Indoor Air Quality Assessment in Terms of CO2 level & Odor Dispersion on Residential Buildings Neighboring to Reppie (Koshe) Landfill Site: Addis Ababa City, Ethiopia

Betelhem Fitsum

A Thesis Submitted to the Department of Architecture and urban planning & design

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Masters of Science in Environmental Architecture

Office of graduate studies

Adama Science and Technology University

Adama, Ethiopia

October, 2022

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APPROVAL SHEET

I, the advisor of the thesis entitled "**Indoor Air Quality Assessment in Terms of CO2 level & Odor Dispersion on Residential Buildings Neighboring to Reppie (Koshe) Landfill Site Addis Ababa City, Ethiopia**" and developed by Betelhem Fitsum hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Belay Zeleke (PhD)	______________________	______________
Major Advisor	Signature	Date

APPROVAL OF BOARD OF REVIEWERS

We, the undersigned, members of the Board of Reviewers of the thesis open defense by **Betelhem Fitsum** have read and evaluated the thesis "**Indoor Air Quality Assessment in Terms of CO2 level & Odor Dispersion on Residential Buildings Neighboring to Reppie (Koshe) Landfill Site Addis Ababa City, Ethiopia**" and assessed the understanding of the candidate about the research. This is, therefore, to certify that the thesis is accepted and we recommend the implementation of the thesis.

Chairperson	Signature	Date
Reviewer 1	Signature	Date
Reviewer 2	Signature	Date

Finally, approval and acceptance of the thesis are contingent upon the submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
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DECLARATION

I declare that this thesis entitled ***"*Indoor Air Quality Assessment in Terms of CO2 level & Odor Dispersion on Residential Buildings Neighboring to Reppie (Koshe) Landfill Site Addis Ababa City, Ethiopia*"*** is my work and has not been submitted to any university for a similar purpose. The references used in this thesis are duly recognized by proper citations.

Betelhem Fitsum

______________________	______________________	______________________
Name of Student	**Signature**	**Date**

RECOMMENDATION

I, the major advisor of this research, here by certify that I have closely advised the student while developing this thesis and read the draft thesis entitled **"Indoor Air Quality Assessment in Terms of CO2 level & Odor Dispersion on Residential Buildings Neighboring to Reppie (Koshe) Landfill Site Addis Ababa City, Ethiopia"** prepared under my guidance by **Betelhem Fitsum**. Therefore, I recommend the submission of the thesis to the department for further review and evaluation

Belay Zeleke (PhD) ______________________ __________________

Major Advisor Signature Date

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LIST OF ABBREVATION

AER ………………………………………………air exchange rate

MSW... Municipal solid waste

LFG …………………………………………landfill gas

WHO …………………………………………World health organization

IAP ……………………………………………Indoor air pollution

GHG..Green House Gas

CH4...Methane

CO2... Carbon dioxide

VOCs ....Volatile Organic Compounds

LEL ……………………………………………… Lower explosion limit

COP ……………………………………………… Conference of the Parties

PAHs.. Hazardous air pollutants

PPM …………… ....Parts per Million

SPSS ....Statistical Package for Social Science

EPA.. Environmental protection agency

ABSTRACT

Landfill Odor and CO_2 pollution are components of the pollutants affecting the human environment indoors and outdoors around landfills. The study was conducted in koshe landfill with the objectives to analyze the effect of the Reppie (Koshe) landfill on the indoor air quality of the residents around it, focusing on the dispersion of CO_2 and Odor to identify the areas which can be impacted by CO_2 and odor released from the landfill and examining the concentration of CO_2 inside residential buildings around Koshe in the extent of 1.5km radius.

To delineate the odor and CO_2 zones of influence, the air dispersion properties of the odor and CO_2 gases were analyzed using the dispersion modeling software, Areal Locations of Hazardous Atmospheres (ALOHA), and mapped with ArcGIS, Part of the study consists of a perception survey to determine the influence of odors on the level of indoor comfort. Carbon dioxide (CO_2) concentration was measured using aeroqual series 500 portable air quality measuring instrument inside the sampled residential houses within the radius of 1.5km. The findings of the study show that odor and CO_2 impact zone tool showed that atmospheric stability, the dominant northwestern and southeastern wind directions could increase the odor impact radius around the landfill evaluated between 322 and 540 percent and the result from CO_2 dispersion suggest that in June CO_2 had a smaller concentration of emission than in April. However, the maximum distance for the dispersion of CO_2 in June was found to be longer than that in April. Descriptive statics using figures and tables were employed to present research findings concerning the survey result. the result implies the level of CO_2 in the radius of 500m was greater than the values taken within the radius of 500m-1.5km even though all values don't exceed the standard values, the values indicates that koshe landfill has some contribution to the increase of CO_2 level considering the landfill as the only source. 34% of the residents agree that koshe have caused indoor malodor contribution to the indoor environment, from the results of the study it is highly recommended that mitigation measures such as Planting green belt as Buffer around the landfill and Passive solution for residential Buildings

KEYWORDS: - CO_2 level: Indoor Air Quality (IAQ); landfill; odor pollution

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Solid waste generation mainly depends on population and urbanization. Open dumping of municipal solid waste is the most common and widespread disposal method. Open landfills cause environmental degradation through open incineration, groundwater and surface water pollution, soil contamination, air pollution and reduced vegetation. Due to poor coverage, poor site condition, lack of leachate collection and treatment, lack of GHG collection and treatment, open landfills are prone to various health problems. Release of gases, leachate, large settlements and other environmental controls (Powrie et al., 2015).

Air pollution can be expressed as the presence of one or more contaminants in the atmosphere that can harm human, animal, or plant life. The disposal of waste on land has been increasing because the quantity of waste arises. The complexity of man's activities has brought about a growing quantity of solid waste worldwide, despite the modern-day technological development and improvement of waste coping with and control options (Ezekwe et al., 2016). Waste gases are a combination of many compounds that are formed during the decomposition of municipal waste and the volatilization of chemical waste. Methane and Carbon dioxides are the primary landfill gas additives and trace concentrations of intensive kinds of different gases, relying on the waste mix (Paraskaki & Lazaridis, 2005). MSW degradation would produce less than 1% v/v of non-methane compounds, which are considered to be a major source of odor emissions (Allen et al., 1997); this odorous 1% is composed of trace chemical species among them Hydrogen sulfide is ranked first (Figueroa, 2019). Over the past 50 years, the production of municipal solid waste (MSW) in Ethiopia has increased dramatically alongside population growth, rapid urbanization, and the process of industrialization.

Reppie or usually known as Koshe is the largest outdoor garbage and rubbish dump in Addis Ababa, the capital of Ethiopia. The location of Reppie (Koshe) is in the southeastern part of Addis Ababa (Tesema, 2010). This landfill site contributes to a negative phenomenon connected, the fact that residential areas are too close. According to Richardson et al. (2010), People living close to waste disposal sites can be exposed to doubtlessly dangerous chemical compounds through the air, water, or the soil medium. However, the predominant dangers to human health from a waste disposal site are likely to be an outcome of air pollution (Richardson et al., 2010) and The release of odorous gases from the landfill has been a serious environmental concern, particularly for residents near the landfill (Shen et al., 2020).

According to other literature, indoor air pollution can be either from the inside source, which includes various activities done inside the house such as cooking and other activities performed by dwellers, or from outside sources (emissions from vehicles, industry, landfills). Indoor air pollution (IAP) has been studied more in Ethiopia than outdoor air pollution, although the evidence base may be insufficient. Many studies have attempted to link IAPs to human health, not by measuring the concentration of pollutants and most studies focus on the contribution of indoor sources to indoor air quality, not outside sources (CDC, 2004).

This study focus on the largest landfill in Ethiopia called Koshe located in the capital of Ethiopia, Addis Ababa. Due to the increase in urbanization, the vicinity of the residential area around the Koshe landfill is increasing. “residential areas close to the disposal sites are exposed to higher concentrations of CO_2 gases’’(Elmi et al., 2021). This study aimed to analyze the concentration and dispersion of CO_2 in and around residential buildings located near Koshe landfill, and odor dispersion. CO_2 and odor have a high dispersion capacity to the surrounding environment contributing to global warming and have effects on peoples’ health (Damiano & Dougan, 2007). The concentration of CO_2 on residents living closer to landfill sites and the overall impact on air pollution are not been closely examined in previous research in Ethiopia.

1.2. Statement of the problem

With rapid population growth and urbanization, waste generation increased. As cities grow rapidly, koshe landfill that were originally located outside of the city become part of the city's domain and now Reppie (Koshe) landfill site is surrounded by a residential area. Reppie landfill is just a damp site is associated with various hazards such as; It is an open field disposal (Not sanitary landfill), No daily cover with soil, Nuisance and health hazard for people living nearby, No leachate containment or treatment protection at the bottom by a geomembrane nor other infrastructures needed, No rainwater drain off and migration occurs through run-off of precipitation, No odor or vector control; No treatment facilities, No fencing, the area is an unprotected area for children, women and scavengers, No large scale composting facility available as a disposal option, Blows litters and spreading wastes outside the site and on the surrounding, organic waste that goes to landfill sites not only pollutes the land and water but also contributes to global warming by producing methane (CH_4) and carbon dioxide ;(Tesema, 2010) so different landfill gases have several options to pollute the surrounding environment. Koshe landfill has raised concerns about the potential negative health effects of people living nearby, particularly residents raised concern on medias (Yimam & Tesfaye, 2020).

1.3. Objective

1.3.1. General objectives

The main objective of the study is to analyze the quality of indoor air in terms of carbon dioxide and odor in the neighboring residential buildings located around Reppi (Koshe) landfill site**.**

1.3.2. Specific objectives

The specific objectives of this proposed study is:

1. To analyze the dispersion of carbon dioxide around residential buildings neighboring to Reppi (Koshe) landfill site.
2. To study the dispersion of odor around residential buildings neighboring to Reppi (Koshe) landfill site.
3. To assess odor existence inside residential buildings through community perception.
4. To analyze the concentration of carbon dioxide (CO_2) inside residential houses neighboring to Reppi (Koshe) landfill site.

