (Number of day) ÷ (1000 kg per metric ton)

2. Per capita generation of MSW

It is estimated that solid waste generated in small, medium and large cities and towns is about 0.1 kg, 0.3 – 0.4 kg and 0.5 kg per capita per day respectively.

3. Composition of MSW : The complex composition of municipal solid waste reflects the heterogeneity of the waste stream , the two factors that vary is the organic matter content and moisture content. Differences in composition also vary between localities / cities. *Ref. Estimation of MSW generation & landfill area in Asian developing countries A Khajuria*, Y Yamamoto & T Morioka , Div. of Sustainable Energy & Environmental Engineering, Graduate School of Engineering, Osaka University, Japan Journal of Environmental Biology September, 2010 Pages 649-654)*

4. Land requirement

A sanitary landfill is a carefully constructed space on the ground to dispose waste to enable it to gradually decompose into chemically inactive material. The landfill gets gradually filled by covering it with alternate layers of soil, however with time it has been observed that the old practice of establishing major ‘centralized’ MSW disposal facilities (Ex landfill) in cities will be challenging, the acquisition of LAND for waste management in particular within cities will face problems for two major reasons – scarcity of land and secondly opposition by public due to the odorous nature of the MSW activity.

The estimated requirement of land for disposal would be 169.6 square kilometer (km²) in 2047 as against 20.2 km² in 1997 (CPCB 2000a).

The information below is used as rough guidance for estimation of the required area for setting up a sanitary landfill

Estimation of area for Sanitary Landfill Vs quantum of MSW

Waste quantity (Tonnes per design life of landfill)		Required site area (ha)
in million	In lakhs	
<1.0	<10	15-20
1.0-2.0	10-20	20-30
2.0-3.0	20-30	30-40
>3.0	>30	>40

Source- All India Institute of Local Self Government (2012). / Reference Material on Municipal Solid Waste Management for Urban Local Bodies – Processing Options. Part II. Mumbai: India

The estimation method of the future landfill area calculated according to (Gerard, 1998) is given below :

Volume of land, filling space annually required (m³ yr⁻¹) =
 (Waste million tonnes yr⁻¹) x (10³) divided by density of waste in kg m⁻³
 Required area (ha) = (hectare) x (years) x (height)
 This value will need to increase by about 1.5 percent to allow for daily cover, roads, receiving areas, fencing, etc.

Regional landfill facilities for MSW – rationale for ‘land’ management

Recognizing that LAND acquisition shall be major challenge for establishing MSW landfills (centralized disposal facility), Solid Waste Management Rules 2016 promotes establishment of Regional landfill facilities as discussed below :

- i. Under Rule 20. Criteria and actions to be taken for solid waste management in HILLY AREAS subrule (b) I
 - *‘in case of non-availability of such land, efforts shall be made to set up regional sanitary landfill for the inert and residual waste.’*
- ii. Under Rule 11. Duties of the Secretary-in-charge, Urban Development in the States and Union territories.- (1) The Secretary, Urban Development Department in the State or Union territory through the Commissioner or Director of Municipal Administration or Director of local bodies shall –
 - *‘(e) direct the town planning department of the State to ensure that master plan of every city in the State or Union territory provisions for setting up of solid waste processing and disposal facilities except for the cities who are members of common waste processing facility or regional sanitary landfill for a group of cities;’*
 - and Subrule *‘(j) facilitate establishment of common regional sanitary land fill for a group of cities and towns falling within a distance of 50 km (or more) from the regional facility on a cost sharing basis and ensure professional management of such sanitary landfills;’*

Key preventive measures in odour abatement at MSW landfill sites

Odourants are generated due to bio-chemical activity on bio-degradable content of MSW at landfills, key global preventive measures that can be adopted at the different stages of MSW management are :

- A. Odour control by site selection and design
- B. Operational management
- C. Minimization of odour release through physical prevention
- D. Odour counteractants

The above four odour abatement measures are discussed below.

PREVENTIVE MEASURES - Odour control by site selection and design

Site selection and designing of landfill site helps in abatement of odour at the inception of the project through scientific analysis of available data. The following factors be considered while designing and selecting a site.

- i. The selection and number of sites for a city shall be considered in a holistic way. The requirement of land for the disposal site shall be assessed considering the present population and projected growth over the next 20 years at least.
- ii. It is better to plan for development of more than one site for a city to provide better accessibility of the site, optimize the travel distance of loaded trucks and minimize the time duration of waste kept dumped at primary collection centre.
- iii. The care should be taken during identification of site that the selected land is free from influence of other odourous sources.
- iv. Topography (slope, nearness to water sources like river, natural springs) and other geological (like permeability) conditions.
- v. Selection of landfill site should be integrated with the urban development planning so that even expansions of city in next two or three decades are not encompassing the selected MSW site. New commercial and residential activity should be restricted near the disposal site for commercial and residential activities should be restricted.
- vi. Urbanization near the sites can be permitted by creating / defining reasonable “buffer zone” between the development areas and disposal site. Extent of buffer zone could be arrived through modeling techniques or in compliance with the existing legislation.
- vii. Green belt development in the buffer zone should be mandatory and the civic bodies should work in close association with scientist, environmentalist for selection of suitable flora to be planted in buffer zone. A model describing preventive measures for odour abatement is depicted in Figure. 1.

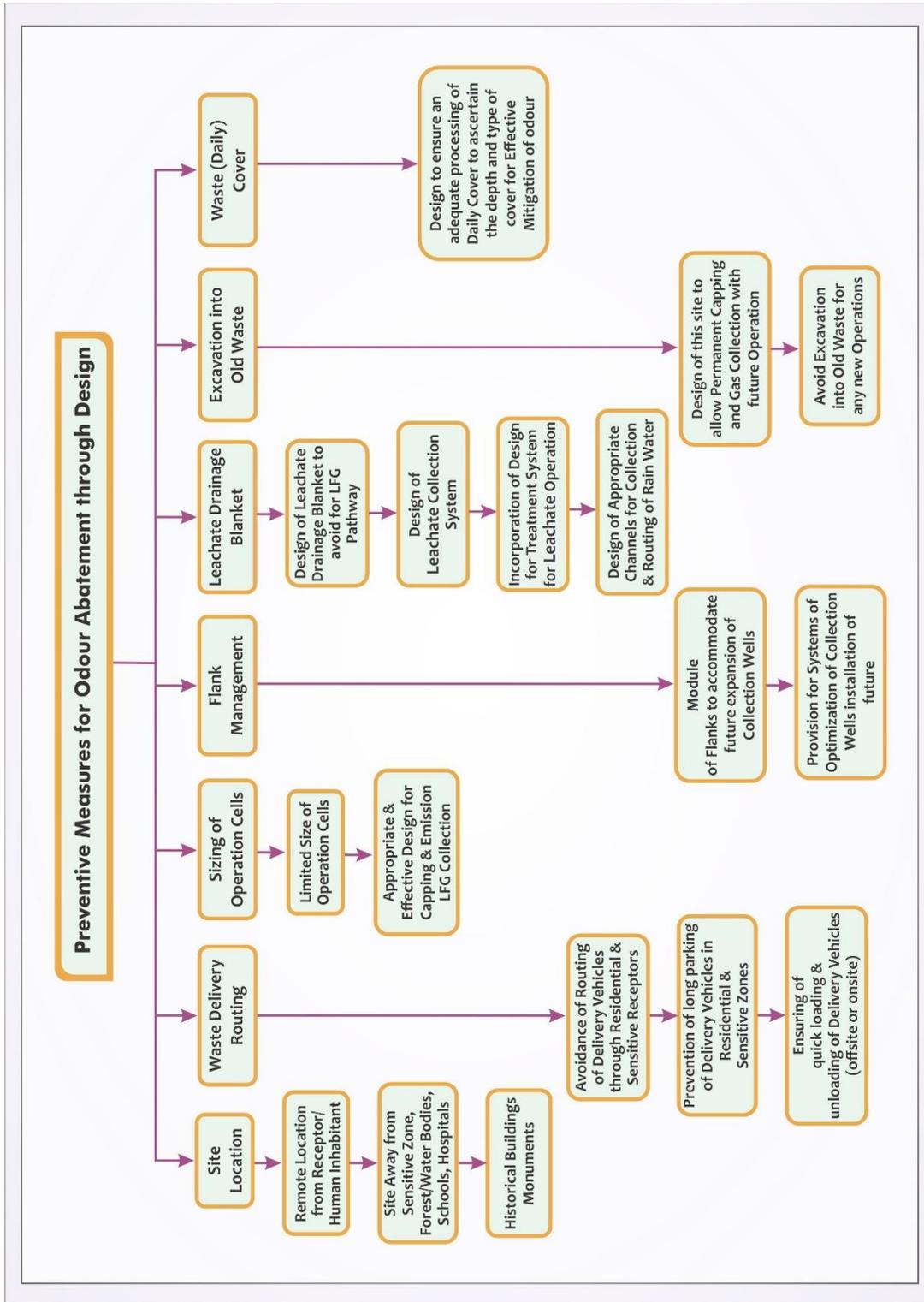


Figure 1: PREVENTIVE MEASURES IN ODOUR ABATEMENT in MSW Landfill site - Odour control by site selection and design

PREVENTIVE MEASURES - Operational Management

Prevention and minimisation of odour releases can be achieved by adopting odour control practices by landfill operators. The details of the operational control of MSW landfill site proposed is given below :

- a) Municipal solid waste acceptance:** Each site will have its own waste acceptance criteria and protocols.
- b) Municipal solid waste handling:** Worldwide, the segregation of waste is being practiced at source (point of generation) however this area needs to be strengthened in India in several cities. Un-segregated waste reduces the utilization efficiency of land earmarked for land filling. Pre-processing (sorting) of waste helps in enhancing the efficacy of treatment process and land utilization.
- c) Area of active cell (Tipping area):** The size of tipping area needs to be optimized for minimising the odourous emission from MSW. It must be
 - i.** Sufficiently large to allow waste to be tipped and compacted
 - ii.** Adequately large to allow received waste to be tipped without delay & prevent trucks from waiting on the site or on the public road network.
 - iii.** Globally the tipping area is around 900 to 1200 m² for most of the sites, However the USEPA working plan prescribe it between 625 m² to 1600 m². Given the un-segregated waste in India it is recommended to adopt (higher) global norms.
- d) Rapid and effective capping:** The engineering design shall ensure rapid and effective capping to prevent fugitive release of gases, which *inter alia* will enhance the collection efficiency of the Landfill Gases (LFG).
- e) Design of LFG collection system and operation:** Depending on the waste type, its condition and the expected life span of the operational area, temporary extraction system may be required in operational area. The system generally consists of impact wells, horizontals or drilled wells and pipe work that may be flexible or rigid, temporary or permanent. Careful planning to be made to minimise escape of odourous gases from potential odour generating areas.
- f) Leachate Management:** Leachate be stored or collected on case to case basis and drain to the leachate treatment plant through suction pipes, booster pumps or through sealed tanks which treat the leachate in addition prevent the odour leakages .
- g) Maintenance of LFG (collection and capping):** There must be a system established for identification of leaks by manual observations, odour monitoring, CH₄ walkover survey and standard leak detection and repair (LDAR). In absence of direct monitoring the mass balancing may be resorted to estimate the efficacy of the treatment.

h) Restoration of Soil: The restoration of soil is carried out when landfill cell has been capped and permanent gas collection system has been put in place. The landfill operator must have the requisite permission from the regulatory authorities for restoration of the soil over the cap and plantation of appropriate species on it.

The diagrammatic representation of operational control of MSW landfill site is given in **Figure: 2 & 3**

- i)** Furthermore following BEST MANAGEMENT PRACTICES (BMP) for odour prevention & control should be adopted;
- i. Segregation of waste to prevent entry of unwanted industrial, metallic, biomedical waste at disposal site.
 - ii. Ensure that all the trucks transporting MSW are covered.
 - iii.** Development of adequate internal roads with in site area for easy movement of transport vehicles and machine vehicles
 - iv.** Fencing of disposal sites to prevent unauthorized entry of person and stray animals.
 - v.** Dumping and disposal functioning through expert contractors only.
 - vi.** Computerized monitoring of the MSW batch from collection up to its disposal or utilization.
 - vii.** Development of facilities for feasible utilization of waste.
 - viii.** Monitoring by authentic organizations or institutes to monitor the health, risk and environmental effects (air, water and odour) due to operation of the disposal site.
 - ix.** Safety and environmental compliances in accordance with the MSW Rules (M&H) 2016.

The implementation pattern of the best management practises (BMP) may vary to an extent on case to case basis. The model BMP is detailed in **Figure. 4.**

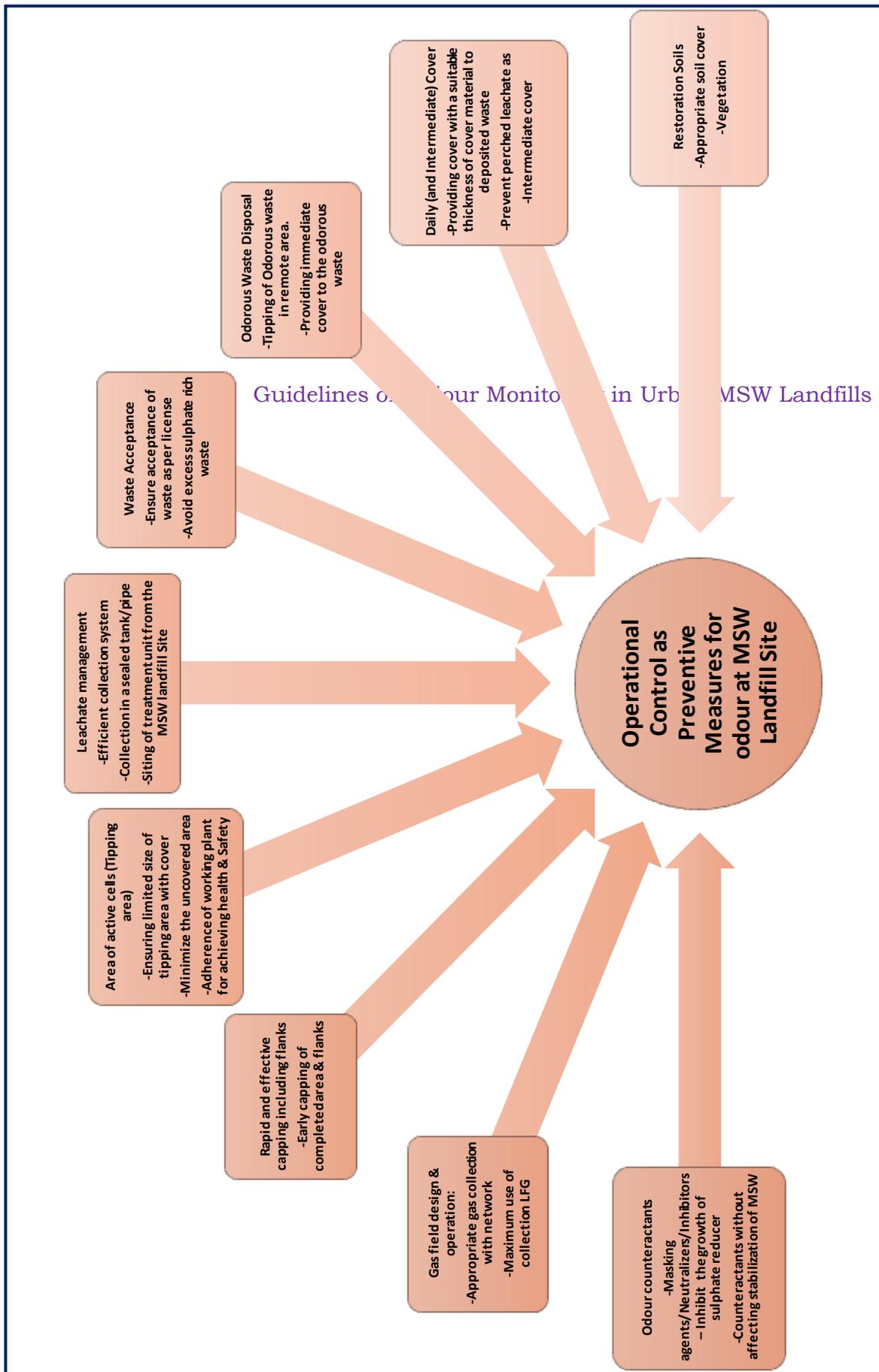


Figure 2: PREVENTIVE MEASURES IN ODOUR ABATEMENT - Operational Control

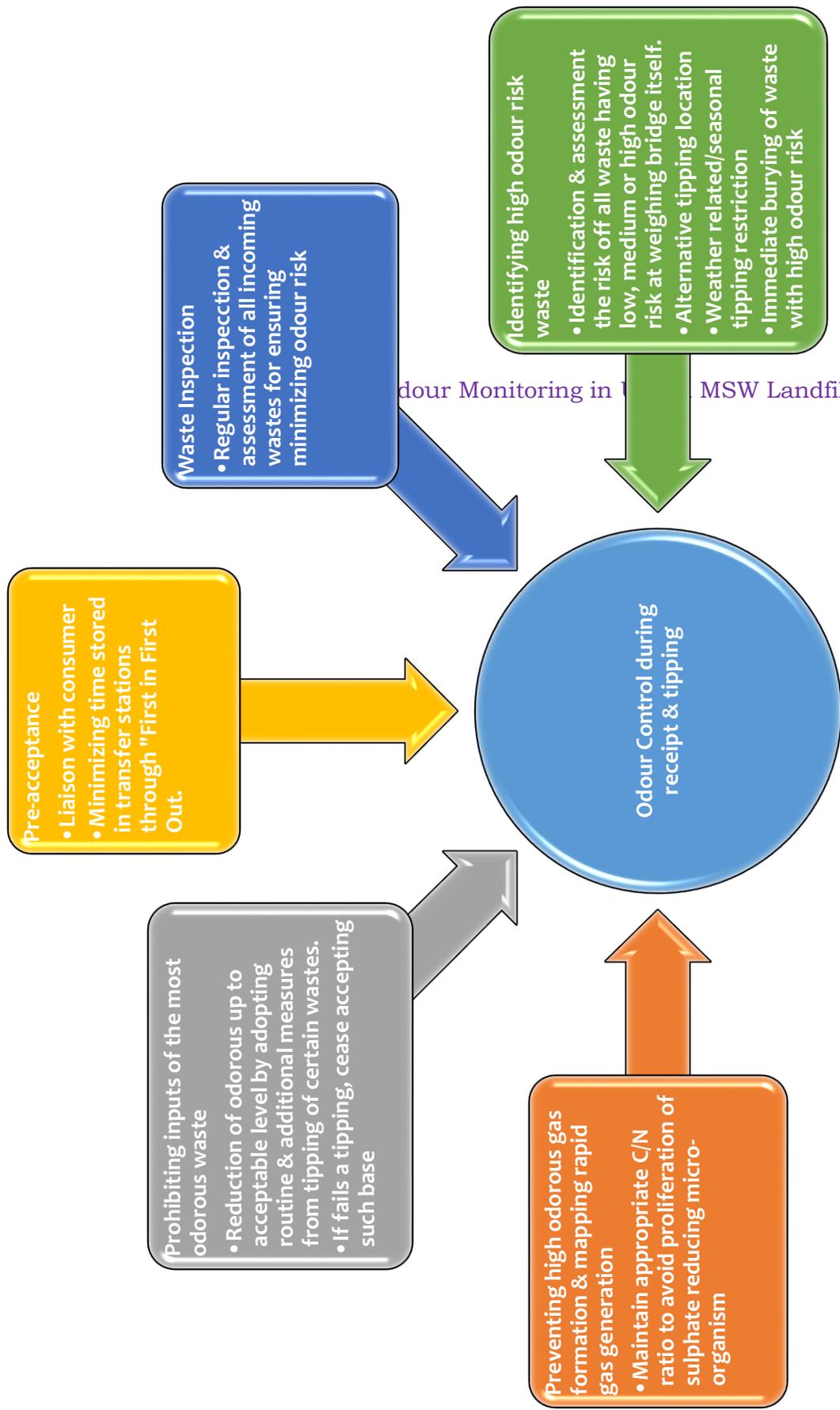


Figure 3: Odour Control during Receipt & Tipping waste

PREVENTIVE MEASURES - Minimization of Odour Release through Physical Prevention

The physical prevention of the odour release may be achieved by adopting different devices or technique adopted globally for various processes and stages of waste.

- i. For Tipping and loading operations: Better engineering practices globally may be adopted if tipping and loading operation is carried out in a closed building with remote controlled fast acting doors. Slightly negative air pressure shall be maintained within the process building to reduce the odour nuisance. In the tipping area maximum waste handling and storage time should be minimize to 24 hrs. The main extraction air pipe should be fitted in the building to collect odourous emissions which may be connected to further controlled devices.
- ii. For active and passive area sources: Capping of the areas having potential odour generation with suitable cover shall be adopted. There are different types of material available for capping having varied efficiency. Use of any of the following material like composite of isophthalic polyester resin and glass fibre, composite of vinyl ester resin and glass fibre, sail cloths- type material made of polyester and PVC are good to prevent odour emission.
- iii. For waste utilization process where onsite sorting of waste is required, use of properly designed closed system with vents for emitted gases should be adopted.
- iv. For final capping of the landfill site after stabilization with concrete, wooden or highly corrosion resistant aluminium/ copper alloy material etc.

PREVENTIVE MEASURES - Odour counteractants

The counter-actants use for prevention of odour release from MSW Landfill site includes:-

- i. Masking agents- Terpenic compounds and some oxygenated molecules like coumarin masks the odourous emission and blocks some specific mal-odourous receptors.
- i. Surfactants: Amphipathic molecules such as alcohols, glycerol and esters compounds increase the apparent solubility of odourous compound in aqueous media, thus reducing the odour emission.
- ii. Neutralizers: Aliphatic and aromatic aldehyde reacts with odourous compounds including viz. Ammonia, TRS etc. which decrease the odourous annoyance. Further fibre degrading enzyme and plant extracts have also been used as a neutralizer.

PREVENTIVE MEASURES - Vegetative cover

Vegetative cover on the open areas of the landfill site also reduces odours. Good plantation cover forms a surface capable of absorbing and forming sinks for odourous gases. Leaves, with their large combined areas in a tree crown, absorb pollutants on their surface, thus effectively reduce odourous compound concentrations near MSW landfill site.