1.4. Research question

The goal of this research study was to address the following scientific questions:

1. What is the direction and level of Carbon dioxide dispersion from the landfill site?
2. What is the spatial extent of the dispersion of odor?
3. What is the community perception of odor to the contribution of indoor air quality?
4. What is the concentration level of carbon dioxide inside residential buildings around Reppie (Koshe) landfill site?

1.5. Significance of the study

Many individuals and groups will benefit from this research; the local community and residents will be the main beneficiaries of this study.

This research will help to:

- Raising awareness in the local community on the contribution of Koshe landfill to their indoor air pollution and creating social engagement to address these issues.

- To serve as reference/secondary information for future studies in areas with similar characteristics/challenges.
- Indirectly helps administrators to know how the lives of the residents around the landfill are affected and help them devise mechanisms by which they can improve the existing situation around the landfill. It can also help the responsible authority to identify the effects the landfill has on resident ‘s daily life and to work on improving the existing situation and take alternative measures.

1.6. Scope and Limitations of the Study

The study was conducted at Koshe landfill site and its neighboring residential areas up to a 1.5km radius from the landfill. This study was limited to analyzing only one of the major greenhouse gas emitted from the landfill site, CO2 gas, and odor focusing only on hydrogen sulfide studied to evaluate indoor air quality. This study was limited to studying only 192 residential buildings purposively, due to budget and time constraints, the study focused on a limited number of samples. The scope of this research only focuses on analyzing how the landfill can contribute to the quality of indoor air. The hardship faced in finding gas detector instruments limit the research executed scope.

1.7. Organization of the Study

This study is divided into five chapters.

The first chapter is concerned with an introduction to the subject matter. This part of the study provides a detailed explanation of the central ideas behind the research. This is done by presenting the study goals and defining the research questions. The next chapter, which is chapter two presents a review of related literature. The theoretical basis of the study is presented in this part of the study. Then it is followed by chapter three which deals with the methods that are used to collect data. Empirical analysis of data collected through instrumental measurement and discussions is presented in chapter four of the study. Lastly, a conclusion and recommendations are made in chapter five of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1. Air pollution

Air pollution is the introduction of chemicals, particles, or biological materials into the atmosphere that cause human discomfort, illness, death, or harm to other living organisms such as food crops, or damage to the natural or built environment (Mahendra Pratap Choudhary and Vaibhaw Garg, 2013). The World Health Organization (WHO) has recognized that air pollution is the world's greatest environmental risk ("WHO Guidelines for Air Quality.," 1998). Human activities have led to a significant increase in air pollution in both rural and urban areas(Murray, 2013). One of the most likely causes of air quality problems is urban population growth combined with land use changes due to the increase in urban areas (Mustafa, 2017). The effects of air pollutants on human and ecological health vary with the type and quantities of pollutants emitted and the sensitivity of individuals exposed to the pollutants (Molina & Gurjar, 2010). The emission of air pollutants is caused by various anthropogenic processes, which can be divided into the source groups car traffic, industry, power plants, trade, municipal solid waste disposal, and domestic heating (Mayer, 1999). Air pollutants that are emitted from different sources are dispersed and diluted in the atmosphere (cited by Mayer, 1999).

Air pollution occurs when unwanted substances are added to the air, especially in excess, with environmental and health implications. In principle, these undesirable substances can be anything in any phase, such as carbon dioxide (CO_2), liquid droplets, and solid dust particles. Material is only labeled as an air pollutant if it is contrary to human interest. For example, sulfur dioxide (SO_2) is considered an air pollutant due to its negative impact on the environment and human health. In another example, the nitrogen content of more than 78% is not considered an air pollutant because it has no discernible negative impact on humans and the environment. On the other hand, although CO_2 was a component of clean, dry air before human history, it wasn't called a greenhouse gas emission until recently, when scientists observed a strong correlation between rising atmospheric CO_2 levels and global warming (or climate change), which could eventually wipe out the existence of humans on this planet (Doty, 2020).

2.2. Air pollution and landfill sites

A waste disposal landfill is defined as a landfill in which both municipal solid waste (MSW) and hazardous or toxic waste has been deposited. The MSW fraction is the most significant both volumetric and weight-based. LFG is produced from the disintegration of household waste by bacteria and typically consists of carbon dioxide (CO2) 40 to 60 percent, 45 to 60 percent methane (CH4), and trace constituents that contain volatile organic compounds (VOCs), odorous gases, and hazardous air pollutants (PAHs) (Robertson & Dunbar, 2005).

The effect of a landfill on air quality depends on the waste, discharge rates of pollutants, native meteorological circumstances, and the proximity of sensitive areas to the location (Richardson et al., 2010). The effect of a discharge on the air quality depends on the waste, during bacterial disintegration, biological waste is broken down by bacteria naturally present in the soil (Parker et al., 2002). When wastes change from a liquid or a solid into a vapor, volatilization will occur. Larger volumes of landfill gas containing carbon dioxide, methane, nitrogen, and hydrogen sulfide (causing odor), are produced when there's greater organic material in the waste. The age of the waste, recently buried waste produces more landfill gas through bacterial decomposition; volatilization and chemical reactions than older waste plays an important role in the amount of gas production. (Parker et al., 2002).

Landfill gas odors are generated by chemical and bacterial processes and can be emitted from active and closed landfills (Richardson et al., 2010). These odors can migrate to the surrounding communities. Landfill gas can migrate from the landfill above or below the ground and exposure occurs on the site itself or in surrounding communities. Gases can migrate over the surface in the ambient air. One of the compounds most likely to cause odors in landfill gas is ethanol and hydrogen sulfide (Parker et al., 2002). The odors of landfills are often a source of the source of municipalities, and people tend to be worried about the health effects associated with gases that cause these odors.

Waste Management and Sanitation in Addis Ababa

In the city of Addis Ababa, the estimated daily amount of solid waste is around 765 tons with a per capita daily production of 0.45 kg. 76% of the total solid waste generated comes from residential areas, 9% from commercial areas, and 6% from the street. Sweeping, 5% from industry, 3% from hotels, and 1% from hospitals. The separation, reuse, or recycling of solid waste is very low as up to 80% of waste is disposed of without reuse or recycling14. Only 65%

of the daily solid waste is collected, 5% is recycled and 5% becomes compost, the remaining 25% is simply dumped in open sites, sewers, rivers, valleys, and roads, and a small percentage is incinerated. (Tesema, 2010).

2.3. Landfill Gases

According to the United States Environmental Protection Agency, the decomposition of municipal solid organic waste such as garbage, yard waste, and paper products generates landfill gas. This process can continue for 20 to 50 years after the initial discharge of MSW. Under near stationary conditions, LFG is typically composed of about 55% CH_4, 40% CO_2, 5% N_2, and small amounts of NMOCs such as benzene, and vinyl chloride, 1 dichloromethane, chloroform, 1, carbon tetrachloride, and other NMOCs. In addition, inorganic species such as hydrogen sulfide and vapor phase mercury are often present in LFG (Doty, 2020).

Numerous investigations have been carried out to characterize LFG emissions and significant changes in the composition of LFGs have been observed. VOC, includes simple alkanes, olefins, aromatics, and a wide range of chlorine compounds. They range from a few parts per billion (ppb) to tens of thousands of ppb. Over fifty different VOCs have been identified in the concentrations of LFG. (Robertson and Dunbar, 2005). The main concern of this research is one of the main greenhouse gas CO_2 and odor, the next subtopic discusses that.

2.3.1. Carbon Dioxide (CO_2)

Greenhouse gases (GHGs) include CO_2, methane (CH_4), hydrofluorocarbons (HFCs), per fluorinated compounds (PFCs), and others. Most of them come from natural sources and have been present in the atmosphere for a long, long time. More recently, additional anthropogenic greenhouse gases may have contributed to global climate change and extreme weather conditions (Doty, 2020). Carbon dioxide (CO_2) is a gas that occurs naturally and acts as the primary source of carbon in life on Earth. CO_2 emissions can also be produced by the biological degradation of biomass from agricultural activities and landfills (Doty, 2020). Symptoms of mild CO_2 exposure may include headache and drowsiness. At higher concentrations, rapid breathing, confusion, increased cardiac output, high blood pressure, and increased arrhythmias can occur (OSHA, 2010). Acceptable CO_2 concentrations in outdoor air are typically between 300 and 500 ppm. High levels of CO_2 in outdoor air can be an indicator of combustion and/or other sources of pollution (Damiano & Dougan, 2007).

2.3.2. Odor

The large volumes of treated waste materials and the complex biological and physio-chemical processes make areas near landfill sites not only vulnerable to emissions of potentially toxic compounds but also nuisances such as odor nuisance. All these factors have a dramatic impact on the local environment and lead to environmental degradation. (Palmiotto et al., 2014). More than a hundred odorous compounds were diagnosed as members to landfill odors, including hydrogen sulfide (H2S), methyl mercaptan (CH3SH), methyl sulfide ((CH3)2S), and ammonia (NH3) (He et al., 2012).

Hydrogen sulfide (H2S) in landfill gas, formed during the biodegradation of municipal solid waste (MSW), is an important odor component in a landfill. It poses a potential risk to humans, causing odor problems and complaints from residents near landfills. Many studies have been conducted on the properties of landfill gas. (Ko et al., 2015). H2S emissions from landfills have become a growing environmental concern. H2S is a colorless, flammable, toxic gas with a characteristic rotten egg odor. H2S is known to be flammable in air at concentrations between 4.3 and 45.5% by volume. The H2S odor threshold ranges from 0.0005 to 0.3 ppm (Lewis, 2020). Odor is one of the main causes of complaints from landfill residents. The odors emitted from landfills can cause temporary symptoms such as nausea and headaches. Especially people with respiratory diseases (e.g. asthma) can react sensitively to odors from landfills (Tansel & Inanloo, 2019).

2.4. Human exposure routes

There are three main Human exposure pathways to landfill gas:

(1) Release of landfill gas to ambient air

(2) Underground vapor migration by convection and subsequent interior vapor infiltration and

(3) Indoor vapor infiltration from contaminated groundwater under buildings.

When a permeable cover is used or when the cover has been intentionally or unintentionally violated LFG is released into the ambient air. Under such conditions, internal pressure carries the gas to the surface or through passive vents to the outside. Exposure can occur on-site and off-site depending on the actual emission rate and atmospheric dispersion. The level of human exposure is determined by the toxicity and concentration of the chemical, as well as the duration and frequency of exposure. The period and frequency of exposure are a function of landfill gas emission rate, atmospheric spread, and human lifestyle. The rate and extent of lateral vapor migration are a function of the internal pressure of the discharge and the permeability of the surrounding environment. Landfill gas that has migrated laterally from the landfill may be released to ambient air and buildings when vertical vapor penetrability is greater than horizontal vapor penetrability (Robertson & Dunbar, 2005).

2.5. Dispersion of carbon dioxide

It is difficult to predict how far landfill gas will travel as many factors affect its ability to travel underground; however, travel distances over 1,500 feet have been observed. Computer models using data about the landfill and surrounding soil conditions can predict approximate migration patterns from existing landfills (Atsdr, 2001). Gases migrating from a landfill can eventually find their way into buildings and homes. Cracks and gaps in the foundation, pressure differentials between the inside and outside of the building or dwelling, mechanical ventilation systems, and leaks (e.g., utility entry points, construction joints, or floor drainage systems) provide entry points for gases (Atsdr, 2001).

2.6. Dispersion of odor

The main compound of strong odors from landfills is hydrogen sulfide (H2S) (Pawłowska, 2014). Hydrogen sulfide is heavier than air and can account for up to 1% (v/v) of landfill gas emissions. Factors such as landfill size and age, environmental conditions at the landfill (humidity, temperature, waste type, pH), and environmental conditions (climate, humidity, temperature, atmospheric conditions) influence the biodegradation processes and the potential odor emission from landfills (Chemel et al., 2012). The type and intensity of odor emissions depend on the design and operation of the landfill; However, the spread of odorous compounds depends on land use, geographical features, and atmospheric conditions around landfills. (Tansel & Inanloo, 2019). Various modeling approaches have been used to assess the effects of odors on receptors. Some dispersion models use a peak-to-average approach to odor dispersion. For example, the Austrian Odor Dispersion Model (AODM) uses a Gaussian dispersion approach with peak-to-average factors that depend on wind speed and atmospheric stability (Piringer et al., 2012).

2.7. Indoor Air pollution

Humans are exposed to air pollutants both indoors and outdoors**.** Globally, people are spending more and more time indoors. There they are exposed to pollutants that are generated outdoors and get into the indoor environment, as well as indoor pollutants, due to space heating, cooking, and other indoor activities or emitted by the products used inside ("WHO Guidelines for Air

Quality.," 1998). With the continuous improvement of our quality of life, indoor air quality has become a major concern in the 21st century. Indoor air quality is affected by many factors, including the type and operating conditions of indoor pollution sources, ventilation conditions, and indoor activities (Leung, 2015). The internal environment of buildings is the result of the interaction between location, climate, building system and; original design and subsequent changes to the structure and mechanical systems and; Construction techniques, sources of contamination (building materials and furniture, moisture, processes, and activities inside and outside the building) and building users (CDC, 2004). Indoor air contaminants may come from inside the building or be sucked in from outside. The concentration of an indoor pollutant depends on the ratio between the volume of air contained in the indoor environment, the rate of production or release of the pollutant, the rate of removal of the pollutant from the air by reaction or sedimentation, the air rate exchanges with the outside atmosphere and the concentration of outside pollutants (Maroni et al., 1995).

Indoor air has to now no longer comprise contaminants that exceed concentrations acknowledged to impair fitness or reason pain to occupants. Such contaminants consist of diverse gases, vapors, microorganisms, smoke, and different particulate matter. These can be found in make-up air or be added from indoor activities, furnishings, constructing materials, floor coatings, and air-managing and air remedy components. Deleterious elements consist of toxicity, radioactivity, capability to result in contamination or allergies, irritants, severe thermal conditions, and objectionable odors (ASHRAE, 2001).

2.7.1. Indoor air pollution around a landfill

The indoor air in buildings located near municipal waste dumps can be contaminated by pollutants emitted from the landfill (Kaźmierczuk & Bojanowicz-Bablok, 2014). Three main mechanisms allow outside air to enter and affect the indoor environment: mechanical ventilation, natural ventilation, and infiltration. Mechanical ventilation may be powered by a home's fan or air conditioner, or by a building's central air conditioning system, all of which draw in outside air from their fresh air intakes. Natural ventilation is driven by the prevailing wind flow and takes place whenever the doors and windows of the room/building are open. Even without these vents, air exchange between the indoor and outdoor environments can occur through cracks and leaks in the building envelope, a process called infiltration, which can be significant for a poorly sealed building. Due to these three mechanisms, outdoor air pollutants can enter the indoor environment and be diluted or accumulated depending on ventilation conditions (Leung, 2015). Investigated the key factors affecting air exchange rate (AER) and the relationship between indoor and outdoor concentrations of traffic-related air pollutants. They found that the AER was affected by both temperature and wind speed, and tended to increase as the number of open windows and doors connected to the outside increased. Additionally, it has been suggested that both outdoor and indoor pollutant concentrations are the variable of choice for predicting indoor pollutant concentration (Johnson et al., 2004).

2.8. Empirical literature review

Developing countries are trying to improve the health and quality of life of the general population, but rapid industrialization combined with increased scale of production has led to increases in energy use and industrial waste, which has made air quality worse than in developed countries. In addition, the processes of rapid unplanned urbanization, the hypothesis of pollution oases and the increase in population density have intensified both the emission and concentration of air pollution in the countries considered. In fact, according to the pollution haven hypothesis, developing countries with cheap resources and labor tend to have less stringent environmental regulations, and conversely, companies in countries with more stringent environmental regulations become more expensive to operate because of the costs associated with meeting those standards (Dockery, 2009).

Studying the human health and environmental effects of landfill sites has generated mixed reactions among scientists, making this a complex study. This study evaluated the health and environmental impacts of the Thohoyandou landfill on the residents living closest to the landfill, and integrated various factors such as waste disposal, air and dust pollution, landfill location, water and noise pollution, fear of future health, real estate value, mosquitoes and rodent contamination, general community life, etc. However, the issues associated with the landfill have helped make the community living closest to the landfill more aware and educated about pollution. The health risk associated with landfill contamination in this study shows that proper landfill management is extremely important (Njoku et al., 2019).

Fugitive emissions of pollutants from municipal landfills can cause nuisance and health impacts on surrounding residential areas. The general objective of this study was to carry out an assessment of the fugitive pollutant emissions and an analysis of the wind propagation of a given landfill. The study was conducted in the Ano Liosia closed landfill, located in the Athens metropolitan area. Human exposure to priority health pollutants emitted from landfill, such as vinyl chloride and benzene, was estimated using landfill gas emission software LandGEM 2.01 in combination with long-term atmospheric dispersion modeling ISC3-LT. The weather and emission conditions under which the models were applied refer to worst case scenarios. This scenario was used for the assessment of the maximum human exposure assessed beyond the Ano Liosia landfill into residential areas. The above scenario provides the minimum downwind distance of the health risk zone calculated at 1.5 km from the landfill. Within this distance, the assessed concentration of air pollutants for several air pollutants was significantly higher than the World Health Organization health criteria for lifetime exposure. Finally, the methodology applied in the Ano Iiosia landfill was used, comparing the atmospheric pollutant concentrations measured in the field with the predictions of the model (Paraskaki & Lazaridis, 2005).

2.9. Air pollution policies and legislation

The United Nations Framework Convention on Climate Change came into force on March 21, 1994, after it had been ratified by 50 countries. The general aim of the convention is to "stabilize greenhouse gas concentrations in the atmosphere at a level that avoids dangerous anthropogenic interference with the climate system". (Article 3). The Kyoto Protocol on Climate Change: The Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change held a conference on December 11, 1997 in Kyoto, Japan, and agreed on a plan to reduce the resulting greenhouse gas emissions by five in the periods 2008-2012 Percent compared to 1990, which is used as the base year. More and more other programs such as REDD + (which are anchored in Articles 2 and 3 of the Protocol) and the conservation and restoration of wetlands are designed to reduce greenhouse gas emissions (United Nations, 1992).

2.9.1. Ethiopia's environmental policy

The general aim of the policy is to improve the health and quality of life of all Ethiopians and to promote sustainable social and economic development through sensible management and use of natural resources, man-made, and cultural resources. and the environment (UNEP, 2018). The policy sets several specific objectives, one of which is the prevention of soil, air, and water pollution at the lowest possible cost; One of the key political statements is that environmental laws must comply with Article 44 of the Constitution and ensure that all people living in Ethiopia have their fundamental right to an environment suitable for their health and well-being.

An obvious gap in the Policy deserves to be pointed out in the section on air pollution and climate change. The section mainly focuses on greenhouse gas emissions (GHG) and climate change but does not address air pollution and its effects from an environmental and air quality perspective. related impacts on health and the environment. As such, the policy primarily states climate change goals without specifically mentioning air quality goals, although the two are interrelated and sometimes complementary (UNEP, 2018).

Constitution of the Federal Democratic Republic of Ethiopia

The Federal Constitution guarantees everyone in Ethiopia the right to a clean and healthy environment (UNEP, 2018). To realize this right, the Constitution defines the following four environmental goals: i. The government ensures that all Ethiopians live in a clean and healthy environment. ii. The design and implementation of development programs and projects must not damage or destroy the environment. iii) People have the right to be fully heard and to express their views on the planning and implementation of environmental policies and projects that directly affect them. IV. States and citizens must protect the environment (UNEP, 2018).

2.10. International Air Quality Standards

In most regions, standards are implemented by using a combination of both air emission and air quality standards. In practice, air quality standards set up by governments define “clean air.” Each standard is set by government agencies, and implementation protocols are also provided. Air emission and air quality standards are widely accepted and used in many countries and are elaborated on in the following subsections. Several guidelines and standards exist for ozone, nitrogen dioxide, particulate matter, and other pollutants in ambient air and indoor air quality (Brunekreef & Holgate, 2002), but most of them did not set the standard for greenhouse gases limit.

2.10.1. ANSI/ASHRAE STANDARD 62-2001

The American National Standard (ANSI) is a national voluntary consensus standard developed under the auspices of the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). ASHRAE makes its best efforts to publish standards and policies for the benefit of the public in light of available information and accepted practices (Damiano & Dougan, 2007).