Best Management Practices in Odour management in MSW landfill sites

Figure 4 displays Best Odour Management Practices in MSW landfills as an approach to Preventive Measure

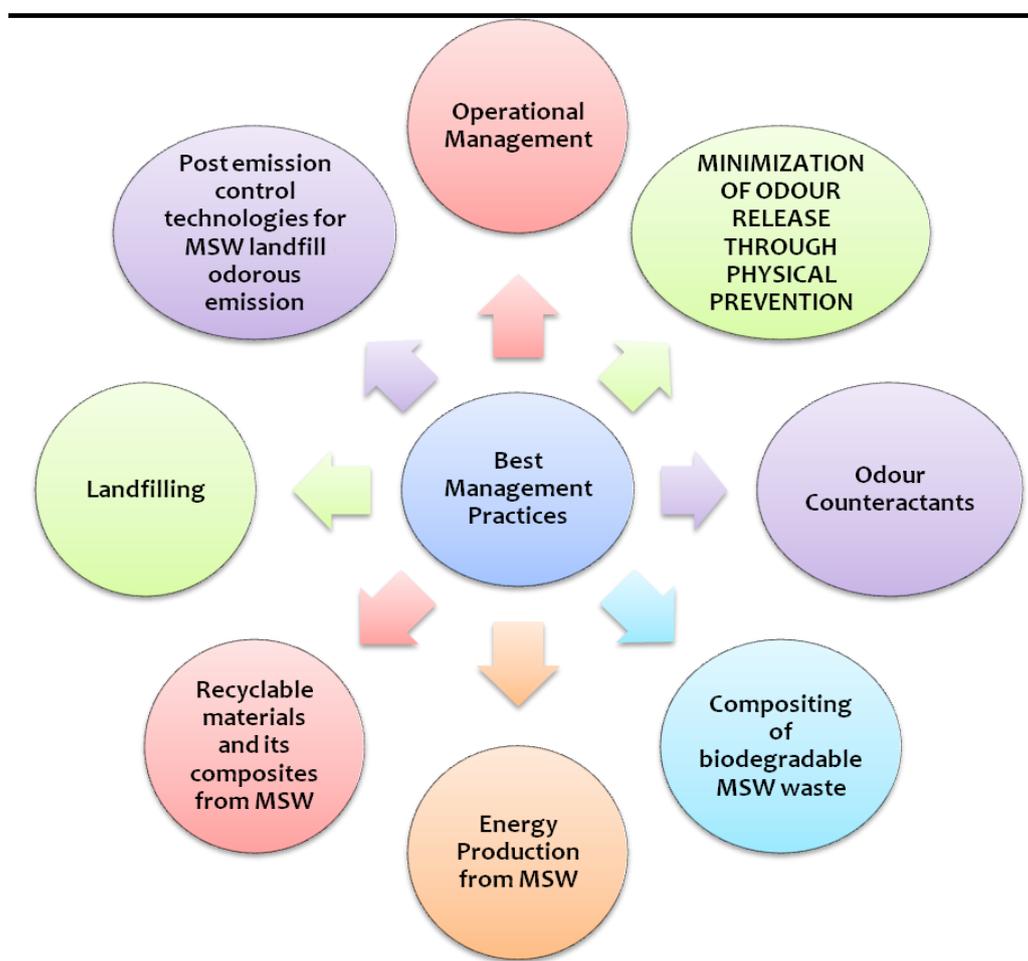


Figure 5: Best Odour Management practices in MSW landfills

ODOUR CONTROL TECHNOLOGIES IN MSW LANDFILL SITES

ODOUR CONTROL TECHNOLOGIES

There are several approaches to odour control as per literature survey, some of the technologies are discussed below :

1. Adsorption processes
 - a. Dry Scrubbers
 - b. Chemical Scrubbers
2. Filtration Technique
 - a. Bio-filters
 - b. Bio-trickling filter
 - c. Bio- Scrubber
3. Chemical treatment
 - a. Odour Control with Chlorine Dioxide & Hydrogen Peroxide
 - b. Irradiation (NEUTRAPOL)
 - c. De-odourization mechanism for various odourous gases
 - d. Hybrid processes
4. Incineration processes (combustion)

ODOUR CONTROL TECHNOLOGIES - Adsorption processes

Adsorption is a surface phenomenon where treatable waste is adsorbed on suitable adsorbents. The commonly used adsorbents for odour control are activated carbon, Graphene, carbon-neon hybrid materials etc. Two key adsorption processes technologies adopted for odour control are discussed below :

- a. **Dry Scrubbers:** Dry scrubbing systems use containerized media that reacts with specific compounds in landfill gas (LFG) such as acidic gases and forms compounds (solids) that can be disposed off. In general, these processes utilize replaceable dry media to extract acidic gases until the media becomes saturated and needs to be separated.
- b. **Chemical Scrubbers:** Chemical scrubbers consist of vessel with an air inlet, scrubbing solution bed, and an air outlet. In these systems landfill gases comes into a direct contact with scrubbing solution that chemically reacts which absorbs and removes the odour causing targeted molecules from the landfill gas (LFG).

ODOUR CONTROL TECHNOLOGIES - Filtration Technique

The Filtration techniques adopted for treating landfill gas (LFG) are discussed below:

- a. Bio-filters : Bio-filtration is a biological process using media such as soil, compost or other media as a substrate for microbes that removes odourous contaminants from landfill gas. Landfill gas is collected and vented through a bio-filter of bacterial slime. Venting landfill gas through such bio-filter can be used to reduce odour. As long as oxygen is present, bacteria will decompose landfill gas under aerobic conditions, producing carbon dioxide and water.
- b. Bio-trickling filter : Bio-trickling filter consist of a column packed with inert packing material for example plastic rings, resins, ceramic materials, etc. The micro organisms are immobilized on the inert surface and get attached to it. A nutrient solution is continuously trickled and also recycled at the rate 10 to 30 litres per minute. This system presents high specific surface areas of in the range of 100 m² to 400 m², which allows mass transfer under low pressure. Odourants are initially absorbed in aqueous medium trickling over the bio-film and degraded afterwards by micro-organisms present in the bio-film. An efficiency of more than 99% has been reported for removal of hydrogen sulphide - H₂S, an odorous.
- c. Bio- Scrubber The mal-odourous emissions can be directly purged into aeration tank with appropriate biomass to minimize odour by degrading the odourants. The mal-odourous compounds defuse from the gas phase to liquid phase and get degraded in the liquid phase that have both - microorganism & nutrients.

ODOUR CONTROL TECHNOLOGIES - Chemical treatment

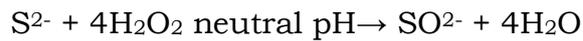
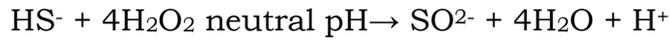
i. Odour Control with Chlorine Dioxide & Hydrogen Peroxide

Injecting controlled quantities of chemicals such as chlorine or hydrogen peroxide into process-gas stream can control odour, however chlorine dioxide is several times more effective than chlorine is commonly used in treatments as it does not generate hazardous by-products.

For removal of Hydrogen Sulphide (odourous gas)

Reactions :

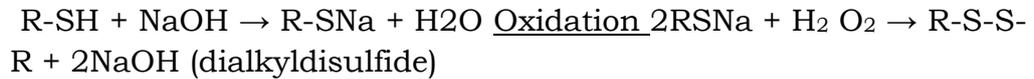
- a. $5\text{H}_2\text{S} + 8\text{ClO}_2 \rightarrow 5\text{H}_2\text{SO}_4 + 8\text{Cl}^- + 4\text{H}_2\text{O}$
 - pH 5-9, min 2.7 ppm of ClO₂ oxidizes 1.0 ppm of sulfide.
 - No colloidal sulfur formed.
- b. $5\text{H}_2\text{S} + \text{H}_2\text{O}_2 \text{ acidic pH} \rightarrow \text{S}^\circ + 2\text{H}_2\text{O}$
 $\text{HS}^- + \text{H}_2\text{O}_2 \text{ neutral pH} \rightarrow \text{S}^\circ + \text{H}_2\text{O} + \text{OH}^-$



- Alkaline pH = 10-11 conditions give fast reaction with removal efficiencies 97- 99.9%.

For removal of Mercaptans R-SH (odourous gas)

Reactions :



- Reaction is very fast and can occur in the scrubber. R-S-S-R is odourous and must be oxidized further.



(The disulfide has very low solubility in water and thus reaction is slow).

ii. Irradiation (NEUTRAPOL)

Ultra-violet (UV) radiation forms ozone a very re-active form of oxygen, it exchanges electrons with target molecules. UV applications for waste purification require high capital investment. Recently it is reported that 'neutrapol' is used instead of ozone which as is harmless and non-toxic. Neutrapol is a monomer, it forms long chain molecules which carry a positive charge.

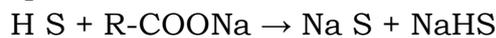
Neutrapol is distinguished from other neutralizers by its ability to de-odourize not just one type of gas but a wide range of gases, acidic, neutral and alkaline, automatically and simultaneously.

iii. De-odourization Mechanism for various odourous gases

- a. Ammonia type: The volatile, odourous elements are combined with an organic acid radical to form a non- odourous compound which is non-volatile.



- b. Hydrogen Sulfide: The hydrogen sulfide is converted into a complex organic sodium salt incorporating sodium meta-bi-sulfide, resulting in a non-volatile, non-odourous and non-poisonous compound.



- c. Methyl Mercaptans: The mercaptans are produced from rotting material e.g. odour of rotten fish, public urinals



The gases are converted to a complex organic salt.

iv. Hybrid processes

The hybrid processes either operate in a combination with either in a sequence :

- chemical + Biological processes or
- Bio filter + Bio trickling filter or

- Bio scrubber + Bio trickling filter.

This enhances the efficiency of odourants removal. In hybrid processes, some of the non-biodegradable odourants gets partially modified in chemical processes and biodegrade in biological reactors. The sequence of removal of odourants may be ascertained after preliminary experiments.

ODOUR CONTROL TECHNOLOGIES - Combustion

Industry uses a number of methods for handling waste gases at upstream oil and gas facilities, the most common being combustion. The most common type of combustion has been flaring, however in recent years, incineration technology has emerged as another method of combusting waste gases. Though flaring and incinerating are adopted however the important issues are public safety and safer environment.

For landfill gas (LFG) there are two options –

- its beneficial utilization (after treatment) or
- by destruction through flaring.

Incineration can be adopted (though not often the chosen option) for controlling the landfill gas in the presence of methane, sulphurous odourants and other VOCs get converted to SO_x , NO_x and CO_2 . These tail gasses can be effectively treated after incineration with a suitable scrubber.

REMEDIAL OPTIONS FOR ODOUR PREVENTATION

Key remedial options for odour prevention

For adoption for odour abatement in existing / proposed MSW landfills in India, based on the literature survey and techno-economical feasibility, the following THREE technologies are proposed including constraints for adoption

Key remedial options for odour prevention	
Remedial options	Constraints
<u>Decentralized MSW collection</u> & active composting without generation of mal-odourants.	May suffer a set back during the rainy and the winter seasons due to reduced biochemical activities.
<u>Anaerobic digestion of biodegradable part of MSW</u> with production of biogas with <i>in-situ</i> LFG treatment facility.	The recommended processes may need to be operated with suitable control mechanisms.
<u>Development of well designed MSW landfill with collection of LFG</u> followed by de-sulphurisation and de-carbonization for enriched production of methane with recovery of elemental sulphur and CO ₂ .	

De-centralized MSW collection & active composting

Under Rule 3 subrule recognizing the major constraint in identifying land in cities for ‘centralized’ waste disposal / processing facilities the Solid Waste Management Rules 2016 defined

- Rule 3, subrule 15. “**de-centralised processing**” means establishment of dispersed facilities for maximizing the processing of biodegradable waste and recovery of recyclables closest to the source of generation so as to minimize transportation of waste for processing or disposal. ‘

De-centralized technologies w.r.t. MSW collection with active composting are gaining acceptance in India, with economy in scale of operation this approach assists in minimization of odour due to better monitoring / supervision of operations. In de-centralized management the segregated MSW is collected at the household or community level in separate dustbins - green colour bin or biodegradable content of the waste transported for either composting at site (community level) or to a nearby community composting plant. The

biodegradable MSW content is mixed anaerobic cultures for achieving effective composting within short duration. The compost manure generated in the process can be used for local horticulture purposes. A flow chart for decentralized MSW collection & active composting without generation of mal-odourants is displayed in the figure below.

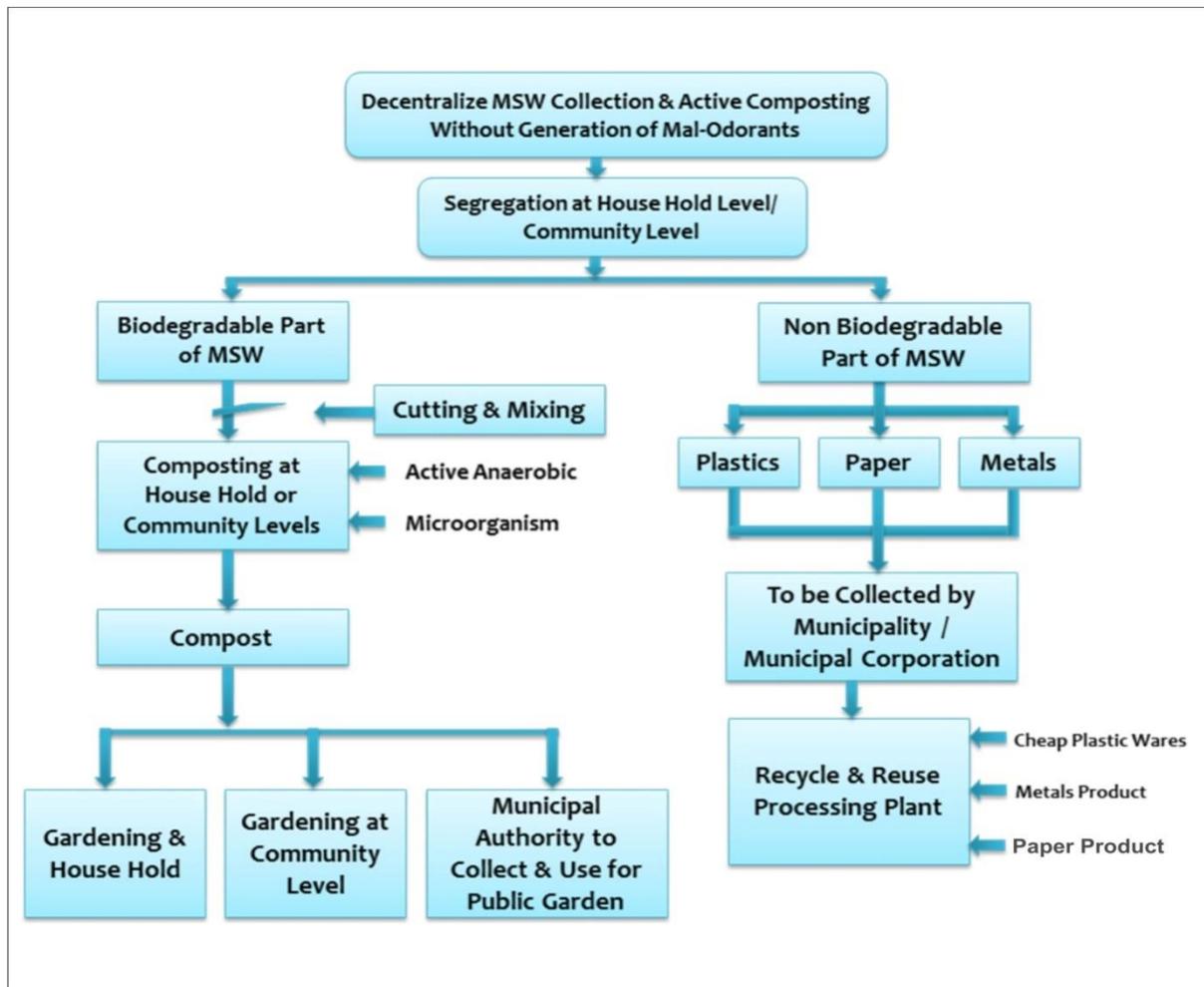


Figure 6: MSW Collection & Active Compositing

Anaerobic digestion of biodegradable MSW - LFG production

Two key stages in anaerobic digestion of biodegradable MSW are :

- a. MSW is required to be segregated into biodegradable and non-biodegradable components, the biodegradable components are cut into uniform small sizes and milled to size in the range of 100 to 200 mm. This process generates significant mal-odour and needs appropriate odour control measure.

- b. The milled bio-degradable material is made into slurry using wherein minimal nutrient medium containing nitrogen and phosphorous is added. The slurry is fed into anaerobic digester having appropriate mixing device to ensure uniform distribution in the reactor. In the anaerobic digester ferric salt is added to encapsulate the obnoxious odourants specially reduce sulphur constituents. The associated processes within the reactor include - hydrolysis, acido-genesis, aceto-genesis and bio-methanation, for further understanding refer **Fig. 8**.

The sludge produced in the anaerobic digestion unit may be mixed with agriculture residue (biomass) to produced green briquettes.

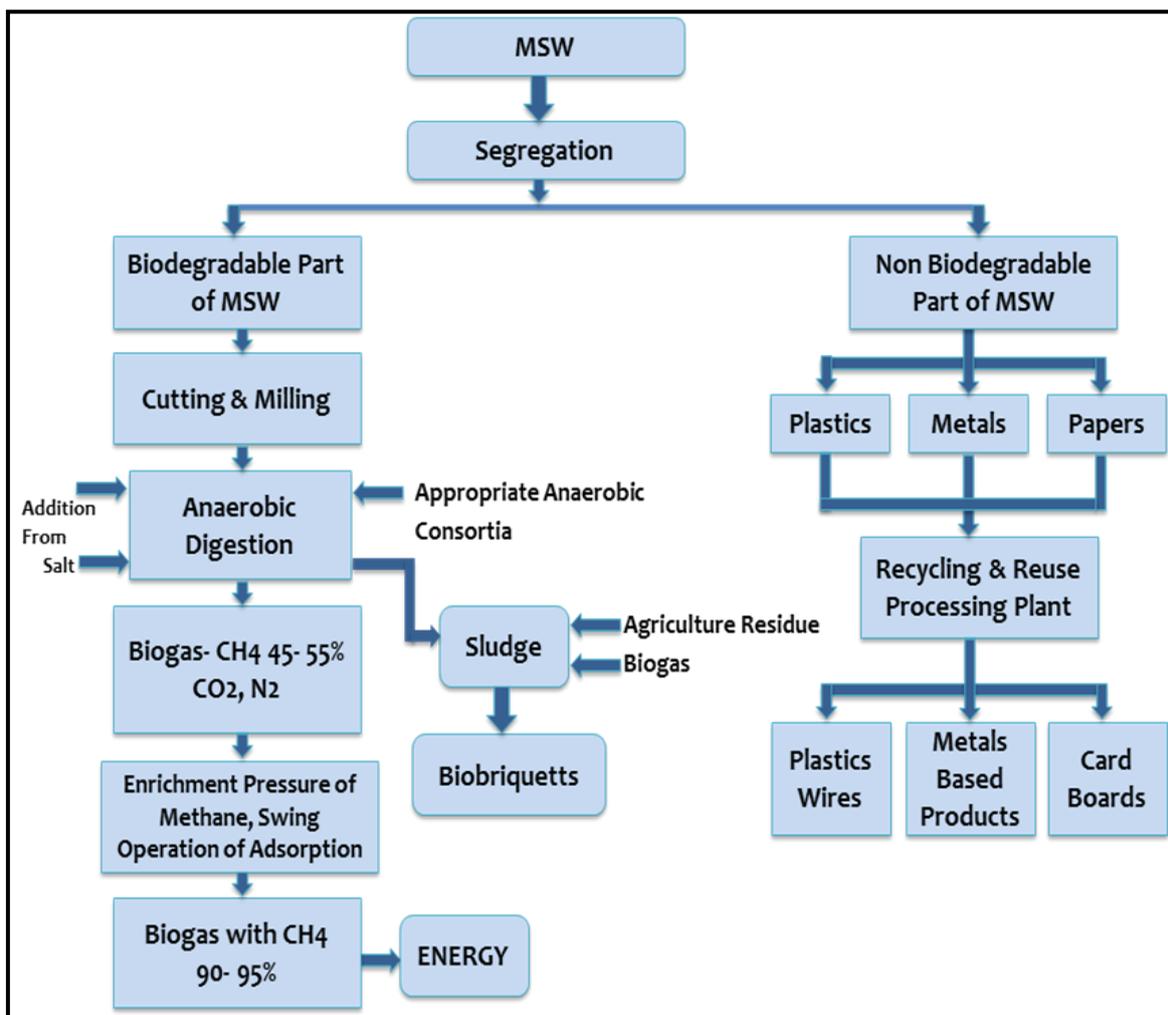


Figure : Anaerobic Digestion of Biodegradable

LFG collection from MSW landfill sites : Active Vs Passive collection

1. Landfill gas with other odourous gaseous are collected either by passive or active collection system. A typical collection system, either passive or active, is composed of a series of gas collection wells placed throughout the landfill.

The number and spacing of the wells depend on landfill-specific characteristics, such as waste volume, density, depth, and area.

- a. Passive Gas Collection Systems : Passive gas collection systems use existing variations in landfill pressure and gas concentrations to vent landfill gas (LFG) into the atmosphere or a control system. Passive collection systems can be installed during active operation of a landfill or after stabilization and closure of site. The efficiency of a passive collection system depends on how well the biodegradable fraction gets converted to gas in available conditions at surface and below the ground. Gas production can be enriched by the landfill collection system design. Use of liners on the top, sides, and bottom of the waste with an impermeable liner (e.g., clay or geo-synthetics membranes) will prevent dispersion of landfill gas within the deposited waste and provide better trapping through redirecting preferred gas migration pathways. The efficiency also depends on environmental conditions, which may or may not be controlled by the system design. If pressure is inadequate to push the gas for venting, passive systems fail to remove landfill gas effectively. High barometric pressure, sometimes results in outside air entering the landfill through passive vents and counter the LFG pressure to escape through vent pipe. In these cases the methane gas may built-up causing auto ignition and fire hazard.

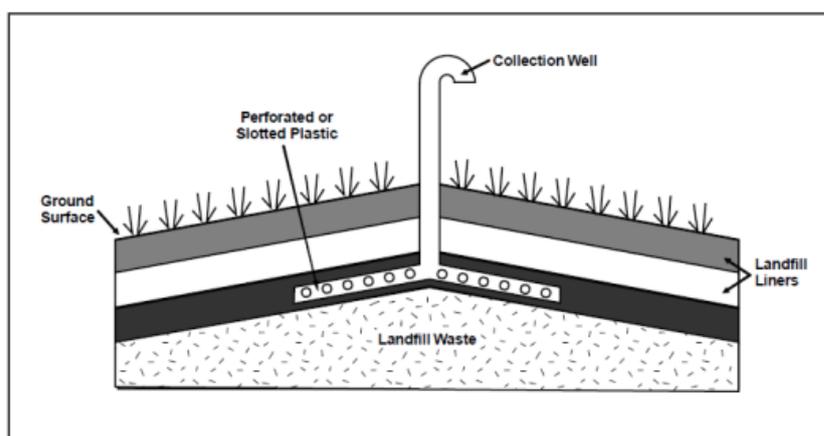


Figure 7: Passive gas collection system

- b. Active Gas Collection system : Well-designed active collection systems are considered more effective for landfill gas collection. Unlike passive system, wells in the active system have valves to regulate gas flow and to ensure proper venting of gas produced through vent pipes, the vents may serve as a sampling port. Active gas collection may work under vacuum or forced draught. The system design should also take into account future gas management needs, such as those associated with landfill expansion.

De-odourization options for LFG treatment

The benefits in de-odourization involves combination of the both de-odourization of LFG techniques mentioned below gives useful by-products ex. sulphur, CO₂ and enriched methane with concentration of more than 80% (v/v). The de-odourization control options for LFG include the following :

- a. De-sulfurization
- b. De-carbonisation

Like all other MSW management processes , 'efficient segregation' of waste is vital to the success of the chosen treatment processes. Segregated MSW has potential to generate LFG containing methane in the range of 40 to 45% (v/v), but the efficiency of methane generation may be reduced (30 to 35%) in heterogeneous waste, however, in both the cases (de -sulphurisation and de-carbonisation) it is generally recommended that the LFG be processed for recovery of valuable products viz. elemental sulphur, pure CO₂ and enriched methane. The schematic diagram of the recommended process is depicted in the **Figure 9**.