Carbon dioxide (CO2)

Carbon dioxide concentration has been widely used as an indicator of indoor air quality. Comfort criteria are likely to be met if the ventilation rate is adjusted not to exceed 1000ppm of CO_2, the referenced clauses are provided as justification for claiming compliance with the standard when CO_2 is kept below 1000ppm (ASHRAE, 2001).

Table 1. Indoor CO_2 threshold

Pollutant	Concentrations of limited or no concern
CO_2	<1000ppm

Hydrogen sulfide (H_2S)

Hydrogen sulfide is the most important trace chemical responsible for odor formation in the biogas according to the detection limits. Hydrogen sulfide has a characteristic rotten egg odor, an average detection threshold of 8 ppb, and annoys 50% of the population at 40 ppb. The California Ambient Air Quality Standard (CAAQS) hourly concentration for hydrogen sulfide is 30 ppb and the World Health Organization (WHO) recommended a 30-minute average maximum concentration is 5 ppb. (ATSDR - Agency for Toxic Substances and Disease Registry, 2008). Human responses to odors depend on the type and concentration of odorous compounds in the air, the duration and frequency of exposure to high concentrations of odorous compounds, the location of exposure, the time of day of exposure, and personal odor sensitivity. The main determinants affecting the odor concentrations found at a given place or time are the odor emission rate at the source, the distance from the odor source, the local weather (including wind speed, wind direction, temperature, atmospheric stability class), the temporal Variability of meteorological parameters and local topography (ATSDR - Agency for Toxic Substances and Disease Registry, 2008).

Table 2. Health effects of hydrogen sulfide. (ATSDR - Agency for Toxic Substances and Disease Registry, 2008)

Exposure limits (ppm)	Health effects
0.008–0.2	Olfactory threshold –” rotten eggs” smell detectable
20	Sense of smell to gas lost Concentrations tolerated for some hours without harm
20–50	Eye irritation
50	Prolonged exposure may cause pharyngitis and bronchitis
60	Prolonged exposure may cause conjunctivitis and eye pain
150	Irritation of upper respiratory tract; sense of smell lost
250	Pulmonary edema with risk of death
500	Very dangerous, evacuation should occur well below this level
1000	Loss of consciousness occurs
1000–2000	Immediate collapse with paralysis of respiration

2.11. Gap identification

From the literature review, it is clear that waste disposal sites pose a major air pollution challenge to indoor air pollution in the surrounding communities**.** According to the United Nations Environment Program (UNEP, 2018), indoor and ambient air quality monitoring in Addis Ababa is not as developed as in most African cities. This is mainly because most of these cities do not have the necessary monitoring infrastructure and capacity to collect and analyze air quality data (Tefera et al., 2016). There have been some studies on indoor air pollution (IAP) in Ethiopia which focus on indoor sources and A cross-sectional study conducted in 2012 E.C in 59 houses in the slums of Addis Ababa (Tefera et al., 2016) has attempted to link PAHs to human health and not through direct measurement of pollutant concentration and health assessment.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of the Study Area

Koshe, is a large open landfill that receives waste and garbage from Addis Ababa, the capital of Ethiopia. The name means "dirty" in Amharic. The site is located in the southeastern part of Addis Ababa in Kolfe Keraniyo sub-city worda 01. It has been in business for about 50 years and had about 36 hectares and is 40 meters in height. This made it the largest single waste deposal site in the country. At its commencement Reppie (Koshe) site was a remote site from business and residential communities but currently, due to the expansion of the city, it become surrounded by residential communities and community service centers (Abebe, 2018).

The climate is subtropical, influenced by altitude, with a rainy season from June to September. The driest period is from November to January. From February to May, the rains gradually increase, but there are still many hours of sunshine. In October and November, after the rains, the weather is usually nice again. In Addis Ababa, the average temperature of the coldest month (December) is 15°C. p> 5 °C (59.9 °F) and in the warmest month (April) 18.8 °C (65.8 °F). Here are the average temperatures. Rainfall is 1,165 millimeters (45.9 inches) per year, so it is quite plentiful. It ranges from 0.3 inches (7 mm) in the driest months (November and December) to 11.4 inches (290 mm) in the wettest (August).

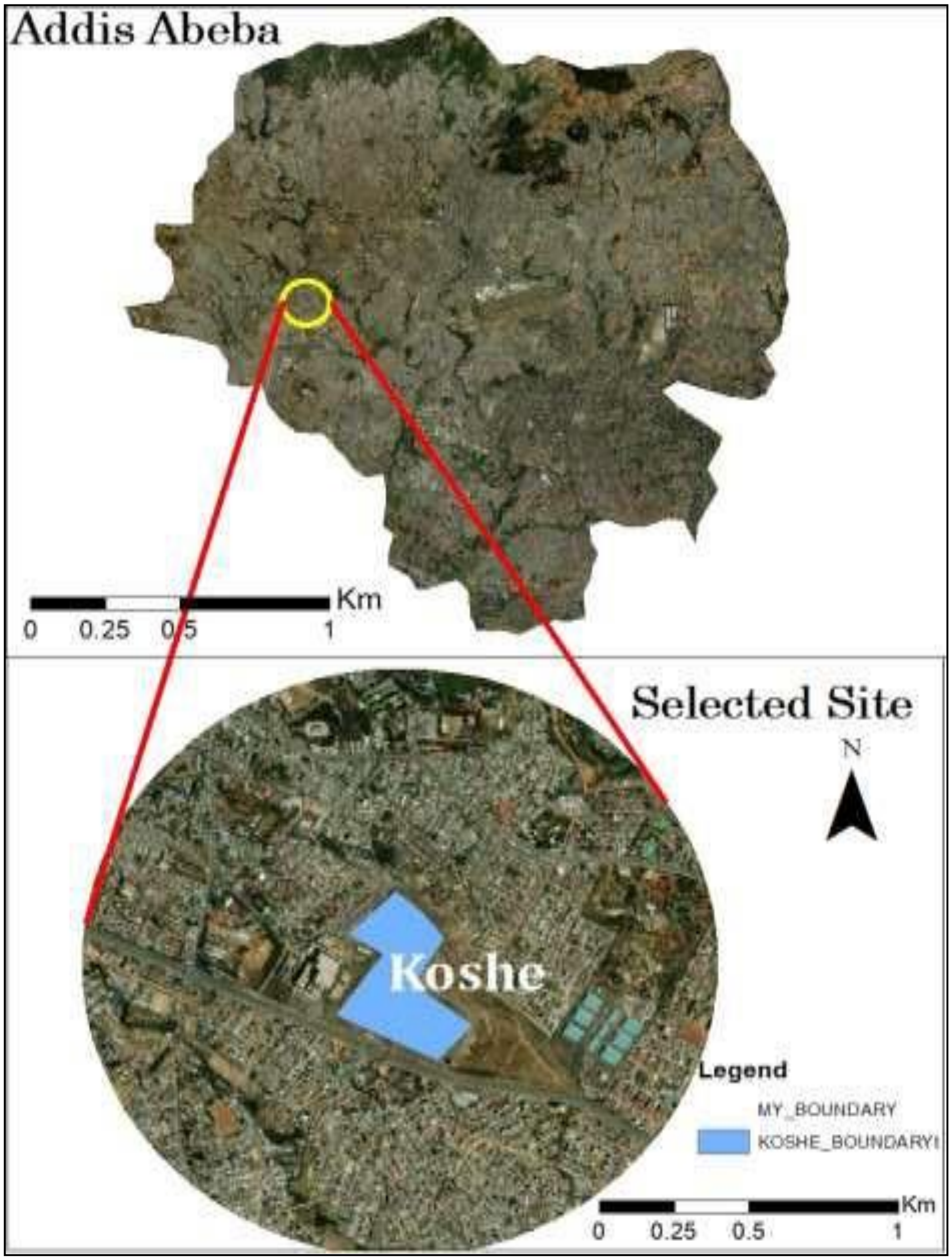


Figure 1. Location map of Koshe landfill site

3.2. Study site

Koshe is located in the southeastern part of Addis Ababa in Kolfe Keraniyo sub-city worda 01. The study site includes residential buildings within a 1.5km radius of the Koshe MSW site in every direction, due to resource and time constraints the radius is limited to only 1.5km. The study site is divided into four regions according to the direction from koshe landfill, region 1 in the northwest, region 2 in the southwest, region 3 in the southeast, and region 4 in the northeast direction.