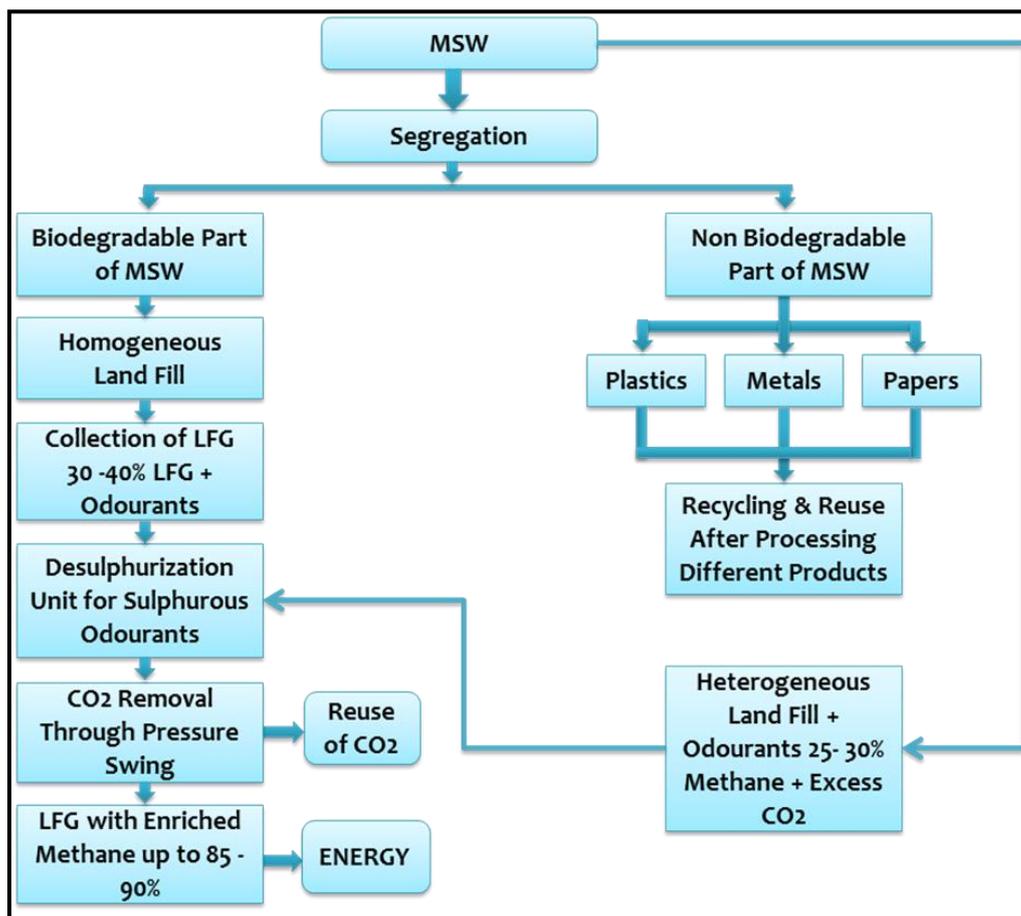


Figure 8: De-sulphurisation and De-carbonisation of MSW

1. De-odourization option : De-sulfurization process

This is a two stage treatment of LFG to reduce odour and odourous compounds containing reduced sulphur.

- In the first stage gases laden with odourants reacts with ferric sulphate which oxidizes Reduced Sulphur Odourants (RSO) into elemental sulfur and ferric sulphate is reduced to ferrous sulphate.
- In the second stage of the process, elemental sulphur is separated and ferrous sulphate solution is immobilized in packed bed reactor with specific microorganism. This ferric sulphate solution is recycled back to the first stage of the process.

Thus this process operates in a closed loop with recovery of elemental sulphur and results in de-odourization of gasses. The efficiency of recovery of elemental sulphur in this process is reported to be more than 95% with reference to reduced sulphur odourants. (Ref. CSIR-NEERI - 'chemo biochemical desulfurization') The schematics of the process are presented in the **Figure 11**.

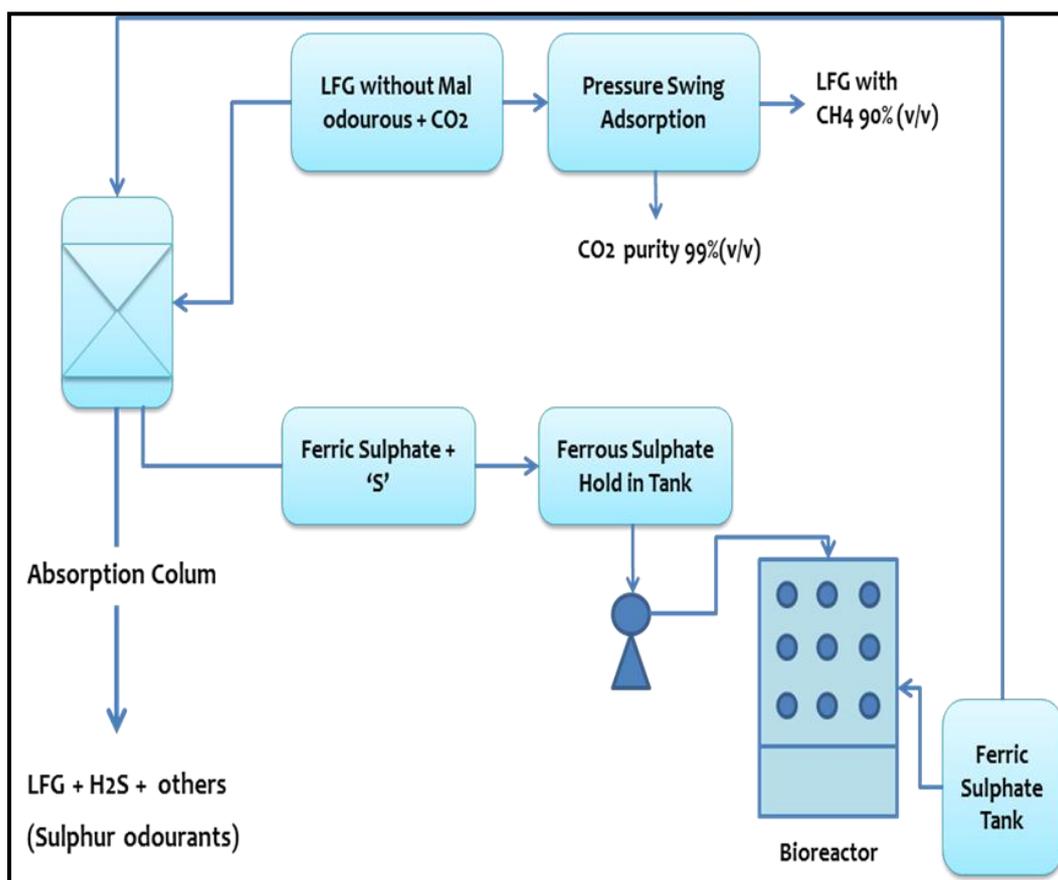


Figure 9: De-odourization / Desulfurization of the LFG

2. De-odourization option : De-carbonization process

This is a high end technique where methane utilization is prime objective, here methane is enriched by removing CO₂ from the gas stream and

collected as a byproduct. The LFG is processed through a pressure swing adsorption column for selective adsorption of CO₂ present in the LFG. The adsorbed CO₂ will be desorbed and more than 99% pure CO₂ is separated from the stream.

Odour abatement strategies proposed for ULBs (civic bodies)

As per Solid Waste Management Rules 2016 under Rule 3 sub-rule 30 defines:

- **"local body"** for the purpose of these rules means and includes the Municipal Corporation, Nagar Nigam, Municipal Council, Nagarpalika, Nagar Palikaparishad, Municipal Board, Nagar Panchayat and Town Panchayat, Census Towns, Notified Areas and Notified Industrial townships with whatever name they are called in different States and union territories in India.'

Based on review of national and international documentation and field experience acquired during execution of present study the following strategies are proposed for effective management of odours generated during the different stages of disposal of MSW for the local bodies (ULBs) :

- i. The civic bodies shall plan, augment the basic infrastructure available to improve efficiency w.r.t. collection & segregation before transport to MSW landfill.
- ii. Dissemination of information & awareness media :
 - a. advertisements painted / flexi-sheets on the sides of buses (mass transport) and passenger vehicles (taxis & auto rickshaws) and also on vehicles deployed for collection & transportation of wastes ;
 - b. Conduct meetings with local communities associating sanitation workers and involve encourage RWAs, schools & colleges, NGOs and community service centers for segregating & sorting wastes and separating biodegradable component of waste.
 - c. Radio FM – 30 second jingles
 - d. TV – advertisement in Doordarshan & private channels
- iii. MSW processing , three models proposed :

1. For community (RWAs) based composting system the management should ensure that :-
 - a. The waste must be processed on “first in and first out” (FIFO) basis
 - b. Appropriate cover on wastes be provided for the household composting unit to prevent odour dispersion and flies.
2. For anaerobic digestion system promote as co-operative effort (includes financial support) between ULBs , individual households and RWAs (multistoreyed) residential complexes. The operational cost of the anaerobic digestion system be realized as cost per family for gas consumption.
3. The ULBs - municipalities / municipal corporations to bear the capital cost for installation of the anaerobic plant, the operational cost be met through the either the Government or users.

CRITERIA FOR SELECTION & DESIGNING OF MSW LANDFILL SITES

FIVE steps in designing a MSW landfill

Until better options arise landfill continues to be the ultimate disposal unit for MSW in the country, hence the landfill sites be designed such that they do not further aggravate the environment ex. Odour. The Government of India (GoI) has prescribed the following basic criteria to be fulfilled in designing a landfill site.

The key steps for designing, implementation and operation of a SANITARY LANDFILL are :

1. Site selection
2. Sanitary landfill design
3. Construction of a sanitary landfill
4. Sanitary landfill operation
5. Closure and post-closure plan.

The Figure below provides helpful inputs for the above key five steps which are discussed further in subsequent sections.

SITE SELECTION	SANITARY LANDFILL DESIGN	CONSTRUCTION OF A SANITARY LANDFILL	SANITARY LANDFILL OPERATION	CLOSURE AND POST-CLOSURE PLAN
<ul style="list-style-type: none"> • LOCATION CRITERIA • SEARCH AREA • DEVELOPMENT OF A LIST OF POTENTIAL SITES • DATA COLLECTION FOR POTENTIAL SITES • FIELD VISIT FOR LOCAL VERIFICATION AND IDENTIFICATION OF POTENTIAL SITES • SELECTION OF BEST-RANKED SITES • PRELIMINARY ENVIRONMENTAL IMPACT INVESTIGATION • FINAL SITE SELECTION • SITE INVESTIGATION AND SITE CHARACTERISATION • SURFACE WATER ASSESSMENT 	<ul style="list-style-type: none"> • DESIGN LIFE • SPECIFIC WASTE VOLUME: SANITARY LANDFILL CAPACITY AND AREA • SANITARY LANDFILL LAYOUT • TECHNICAL DESIGN REQUIREMENT. • BASE SEALING SYSTEM • LANDFILL PHASING • LEACHATE MANAGEMENT • WASTE PLACEMENT • SURFACE SEALING SYSTEM • INFRASTRUCTURE FOR SANITARY LANDFILL 	<ul style="list-style-type: none"> • SUPERVISION OF CONSTRUCTION WORKS • QUALITY ASSURANCE • THE DRAINAGE LAYER • LEACHATE COLLECTION SYSTEM • SLOPE STABILITY ASPECTS AND SEISMIC ASPECTS 	<ul style="list-style-type: none"> • GENERAL REQUIREMENT • WASTE RECEPTION AND CONTROL OF INCOMING WASTE • WASTE MANAGEMENT • FILLING AND COMPACTION PROCEDURE OF WASTE • COVERING OF WASTE • FINAL COVER (SURFACE SEALING SYSTEM) • LANDFILL GAS MANAGEMENT • SANITARY LANDFILL ROADS • STORM WATER MANAGEMENT • LANDFILL EQUIPMENT • HOUSEKEEPING ON THE SANITARY LANDFILL • ENVIRONMENTAL MONITORING 	<ul style="list-style-type: none"> • PLAN FOR VEGETATIVE STABILISATION OF THE FINAL LANDFILL COVER • PLAN FOR MANAGEMENT OF SURFACE WATER RUNOFF WITH AN EFFECTIVE DRAINAGE SYSTEM. • PLAN FOR PERIODICAL INSPECTION AND MAINTENANCE OF LANDFILL COVER (SETTLEMENTS) AND FACILITIES • PLAN FOR QUANTITY AND QUALITY OF LEACHATE MONITORING IN THE LANDFILL • PLAN FOR QUANTITY AND QUALITY OF LANDFILL GAS MONITORING • PLAN FOR GROUNDWATER QUALITY (UP GRADIENT AND DOWN GRADIENT) • PLAN FOR SURFACE WATER QUALITY AT THE PERIPHERY OF LANDFILL AND AT RECEIVING WATER BODIES