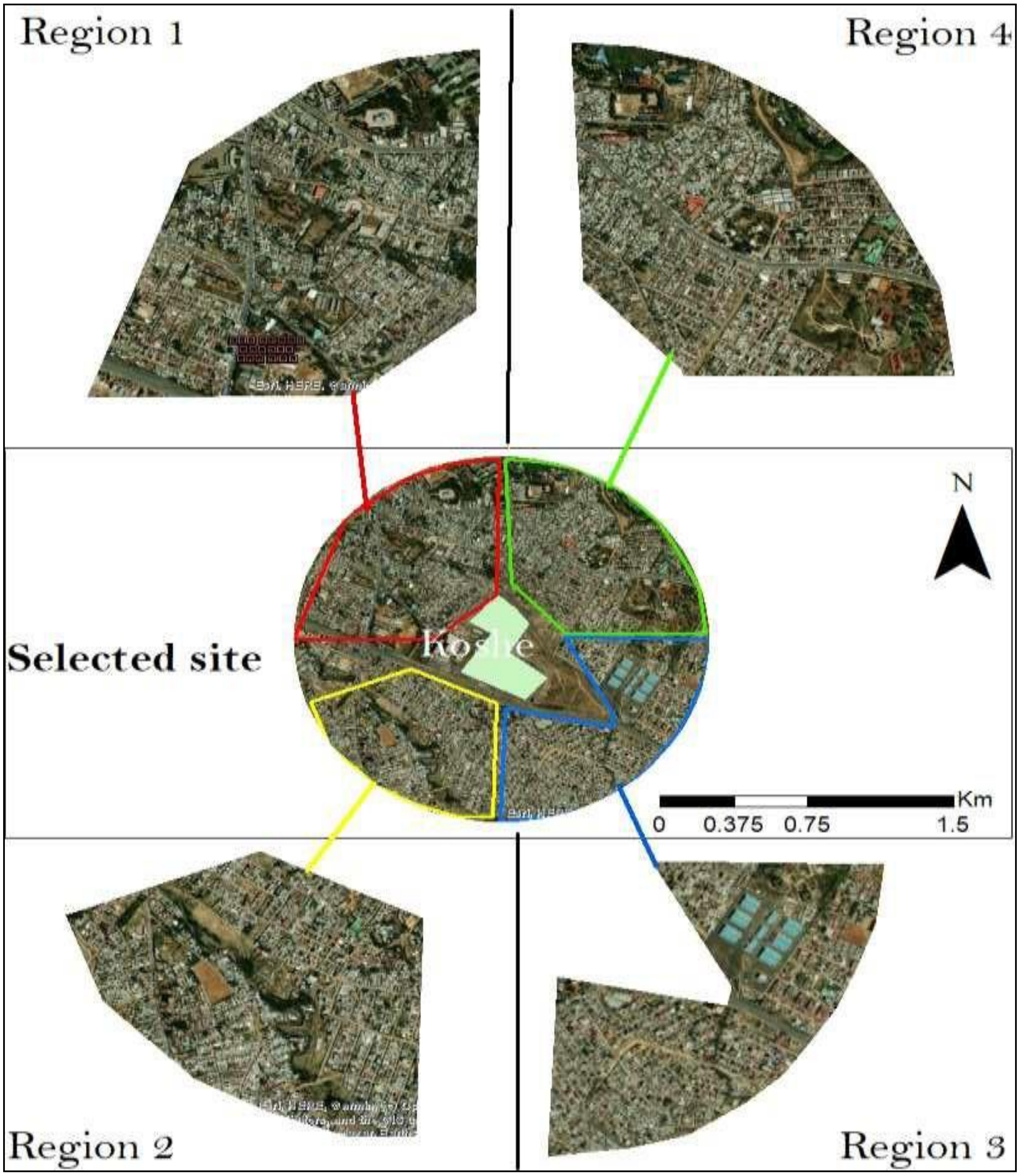


Figure 2. Study site categories

3.3. Sampling site and Methods

Simple random sampling was used for sampling,192 samples, and the sample size is taken from the sample size calculated. There are 4 sampled residential regions. From each sample region, 48 sample residential houses were selected randomly, and samples were taken within a radius of up to 500m and 500m-1.5km.

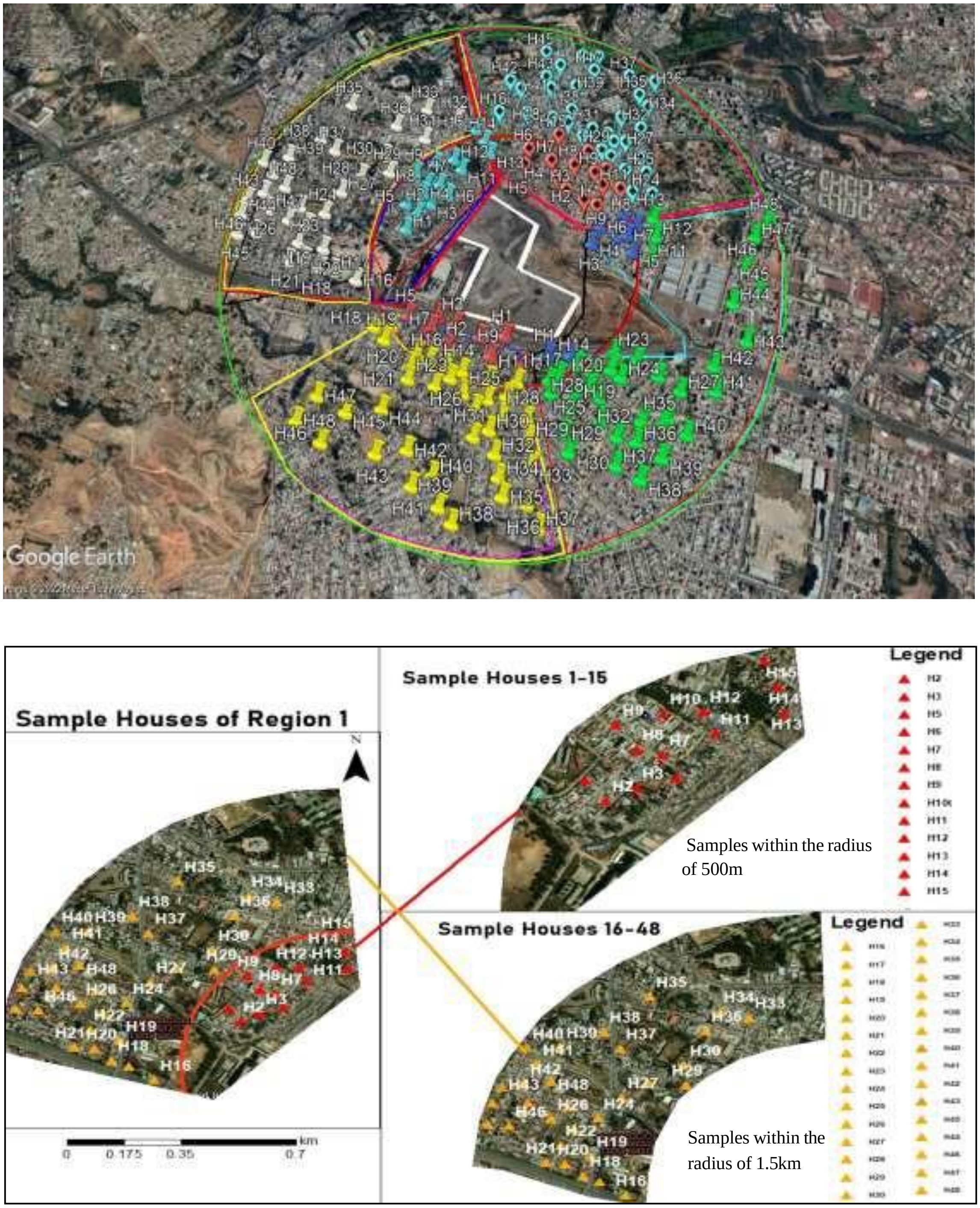


Figure 3. Location of Specific sample houses for region 1.

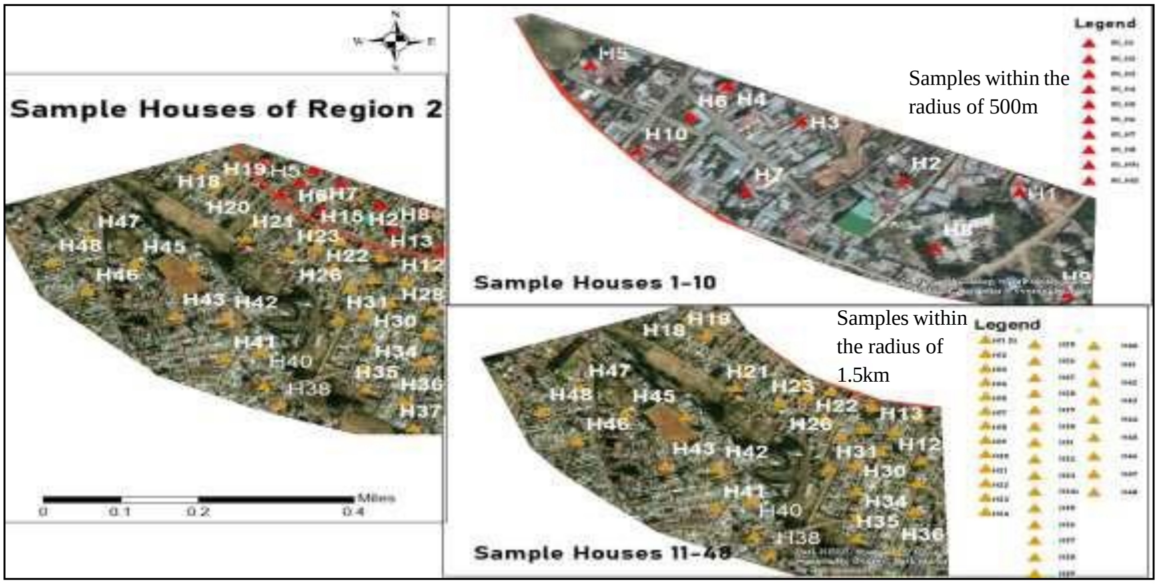


Figure 4. Location of Specific sample houses for region 2.

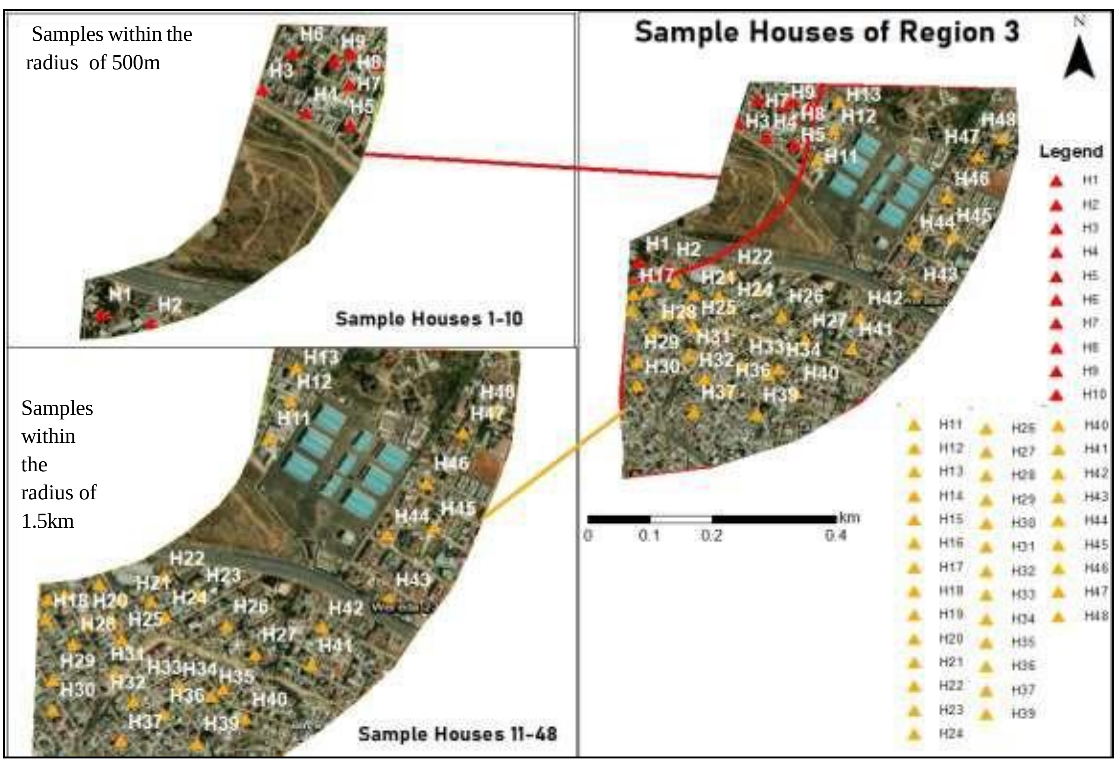


Figure 5. Location of Specific sample houses for region 3.

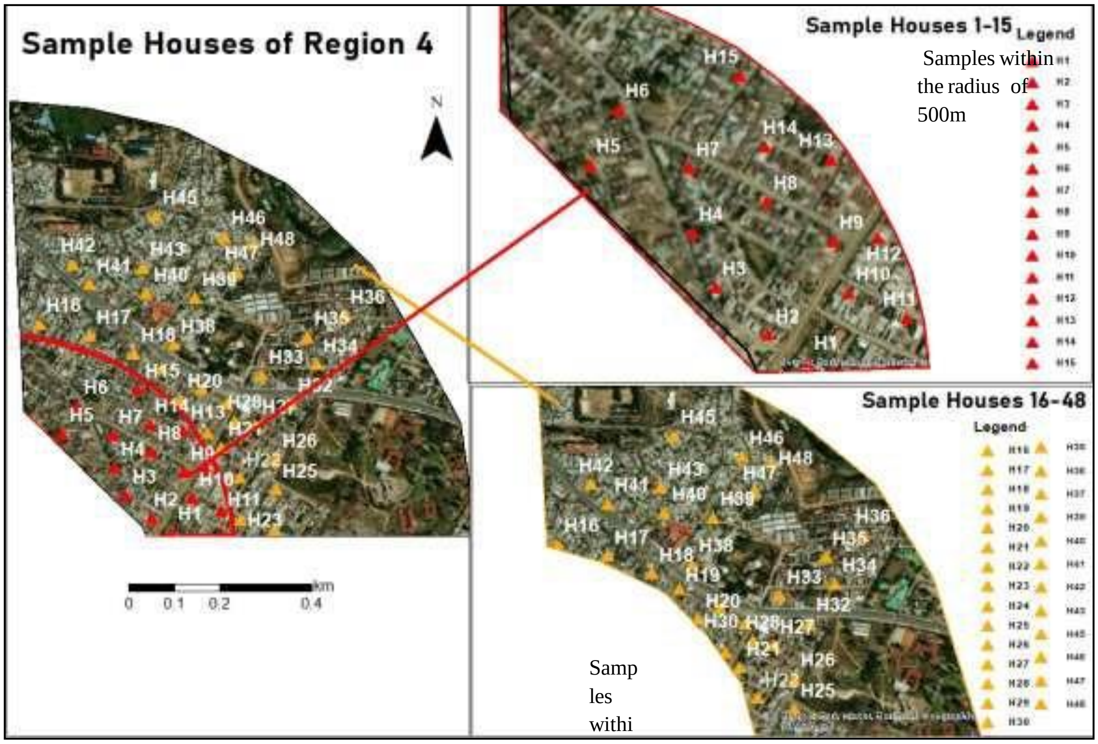


Figure 6. Location of Specific sample houses for region 4.

3.4. Study Design

A cross-sectional study design was conducted from April 15 to April 19, 2022, and June 21- 25, 2022. Measurements were taken from 8 a.m. to 6 pm, for each sample area to generate the required data. This study aimed to analyze the concentration of carbon dioxide inside sample residential houses and the dispersion of carbon dioxide and odor around residential areas near the Reppi (Koshe) landfill site to achieve sustainable indoor air quality management. A direct electronic instrument was used to measure the concentration of CO2, Odor, and ALOHA dispersion modeling software to estimate the dispersion of CO2 and odor.

3.5. Sample Size Determination and Sampling Techniques

3.5.1. Study Population

According to the Kolefe Keranio Woreda 01 administration Office, there are 9,216 households around the landfill area and the target population for this study was residential blocks within a radius of 1.5 km since it was hard to estimate the number population in the radius of 1.5 km the researcher just took the whole population number for sample calculation.

3.5.2. Sample Size Determination

According to Kolefe Keranio Woreda 01 Office, 9,216 households exist around the landfill. More than half of these residents were closer to the landfill and are the target population of the study. The sample size was determined according to Daniel WW (1999) (as cited in Gosaye B, 2007), and (Asgedom, 2014).

Formula 1: N_t =n/1+N/n (1) Formula 2: n = (Z^2* p*q)/d^2 (2) Formula 3: q= 1-p (3)

Nt=n/1+N/n… ....(1)

n=Z *Z *p*q /d*d .... (2)

n=1.96*1.96*0.5*0.5/ (0.1*0.1) =96.04 Nt= (96.04/1) +9216/96.04

Nt=192 were taken as a sample.

Where: Nt= desired the total number of households or sample size.

N = target size of population =9216 n = the sample size

p = population reliability or frequency estimated for a sample size n, where =50% which is taken for all developing countries' populations

q = 1 – p=0.5

z = the value of the standard normal variable at 95% confidence level = 1.96 e = margin of error (the precision) considered for this study (5%).

d=level of statistical significance precision (in proportion of one; if 10%, d = 0.1). Data Collection

3.6. Data collection

3.6.1. Data Sources

An assessment of indoor air quality issues in the region of Reppi (koshe) landfill site necessitated an interdisciplinary approach that will engage natural and social science methods. Primary data was collected using an air quality monitoring instrument by direct measurement of CO2 inside the sampled houses near Koshe landfill site as the source of input data for the dispersion modeling software. Secondary data was another important source of information for the study. Secondary data for this research were collected from related published and unpublished materials, books, journals, articles, various research papers, and government publications found in the library and website, socio-demographic data, and Arial photos of the study area.

3.6.2. Data gathering tools

To obtain sufficient and reliable information from primary and secondary data sources, the researcher used a basic method of data collection, namely instrumental measurements, a subjective survey to get the perception of odor, and ALOHA dispersion modeling software for simulating the dispersion of CO_2 and odor.

Instrumental measurements: -Portable air quality monitors

Indoor CO_2 data were measured with a portable digital instrument from April 15 – 19, 2022, and June 21 -25,2022, An average of 15-minute measurements were recorded for each sampled dwelling for each region. The measurements were carried out in the living rooms of the sample residential buildings, to minimize the interruption of other indoor sources.

Input data for dispersion of CO_2 and odor were measured in the morning, afternoon, and noon time on site to estimate the emission. To ensure quality, the devices have been pre-calibrated before use.

Gas monitoring

Aeroqual's Series 500 Gas Sensing

According to EPA 2014, Air Sensor Guidebook featuring low-cost air sensors, Aeroqual's Series 500 was used to measure carbon dioxide sensors. Aeroqual's portable air quality monitors are tools for air quality professionals and enthusiasts to collect real-time information about indoor or outdoor air quality. They are a flexible air quality monitoring solution that can be configured with 27 different gas sensors including CO_2 and H_2S and particle sensors for a variety of applications from environmental monitoring to industrial applications. But in this the study, portable air monitors aim to make it easier to monitor indoor air quality. They are used by researchers, professionals, and non-experts who like to collect data on air quality. These tools are small enough to fit comfortably in your hand, and they can be used anywhere: indoors or outdoors, on the road, in the mountains, and they've even been used in Antarctica.

Figure 7. Aeroqual's serial 500 series gas sensing

Air dispersion model

The dispersion model chosen for this study was the ALOHA model, which was built upon the Gaussian dispersion model of buoyant air pollution flumes. The ALOHA dispersion model is a free application provided by the US National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA) and is the USEPA-recommended tool for assessing toxic gas cloud hazard zones (Tseng et al., 2012). The model is capable of simulating the dispersal model of more than 900 chemicals and is mainly used to simulate the accidental release of hazardous substances and the dispersal of chemical vapors (I et al., 2009). The Area Locations of Hazardous Atmospheres (ALOHA) air dispersion model used was developed to assess the spread of hazardous chemical vapors, including toxic gas clouds, fires, and explosions (NOAA, 2005). Based on the release characteristics of the compounds, the model estimates the impact zones (referred to as hazard zones) where the concentration of the chemical in the air is expected to exceed the levels specified by the user. (Kottayam, 2013).

Danger zone estimates are displayed in a grid in ALOHA and can also be plotted on maps in MARPLOT, Esri's ArcMap, Google Earth, and Google Maps. The red threat zone represents the worst threat level, and the orange and yellow threat zones represent areas of decreasing threat.

3.6.3 Data collection procedures

Based on the following steps data were gathered through monitoring sensors; -

Step 1: Gather data, the portable indoor air quality monitoring instrument was used to measure the concentration of CO_2 inside the sampled residential houses.

Step 2: measure the concentration of CO_2 and odor on Koshe landfill site for input data for dispersion software.

Questionnaire survey: A total of 192 questionnaires were carried out in a 1.5 km radius of the landfill during April 2022, out of this only 147 questionnaires were returned. The respondents (sensitive receivers) of the study involved exclusively the residents within the study area. The respondents were interviewed in the vicinity of their homes during the survey to ascertain their perception of odor impacts in their homes. Data Analysis

The descriptive data analysis method was used for this study. The data findings were presented using figures and tables for mean, minimum, and maximum. Excel sheets tool was used for data analysis to find meaningful correlated data.

3.7. Ethical Consideration

This research anticipates and addresses any ethical dilemmas that may arise in the study. The willingness of the homeowners to host the indoor air sampler was requested after explaining the purpose, the reason for selection, and demonstrating how the instrument operates. The air sampling was arranged only after getting their verbal agreement.