Site selection

Selection of a sanitary landfill site are governed by the following :

- a. State Government policy
- b. SWM strategy of local bodies
- c. municipal solid waste management (MSWM) plan

Site selection usually include the following :

1. **LOCATION CRITERIA** : The location as per SWM Rules 2016 (Section 4.1 of Part II). Further data to comply with criteria specified by regional regulatory agencies (e.g. SPCB and PCC). Central Pollution Control Board (CPCB) report “Guidelines for the selection of site for Landfills” Annexure 6 be referred, also guidance for developing site sensitivity index of potential sites is included in Table below

Table 1: Location Criteria of MSW Site

Place	Minimum Siting Distance
1. Coastal regulation, wetland, critical habitat areas, sensitive eco-fragile areas, and flood plains as recorded for the last 100 years	Sanitary landfill site not permitted within these identified areas
2. Rivers	100 meters (m) away from the flood plain
3. Pond, lakes, water bodies	200 m
4. Non-meandering water channel (canal, drainage, etc.)	30 m
5. Highway or railway line, water supply wells	500 m from center line
6. Habitation	All landfill facilities: 500 m
7. Earthquake zone	500 m from fault line fracture
8. Flood prone area	Sanitary landfill site not permitted
9. Water table (highest level)	The bottom liner of the landfill should be above 2 m from the highest water table
10. Airport	20 km

2. **SEARCH AREA** : This feature helps to decide the location & identification of the potential sites for MSW landfill. The ULB to delineate an appropriate search area, which should ideally be located within the municipal boundary, though it is mainly governed by the economics of waste transportation. In case land is scarce (city / town) the potential sites could be abandoned

quarries, old waste dumpsites or degraded areas. However with regional MSW landfills being promoted under the SMW Rules , the issue needs inter – district consultation.

3. Development of a list of potential sites: After demarcating the search area and noting the various locations that are potential MSW landfill sites for development, the same to marked on a map. Potential sites for sanitary landfill development should also conform to the long term landuse goals. The Table below can be used as rough guidance for estimation of the required sanitary landfill area including the related infrastructure.

Table : MSW Sanitary Landfill Vs quantum of MSW handling

Waste quantity (Tonnes per design life of landfill)		Required site area (ha)
in million	In lakhs	
<1.0	<10	15-20
1.0-2.0	10-20	20-30
2.0-3.0	20-30	30-40
>3.0	>30	>40

Source- All India Institute of Local Self Government (2012). / Reference Material on Municipal Solid Waste Management for Urban Local Bodies – Processing Options. Part II. Mumbai: India

4. Data collection for potential sites This selection process is initiated after excluding the unsuitable areas which do not conform to specified criteria. Maps and other available sources and information need to be referred as mentioned in the table below for ascertaining suitability of a landfill site.

Table 2: Data Collection and Sources

DATA	INFORMATION	SOURCES
a. Topographic maps	The topography indicates low and high areas, natural surface water drainage patterns, streams, and rivers as well as roads, railways, and location of airports.	Survey of India
b. Soil maps	These maps, primarily meant for Agricultural use, show the types of soil near the surface.	Indian Agricultural Research Institute (IARI)
c. Land use plans	These plans are useful in delineating areas with definite zoning restrictions. There may be restrictions on the use of agricultural land or forest land for sanitary landfill purposes.	Town planning authority or Municipality.
d. Water use plans	The plans indicating the following items: <ul style="list-style-type: none"> • private and public drinking water wells • drinking water supply line(s), • wells located on surface water bodies and open wells and protection areas for drinking water 	--
e. Flood plain maps	These maps are used to delineate areas that are within a 100 year flood plain	Irrigation Department
f. Geologic maps	These maps indicate geologic features and bedrock levels. They may be used to identify predominantly sandy or Clayey areas.	Geological Survey of India (GSI)
g. Aerial photographs, satellite imagery, Google maps	These can identify surface features such as small lakes, intermittent stream beds, and current land use, which may not have been identified in earlier map searches.	--

DATA	INFORMATION	SOURCES
h. Groundwater maps	These maps indicate the depth to groundwater as well as regional groundwater flow patterns.	Ground water boards or minor irrigation tube well corporations
i. Rainfall data	Precipitation data are used for designing the amount of possible leachate in cities.	Indian Meteorological Department (IMD)
j. Wind rose maps	Wind rose maps indicate the predominant wind direction in the area, based on which the location and orientation of the landfill footprint has to be decided.	Indian Meteorological Department (IMD)
k. Seismic data	The seismic activity of a region has to be considered in the design of sanitary landfills; landfills should ideally not be located in zone 5 seismic zone. However, in case of siting in zone 5, complete structural analysis should be carried out for designing the landfill and the design should include appropriate structural controls.	GSI or National Geophysical Research Institute (NGRI)
l. Road maps	Road maps indicate accessibility of the Potential site.	--

Source- *Anthena Infonomics (2012). / Public Private Partnership in Municipal Solid Waste Management- Potential and Strategies. India.*

5. Field visit for local verification and identification of potential sites

A visit must be planned as a part of preliminary survey for collection of data & maps for screening , this assists in ascertaining relevant features for confirmation. The potential sites be evaluated also on the basis of the topographical features as given below :

- i. Sufficient land size
- ii. Flat area with low slope / gradient)
- iii. Connection to highways and conditions of the access roads
- iv. Flooding during monsoons

- v. Land use and soil type
- vi. Depth to groundwater table (as observed in open wells or bore wells)
- vii. Information on the sub-ground from clay, stone, or sand pits
- viii. Crossing of electrical lines; and
- ix. Actual settlement patterns (eventual new or informal settlements).

6. Selection of best-ranked sites

The CPCB Guidelines (2003) for selection of site of landfills based on a SITE SENSITIVITY INDEX to be noted before ranking the sites on the basis of defined criteria for the preliminary environmental impact investigation and final site selection.

7. Preliminary environmental impact investigation

On the basis of the ranking scores of various potential MSW landfill sites, two or three sites may be chosen for a preliminary environmental impact investigation. The impact of the sanitary landfill should be assessed and be quantified according to the national rules and the local conditions.

8. Final site selection

The available best-ranked alternatives site should be compared on the basis of following criteria :

- a) Environmental impact
- b) Social acceptance
- c) Land availability
- d) Transportation costs
- e) Sanitary landfills costs (site specific costs are to be considered).

Transportation costs of the waste to landfill play a critical role in selection of landfill site and it must be compared on the basis of average handling distance from the centre of waste generating area.

In general, the material costs for liner system, leachate collection system, daily covers, final cover system, and all facilities are similar for all sites, considering standard site conditions (this shall change in areas of high water table, in hilly areas, and other site specific issues).

Some key issues that need to be also taken into consideration are :

- a) Distance to waste generators and waste processing facilities.
- b) Distance of the access road to regional road system
- c) Sub-ground conditions for earthworks to prepare the base of filling area

9. Site investigation & site characterization

For appropriate design of the sanitary landfill at the selected site following investigation will be required;-

- a) Subsoil investigation
- b) Hydro-geological investigation

- c) Surface water investigation
- d) Topographical investigation
- e) Environmental investigation
- f) Traffic investigation

Hydro-geological and surface water investigations are critical for determining the detailed design of the landfill which include groundwater and surface water quality that are required to be monitored regularly during the active life and post-closure of the landfill to ensure no contamination. Critical assessment should also be made to develop effective ground water and leachate monitoring plan with following objectives:

- a) Obtaining samples to characterize soil or bedrock conditions,
- b) Mapping groundwater depth and pressure within the site, and
- c) Assessing baseline groundwater quality.

An analysis of the groundwater flow and pressure will result in the determination of groundwater flow paths and informed leachate control mechanisms and contingency plans in case of failure of the leachate liner. The hydro geological investigation report for a landfill site should conform to the prerequisite as led down in the manual of *‘Technical Aspects: Municipal Sanitary Landfills, 2016, MOUD.’*

10. Surface water assessment

The baseline for surface water quality of the different resources falling within the boundary of 500 meter requires to be also characterized

Sanitary landfill design

The following criteria should be considered while designing the sanitary landfill site:

- i. Design Life
- ii. Expected Waste Volumes: Sanitary Landfill Capacity & Area
- iii. Sanitary landfill layout
- iv. Technical design requirement
- v. Base sealing system
- vi. Landfill phasing
- vii. Leachate management
- viii. Waste placement
- ix. Surface sealing system
- x. Infrastructure for sanitary landfill

1. Design life

The life of sanitary landfill consists of three phases of its Span of existence:-

- a. Active period (10-25 years)
- b. Closure period
- c. Post-closure period

The closure period and post closure period starts at the end of the active period and its life is for 25 years. Close monitoring is required in all the three phases of landfill.

2. Specific waste volume : Sanitary landfill capacity & area

The following points may be considered for designing waste volume landfill capacity and area of the landfill site:

- a. ONE tone of waste is equivalent to one cubic meter (m^3) of sanitary landfill volume. (in reality, the specific weight of waste in a sanitary landfill is $0.8 \text{ t}/m^3$ during the first year and will increase after settlement over the time to $1.2 \text{ t}/m^3$.)
- b. Covering of waste will require about 10% more volume.

Keeping the above facts one can design the volume of landfill capacity and area required for MSW landfill based on quantity of the solid to be treated.

3. Sanitary landfill layout

The general layout the landfill consists of area where actually a landfill is carried out while there will be areas where other structures viz. access roads, equipment shelters, office space, location of waste inspection and transfer station (if used), waste processing (e.g., shredding), weigh bridge, gate, recycling area, compactor garage, pre-treatment area etc. will be located as depicted in **Figure:-12**.

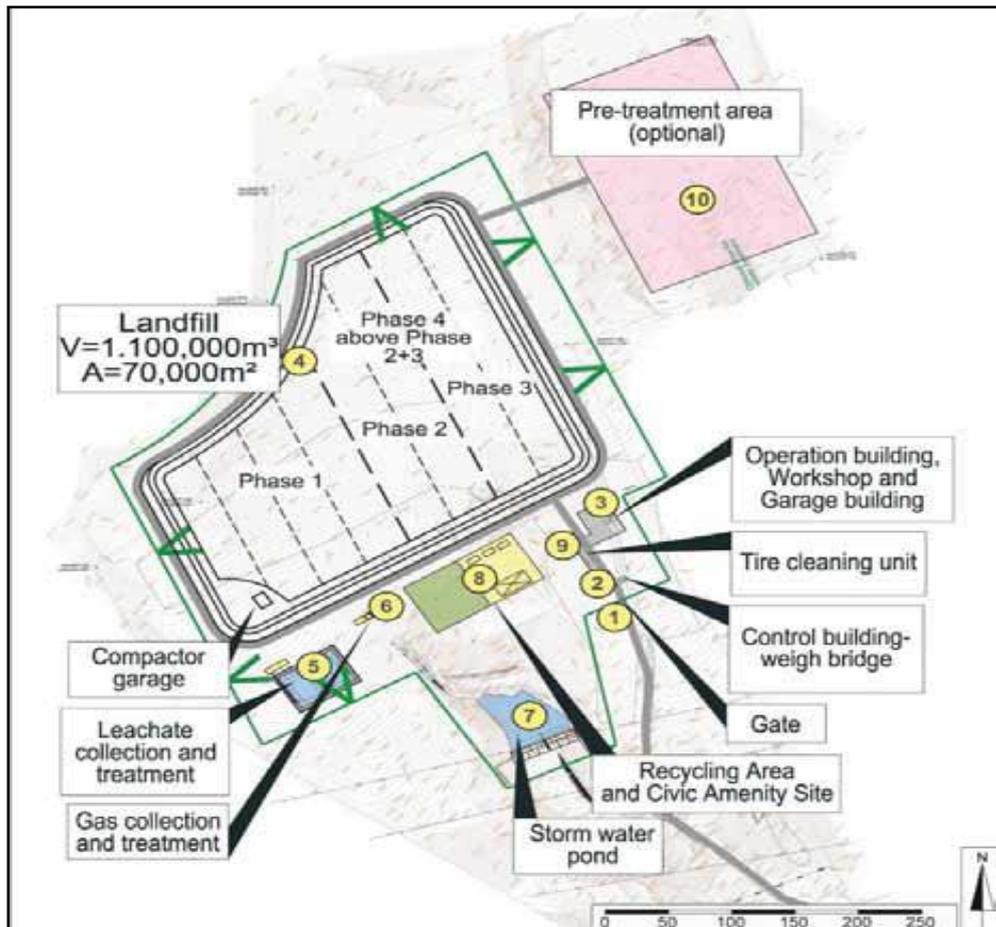


Figure 10: Sanitary Landfill Layout

4. Technical design requirement

The technical design specification of sanitary landfill focus on efficient leachate collection and management. There are three types of leachate situations:

- i. The landfill may have the hydro geological situation where abandoned quarry are to be used as a potential landfill sanitary site. The landfill could be below the ground level.
- ii. Landfill site above the ground have advantage as leachate flows by gravity according to natural surface slope. In such case leachate is collected in main leachate pipe which can be extended beyond the area of landfill and pumped outside the landfill resulting in reduction in size of the footprints.
- iii. In the case is the water table is sufficient below the ground surface, landfill can be located at a level below the ground by excavation, to accommodate more waste per unit area of land. But it should be engineered and constructed appropriately to address the following issues:
 - a) Extra costs for excavation
 - b) Energy Input for pumping leachate during and beyond the active life of landfill.
 - c) Environmental risks during failure (mechanical/electrical) of pumps.
 - d) Potential for retention of leachate in the waste body
 - e) Pipe cleansing and controlling is nearly an impossible task.
 - f) Pumping cost for the leachate (during the lifetime and the aftercare phase of the landfill).

5. Base sealing system

- a) Adoption of shape of site as per the existing condition with minimum of fills and cuts but the overburden that will be replaced by the sealing system has to be excavated.
- b) Excavated soil could be used as a potential base sealing system and can also be compacted to be used as overlying clay liner.
- c) The natural soil should be levelled and compacted to achieve 90% maximum dry density as obtained from Proctor compaction tests. This is sufficient to compact the overlying clay liner.
- d) The base area may be made sufficiently sloping to ensure draining of leachates and storm water.

The composition of base sealing system has to be in compliance with SWM RULES 2016 and should consist of the following :

- i. Mineral sealing liner: will be made of three layers of clay or equivalent amended soil, at least 30 centimetres (cm) thickness each. If adequate clay (quantity & quality) is not found in the vicinity, amended soil mixed with bentonite can be used. The permeability of the mineral sealing must be less than $k_f \leq 1 \times 10^{-7}$ cm per second (cm/s).

- ii. Geo-synthetics clay liner: In hilly regions, the mineral part of the sealing system can be reinforced by a geosynthetics clay liner.
- iii. High-density polyethylene geo membrane: The high-density polyethylene (HDPE) geo membrane should have a standardised thickness of 1.5 millimetre (mm).
- iv. Protection layer: Silty soil with thickness of 20–30 cm or, geotextile of 400 grams per square meter (g/m^2) for bottom liner and $200 \text{ g}/\text{m}^2$ for top cover, depending on the landfill height. In the case of landfill height in the landfill is more than 20 m, geotextile should be $800 \text{ g}/\text{m}^2$.
- v. Leachate drainage layer: A leachate drainage layer should be 30 cm thick made of filter gravel, ensuring permeability greater than $10^{-2} \text{ cm}/\text{s}$.

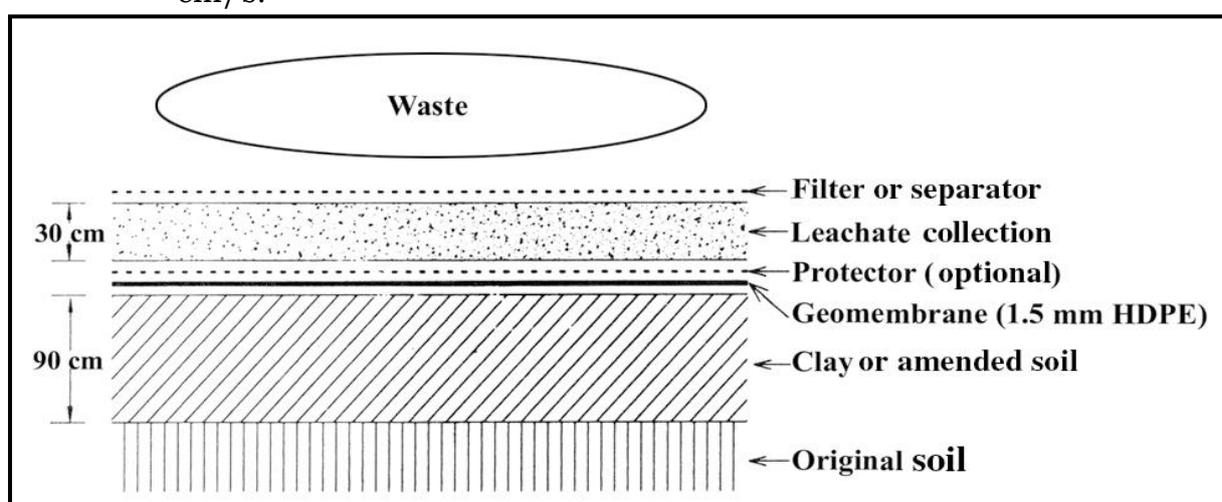


Figure 11: Leachate drainage layer

6. Landfill phasing

The important criteria and must be adopted as per the pre-determined plan. Landfill phasing is essential to:-

- a) To minimise damage to the landfill base layers
- b) Ensure continued integrity of base layers over the lifetime of the landfill
- c) Minimise potential rainfall infiltration.

However phasing must be as per site specific decision, site condition and care must be taken in design so that the proposed landfill volume should be large enough accumulating MSW generated/brought for one year.

7. Leachate management

It must be carried out by pre-identified leachate generating sources and its appropriate collection and management as per the standard norm documented in the MSWMM, MOUD, GoI 2016.

8. Waste placement

It should follow the following steps:

- i. A 30 cm thick layer of select waste without compaction will be placed on the geotextile as and when the laying is completed.

- ii. In order to dump subsequent layers of waste, soil should be pushed gently by a light dozer for access path.
 - iii. One or two main routes with extra thickness of soil layering (60-90 cm) should be created for use by heavier equipment for the purposes of soil moving.
 - iv. Avoid damaging the geo membrane due to movement of machinery.
 - v. The first loading of waste should be spread and slightly compacted with light machinery.
 - vi. No bulky items should be dumped in the first charge.
9. Surface sealing system

The surface sealing must follow the following sequence from waste surface to top:

- a) Gas drainage layer- 30 cm thick formed by crushed gravel or crushed demolition waste to facilitate gas collection.
- b) Mineral clay layer: Mineral clay layer should be a 60 cm: either of clay or amended soil and should satisfy permeability requirements of $k = 10 \text{ cm/s}$. If the permeability is higher than 1.5 mm HDPE may be installed over 60 cm thick soil layer. 1.5mm HDPE liner should be covered with a 20 cm protection layer or geotextile.
- c) Water drainage layer: The water drainage layer should be 30 cm thick formed by crushed gravel. The gravel layer should be covered by a geotextile or alternate separator to prevent clogging of the drainage layer by the overlying soil.
- d) Vegetative soil layer: The top layer should be 45 cm thick vegetative (culturable) soil.

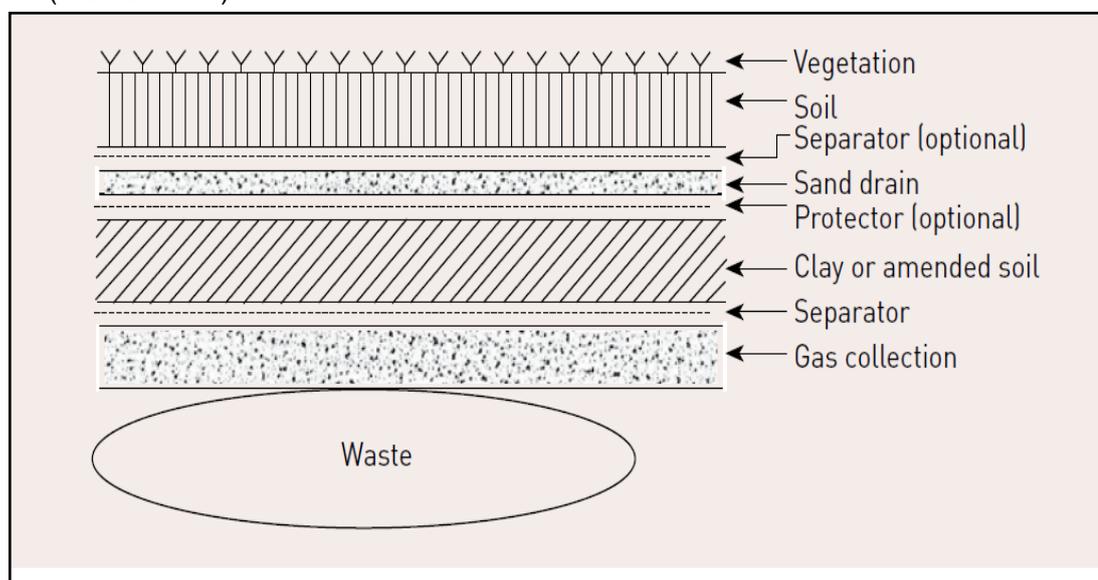


Figure 12: Surface liner system

10. Infrastructure of sanitary landfill
- i. Road Construction
 - ii. Equipment and Resources
 - iii. Waste Inspection Area or Emergency Area

- iv. Security and Fencing
- v. Tyre Cleaning Unit
- vi. Sanitary Landfill Buildings

Construction of sanitary landfill (SLF)

Construction of sanitary landfill must be carried under the supervision of qualified engineers with following assigned tasks:

- i. Supervision of construction works
- ii. Quality assurance
- iii. The drainage layer
- iv. Leachate collection system

1. Supervision of construction works

The construction of a sanitary landfill should be supervised by an independent engineer on behalf of the municipality or the employer.

- i. Approval of the drawings and the final design.
- ii. Quality assurance of all operations related to the landfill.
- iii. Compliance with the SWM Rules, 2016.
- iv. Time scheduling, steering, and coordination of/at the construction sites.
- v. Acceptance of the construction work and supplies.

2. Quality assurance

Quality assurance and quality control are integral parts of a landfill design scheme. Quality assurance / quality control plans should be used to ensure that the design and construction of the facility is carried out as per approved standards.

3. The drainage layer

The drainage layer is built on the protection layer. The drainage layer must comply with the following requirements:

- i. The chemical, physical, and mechanical stability of the material selected for the drainage layer must ensure that there is no adverse effect on the drainage efficiency from the chemical and physical leachate characteristics and the mechanical load of the landfill body.
- ii. For the drainage layer, washed material should be used and rounded grains (grits) preferred.
- iii. Grain-size distribution of the material should be used for the drainage layer, with permeability greater than 10^{-2} cm/s.

4. Leachate collection system :

It must be carried out by identified leachate generating sources and appropriate collection as per the standard norm documented in the MSWMM, MOUD, GoI 2016.

5. Slope stability aspects and seismic aspects :

The stability of a landfill should be checked for in the following situations:

- a) Stability of excavated or filled slopes
- b) Stability of liner system along excavated or filled slopes

- c) Stability of temporary waste slopes constructed to their full height (usually at the end of a phase)
- d) Stability of slopes of above-ground portion of completed landfills
- e) Stability of cover systems in above-ground landfills

The aforementioned tasks must be carried out as per specification laid down in the “MSW Manual , MoUD, GoI 2016.”