CHAPTER FOUR

RESULTS AND DISCUSSION

This study presented a measurement of indoor air quality of sampled residential buildings in terms of CO_2 level and Odor dispersion in and around Reppi (Koshe) landfill site. The concentrations of Carbon dioxide (CO_2) were measured indoors and have been compared to limit values set out in international Standards and the dispersion of odor and CO_2 were simulated by ALOHA software to determine the extent of the affected areas.

Figure 8. Photo captured during data collection

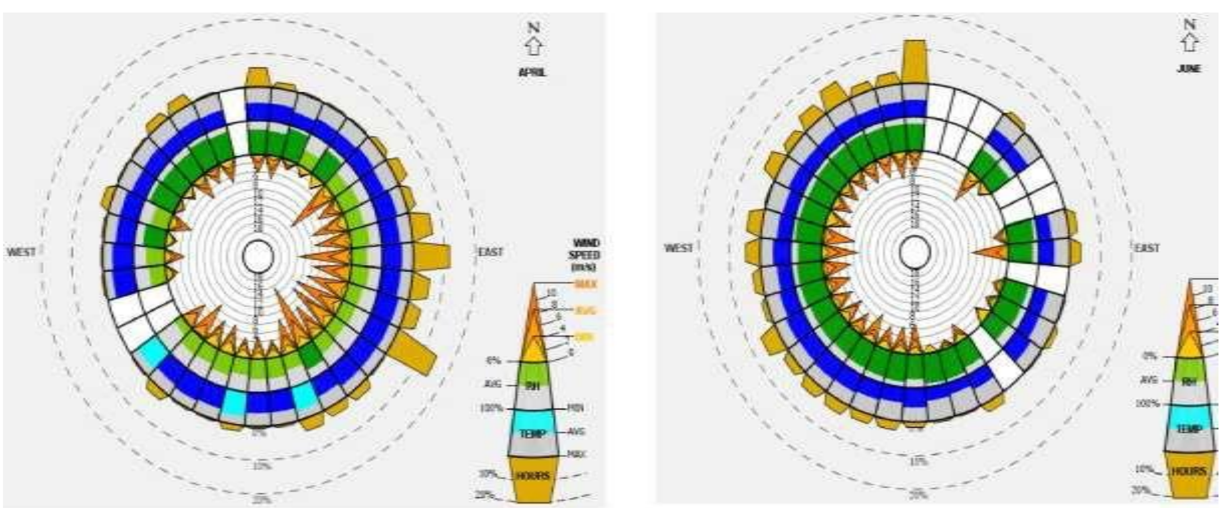
There is no PEL standard for CO_2 set in Ethiopia either for outdoor or indoor air pollution but according to American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) guidelines for comfort and OSHA Field Safety and Health Manual normal atmospheric air contains approximately 314 ppm of CO_2, and breathing air quality must contain CO_2 concentration less than 1000ppm (<1000 ppm) (ASHRAE, 2001; OSHA, 2015).

4.1. Dispersion of Carbon dioxide (CO_2) and Odor

Landfills are the most common method of waste disposal in Addis Ababa, koshe being the largest landfill in the city it remains a concern for the residents around it, which is why it is necessary to evaluate to what extent gases produced at landfills can disperse over the surrounding areas. The air dispersion modeling at koshe landfill sites has been undertaken to determine the dispersion of CO2 and odor emissions.

4.1.1. Dispersion of Carbon dioxide (CO2)

Carbon dioxide is a greenhouse gas that is often emitted into the atmosphere from sources such as municipal landfills. The carbon dioxide concentration in the Koshe landfill is between 5000-10000 ppm. This estimate is only for the carbon dioxide emitted from the Koshe landfill and does not take into account other sources of carbon dioxide such as vehicles and industry (OSHA, 2015). CO2 concentration trends change seasonally depending on variations in weather conditions. Emission source and meteorological data were used as model inputs to simulate distributions of near-surface CO2 concentrations. In general, wind field (wind direction and speed) and atmospheric stability (stable, neutral, and unstable) determine the dispersion of air pollutants. For example, the spread of pollutants under stable conditions is lower than under neutral and unstable conditions. **Figure 10** illustrates the spread of the CO2 concentration in April and June.



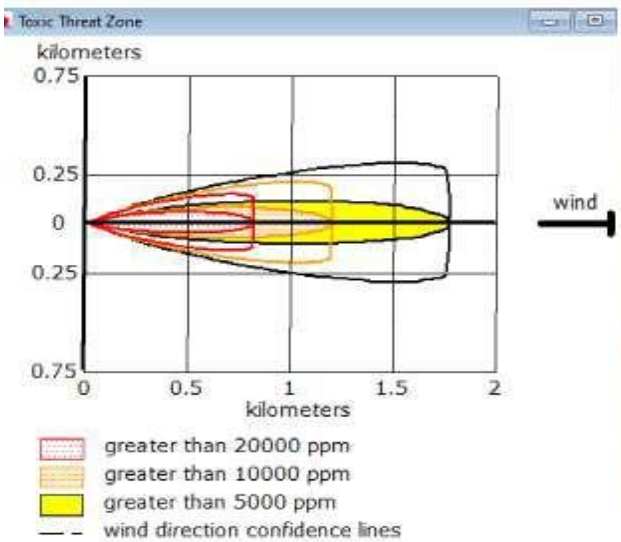
(a) (b)

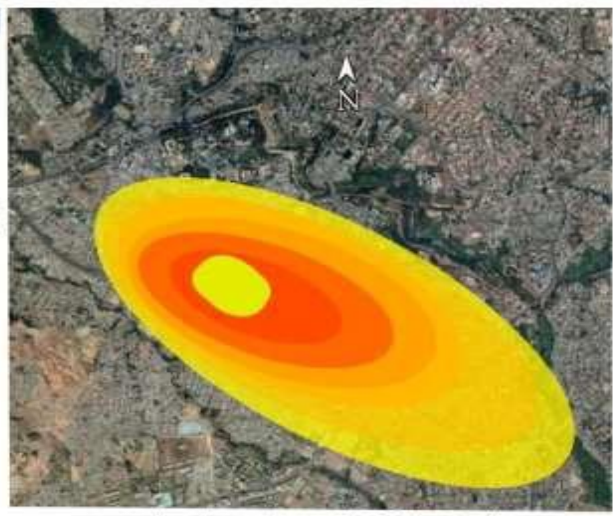
Figure 9. Wind wheel during (a) April and (b) June.

Table 3. Recorded CO_2 level on Koshe landfill site.

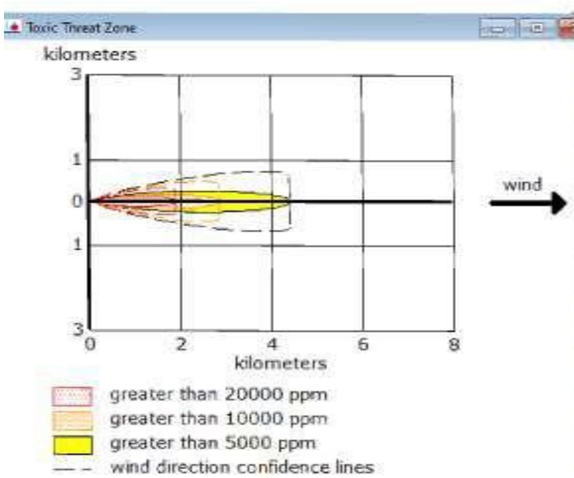
Days	CO_2 concentration level			
	Morning	Afternoon	Noon	
April 15	5694	3420	6254	
April 16	7012	4006	5439	
April 17	10238	2604	6736	
April 18	8637	5391	6498	
April 19	8823	4307	7531	
Average	8080.8	3945.6	6491.6	Total average= 6172.7
June 21	4961	3246	5127	
June 22	5683	4069	5963	
June 23	5254	4806	4753	
June 24	6742	4581	5028	
June 25	5697	3743	5675	
Average	5647.4	4089	5309.2	Total average= 5015.2

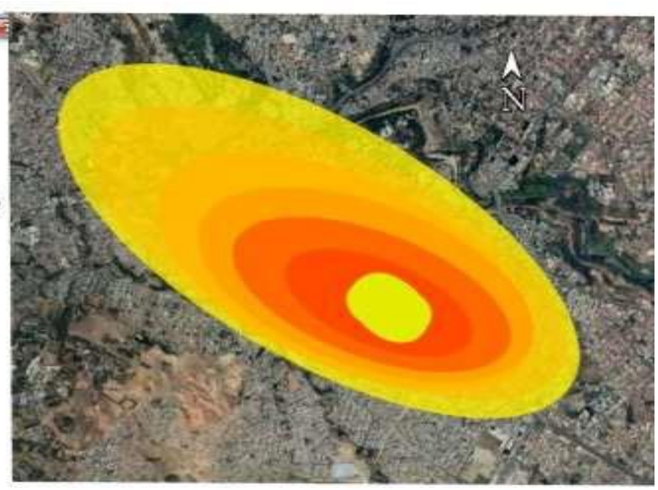
(a).Koshe landfill site





b.Dispersion of CO2 in April





c.Dispersion of CO2 in June

Figure 10. Koshe landfill site (a), Dispersion of CO_2 on April (b) and June (c)

The highest concentration of CO_2 emissions for April and June were 6,790 ppm and 5320 ppm, respectively. The CO_2 emissions dispersed mainly to the southeast direction due to the prevailing wind directions from the east and southeast in April. The maximum wind speed recorded was 7.6 m/s, leading CO_2 emissions to reach 1.8 km from the landfill site in the southeast direction.

The dispersion of CO_2 emission in June was shown in **Figure 10** (c). in June, the weather is relatively cold with light rain, atmospheric conditions are relatively stable, and therefore, plumes rise more slowly in the vertical direction with wind speed reaching up to 8.14 m/s. In June the dispersion rates are high and low concentrations of pollutants. The dispersion distance of CO_2 was 4.6 km from the landfill site to the northwest direction. The highest concentration of CO_2 emission was estimated to be 5320 ppm. These results suggest that in June CO_2 had a smaller concentration of emission than in April. However, the maximum distance for the dispersion of CO_2 in June was found to be longer than that in April.