Operation of Sanitary landfill (SLF)

Sanitary landfill operation must be carried out under the supervision of qualified engineers with following assign tasks:

1. General requiremnt

- a) Operation Manual
- b) Employee Assignments and Responsibilities
- c) Staff Responsibilities and Qualifications
- d) Time of Opening and hours of Operation
- e) Site Notice Board
- f) Site Security

2. Waste reception and control of incoming waste

All deliveries by collection vehicles of the municipality and from private service providers should be documented by checking the (registered) license plates, the respective labelling on the vehicles for source and type of MSW, or the respective license. Corresponding lists with the license plate numbers have to be compiled before handover to the landfill supervisor to help the weighbridge operator identify the vehicles.

3. Waste management

Spotters should be engaged to guide the deliveries to pre-identified locations for waste unloading at the landfill. The following unloading areas should be available:

- Waste disposal area
- Temporary storage areas for C&D (Construction and demolition) waste, and excavated earth/soil (cover material)

4. Filling and compaction procedure of waste

A high degree of waste compaction extends the capacity and thereby the lifetime, of the landfill, reduces the need for cover material, minimizes litter problems and cuts down on long term land requirements.

5. Covering of waste

Cover includes imported cover such as

- a) Soil and other inert waste
- b) Other material such as fine portion of C&D waste, street sweepings, and silt from dry drain. The cover soil should be pushed by a bulldozer or wheel loader up the slope and spread out as evenly as possible. When constructing a body in an open area, the side slopes also require soil cover.

Landfill must be covered with following types :

- Daily Cover
- Intermediate Cover
- Temporary Surface Cover
- Covering during the Monsoon

6. Final cover (surface sealing system)

To minimise infiltration of storm water in the landfill body and to allow storm water runoff, a surface sealing system has to be installed after the final completion of each portion of landfill.

7. Landfill gas management

A large part of mixed waste (50%–60%) consists of biodegradable components which produce methane gas. To reduce GHG emissions and thereby reduce environmental impacts, it is mandatory to install a de-gassing system for sanitary landfill. The gas management strategies should follow one of the following options:

- a) Controlled passive venting
- b) Controlled active collection and treatment or reuse.
- c) Flaring of LFG also may be a option

8. Sanitary landfill roads

An important part of the landfill operation activities is enabling vehicles to reach the landfill area (accessibility) on a daily basis until the landfill closure procedures are in place. Therefore need for maintenance of access roads having appropriate signages.

- Road Construction
- Main and Temporary Roads
- Road Maintenance

9. Storm water management

All surface water ditches, culverts, drainage channels, and settling ponds (storm water ponds) should be designed by a hydrologist using hydrometeorological data.

- a) Surface Water Collection
- b) Storm Water Retention Pond
- c) Maintenance of the Storm Water System

10. Landfill equipment

- a) Necessary required equipment and
- b) Maintenance of all equipment stationary & mobile equipment

11. House-keeping of the sanitary landfill

Housekeeping should be conducted in such a manner that it protects the public and surrounding environment from risks and odour nuisance emanating from landfill operations. A well-controlled landfill operation will enhance public perception and acceptance of the landfill site.

The following general measures be considered:

- a. Health and Safety
- b. General Safety Measures

- c. Person Related Safety Measures
- d. First Aid
- e. Personnel Accidents
- f. Fire Prevention and Protection

12. Environmental monitoring

The environmental monitoring of landfills should be performed as per SWM Rules, 2016.

Closure and post-closure plan of SLF

Determination of the end use of a landfill site is an essential part of the plan for landfill closure and post-closure maintenance. A closure and post-closure plan for landfills involves the following components:

- i. Plan for vegetative stabilisation of the final landfill cover
- ii. Plan for management of surface water runoff with an effective drainage system.
- iii. Plan for periodical inspection and maintenance of landfill cover (settlements) and facilities
- iv. Plan for quantity and quality of leachate monitoring from/at the landfill
- v. Plan for quantity and quality of landfill gas monitoring
- vi. Plan for groundwater quality (up gradient and down gradient)
 - i. Plan for surface water quality at the periphery of landfill and at receiving water bodies

The post-closure care of landfill site shall be conducted for at least 15 years in line with the SWM Rules, 2016 as mentioned above. The authority or concessionaire that operated the sanitary landfill shall be responsible for post-closure activities and monitoring.

- a) Plantation at Landfill Site.
- b) Considerations for Landfill Costing.

Ref. Municipal Solid Waste Management Manual, Ministry Of Urban Development (MoUD) , Government Of India.

RECOMMENDATION & WAY FORWARD

Recommendations to control odourous emission from MSW landfills

The guidelines have proposed various strategies to abate Odour drawing from the experience in the field while executing pilot study on Odour monitoring at MSW landfill at Ghazipur, Delhi. The reader is advised to review the following chapters in this report :

- a. IMPORTANCE IN ODOUR MONITORING IN URBAN MSW LANDFILL SITES
- b. PREVENTIVE MEASURES - ODOUR ABATEMENT AT MSW LANDFILLS
- c. ODOUR CONTROL TECHNOLOGIES IN MSW LANDFILL SITES
- d. REMEDIAL OPTIONS FOR ODOUR PREVENTATION
- e. CRITERIA FOR SELECTION & DESIGNING OF MSW LANDFILL SITES

For further emphasis some key features are deliberated upon below :

- i. Segregation of MSW must be adopted appropriately particularly at the source
- ii. Design, construction and operation of MSW be carried out as per Municipal Solid Waste Management Manual, Ministry Of Urban Development (MoUD) , Government Of India.
- iii. The main odourous compounds are :
 - a. Ammonia
 - b. Mercaptans
 - c. Butyric acid

The concentration of such odourous emission can be minimized by adopting:-

1. Appropriate C/N ratio in the MSW landfill system
2. Operating the landfill in such way that the population of sulphur reducing micro-organisms are maintained rationally.
3. Process design and operation of the landfill should be in such way that partial aerobic condition may prevail which will reduce generation of VOCs and solubilising the sulphur and nitrogen constituents as leachate, which will reduce availability of nitrogen and sulphur to anaerobic microorganism to transform to ammonia and reduced sulphur odourants.

- iv. Selection of appropriate plant species for vegetation cover around the landfill site assist in reducing odours
- v. MSW Landfill system be designed for tapping LFG efficiently to mitigate fugitive odorous emissions
- vi. The materials used for high and low covers must be non-corrosive and be put in appropriate configuration of the landfill system such that it acts as a odour preventive measure
- vii. Where the implementation of other odour abatement measures is difficult in the MSW Landfill , appropriate arrangement be made for spraying intermittently inhibitory agents, masking agents, neutralizers the rationale being that they will reduce the inherent unpleasant hedonic tone of the landfill emissions. Chemical agents ex enthro quenone, ferric salt , a nano- iron oxide polymer network (NIOPN) – sulpha sponge etc may be dispersed over MSW landfill site to reduce odours



Figure 13: Views of Ghazipur Landfill site with green facade (facing NH 24) after part closure

Way forward

Common Odour sources in urban areas :

- Garbage (bio-degradable MSW) & sewage

Challenge to odour monitoring :

- a. Characterise 'signature ' odourous gaseous mixture of a region ex. MSW landfill, sewage (open drains) , STPs, eutrophic lakes
- b. Lack of source based database on Odour levels
- c. Awareness on odour is low (public nuisance)
- d. Lack of legislative obligations

To initiate legislative norms there is a need for creating baseline data on ODOUR. However as manual measurements are time consuming hence there will be a need for gradual shift for installation of an efficient tool i.e. Continuous Odour Measurement Systems (sensor based) that similarly being adopted by CPCB for other environmental parameters ex. Continuous Air Quality Monitoring Stations (CAAQMS) , Continuous Noise Monitoring Stations' and Continuous Water quality monitoring stations which provide real time data.

The Guidelines have been prepared keeping in view of the various mandatory and statutory provisions and the climatic conditions that accelerate biodegradation of organic wastes. This is the first initiative by CPCB to address odour problems by a scientific investigation way, similar studies can be undertaken by other institutions for areas (ex. Industrial estates) other than MSW landfills so that a database can be created to highlight importance of odour minimisation and prepare a framework for odour management in urban areas.



Figure CPCB's Real Time Water Quality Monitoring Station (AWQM in River Ganga)

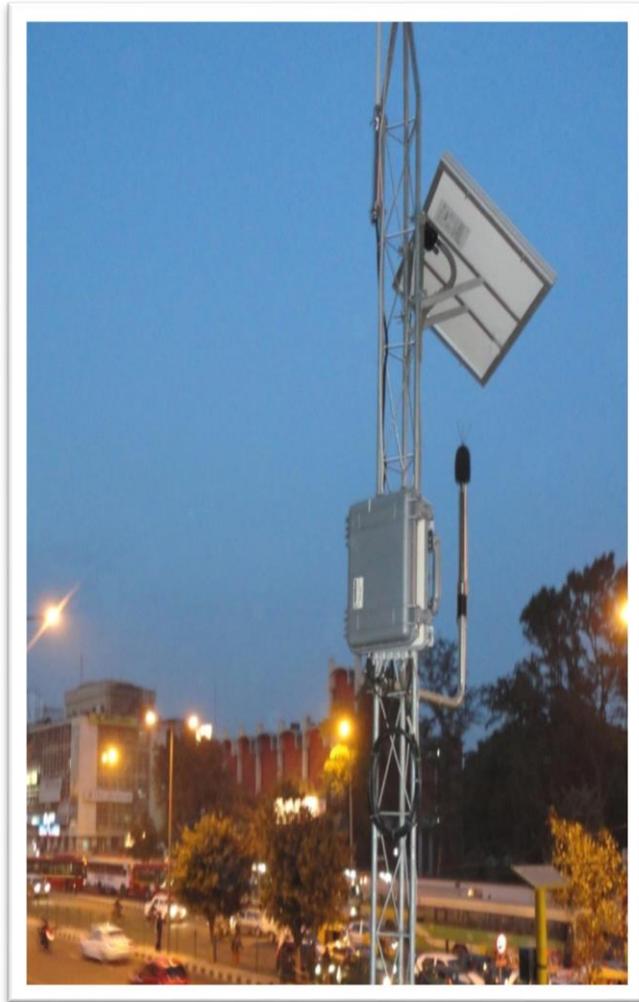


Figure : Continuous Noise Monitoring System (NMS) measuring real time noise levels (CPCB)



Figure : CPCB's Continuous Air Quality Monitoring Stations (CAAQMS)

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To the READER

Central Pollution Control Board (CPCB) awarded the project “Development of National Guidelines on Odour Monitoring & Management of Urban Municipal Solid Waste (MSW) Landfill Site” to M/s. J.M. EnviroNet Pvt. Ltd. (henceforth Project Consultant), Gurugram, Haryana, India in September 2015. The sampling & analysis protocols for determining odour emission from MSW Landfill site is the core of this study around which the pilot study on Odour monitoring was conducted at the identified MSW landfill site at Ghazipur located in East Delhi. Dynamic Olfactometry is the internationally accepted & recommended method which facilitates field sampling cum laboratory analyses by expert panelists – both, the expertise & instrumentation is cost prohibitive for a pilot study. In India ODOUR is a NEW area which needs to be familiarized, hence literature survey on various aspects and also to explore economically feasible and adaptable methods to create a database that can assist in generating mass awareness. For CPCB’s pilot study on Odour monitoring the use of Field Olfactometry was accepted. Odour Dispersion modeling & mapping was done by IIT Delhi. The above exercise assisted in preparing the **Guidelines on Odour Monitoring in MSW Landfills** which recognizes the diverse climatic zones of our vast country, hence odour surveys at MSW landfill sites cannot be generalized but to be assessed on a case to case basis taking into consideration the unique temporal & spatial influences of each MSW landfill site. This report is in compliance of the project’s ToR conditions. For simplification, the entire study is being presented in following **FOUR PARTS** in order of their development.

1. **Sampling & analysis protocols for determining odour emission from MSW Landfill site (page 1-94)**
2. **Case study – Pilot Study on Odour Monitoring at Municipal Solid Waste (MSW) Landfill Site, Ghazipur, East Delhi in year 2016 (page 95-130)**
3. **Odour Dispersion modeling & mapping - Ghazipur MSW Landfill, Delhi (page 131-160)**
4. **Guidelines on Odour Monitoring in Urban MSW Landfill (page 161-230)**



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