Table 4. Carbon dioxide (CO_2) concentration (ppm), the extent of dispersion (km), and wind speed (m s^{-1})

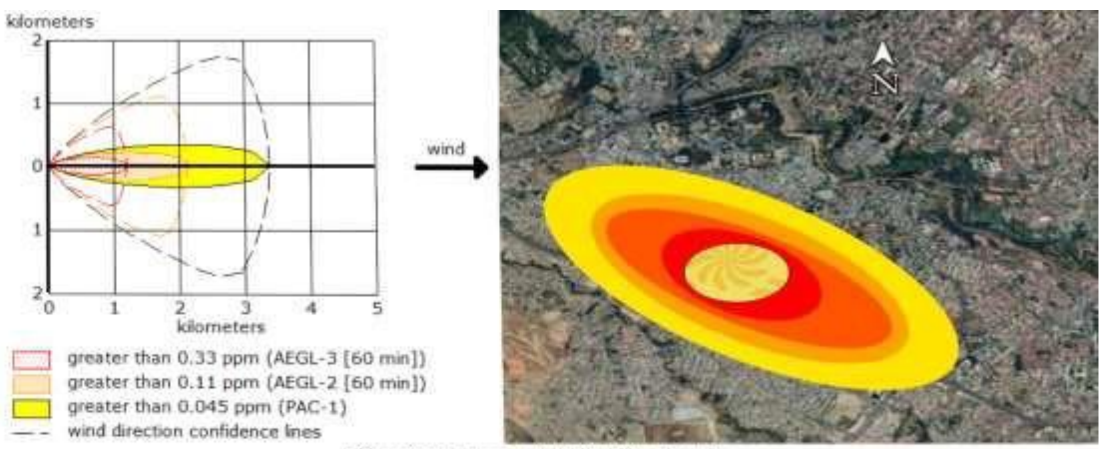
Month	Average Concentration CO_2 (ppm)	Dispersion CO_2 (km)	Wind speed (m per second)
April 15-20	6172.7 ppm	1.8 km	7.56 m/s
June 21-26	5015.2 ppm	4.6 km	8.14 m/s

4.1.2 Odor dispersion

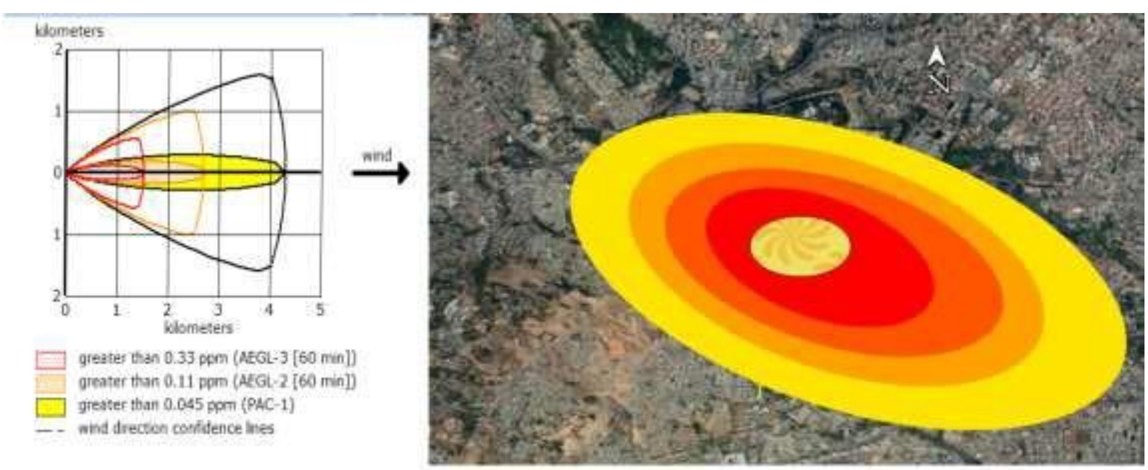
The airborne dispersion model (ALOHA) was used to visualize odor pollution zones around landfills based on the size and operational characteristics (e.g. assumed annual waste) of the landfills and atmospheric conditions. Residents who live near landfill sites do not experience the same level of odor intensity. Odors often reach at certain times of the day (e.g. early in the morning) or under certain climatic conditions (e.g. high humidity and after rain) which are directly influenced by atmospheric stability conditions.

ALOHA provides estimates of how fast a chemical will escape and form a gas cloud, and how the gas cloud will move downwind. A series of dialog boxes prompts the user to enter information about the release scenario (e.g. chemicals, weather conditions and type of release). The software maps the estimated threat zone, which corresponds to the area where a specific hazard occurs (e.g. toxicity, concentration level) expected to exceed the user-defined level of concern (LOC) after release. However, ALOHA concentration estimates may be less accurate if the odor pollution zones were estimated conservatively, assuming that the hydrogen sulfide contained in the landfill gas would be emitted from the entire landfill and the odor pollution zone buffers were delimited by the overflow boundary. Odors often reach at certain times of the day (e.g., early morning) or under certain weather conditions (e.g. high humidity and after rain) directly affected by the atmospheric stability conditions. Since the atmospheric conditions (i.e., temperature, humidity, solar radiation and turbidity) affect the distribution of odorants, three different atmospheric stability conditions were analyzed as representative conditions. Stabilities B and C refer to daylight hours with unstable conditions. Stability F refers to stable nighttime conditions and is based on the amount of cloud cover. Propagation analysis inputs include wind direction and speed, humidity, date and time, temperature, location, and chemical odor properties. For the analysis it was assumed that all landfill gas produced was emitted to the atmosphere and dispersion calculations were performed using the maximum emission rate. The estimated odor nuisance distance was delineated as a buffer zone around the landfill using ArcGIS software. Around the Koshe landfill, odor stress zones have been demarcated for different atmospheric stability conditions, corresponding to unstable, neutral, and stable conditions; using atmospheric stability conditions B, C and F.

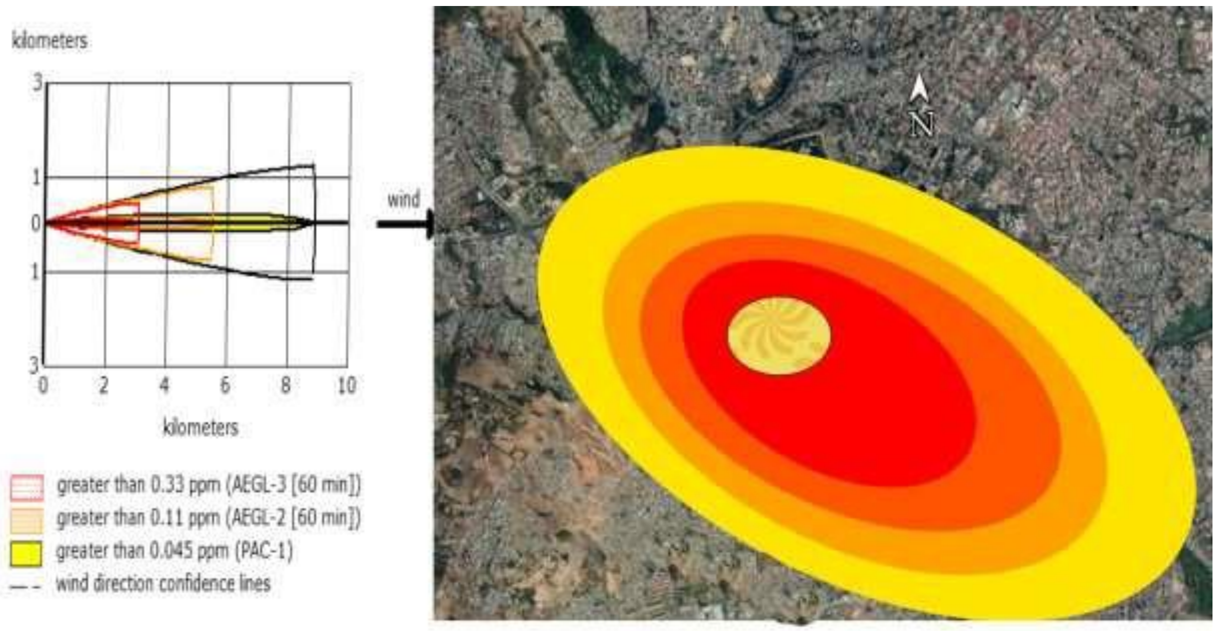
a.Koshe landfill location.



b.Odor impact zone under stability class B

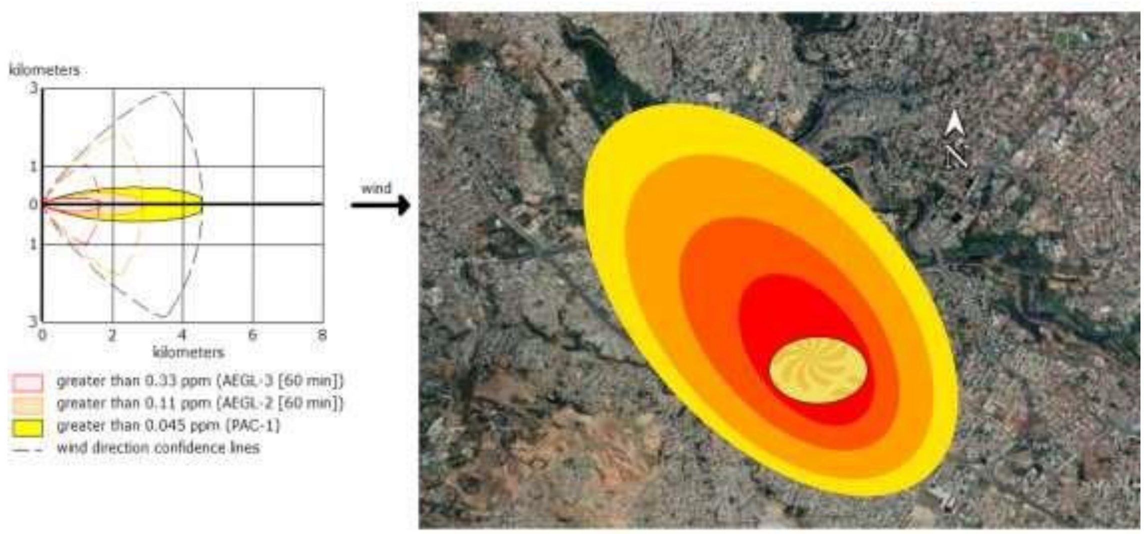


c.Odor impact zone under stability class C.

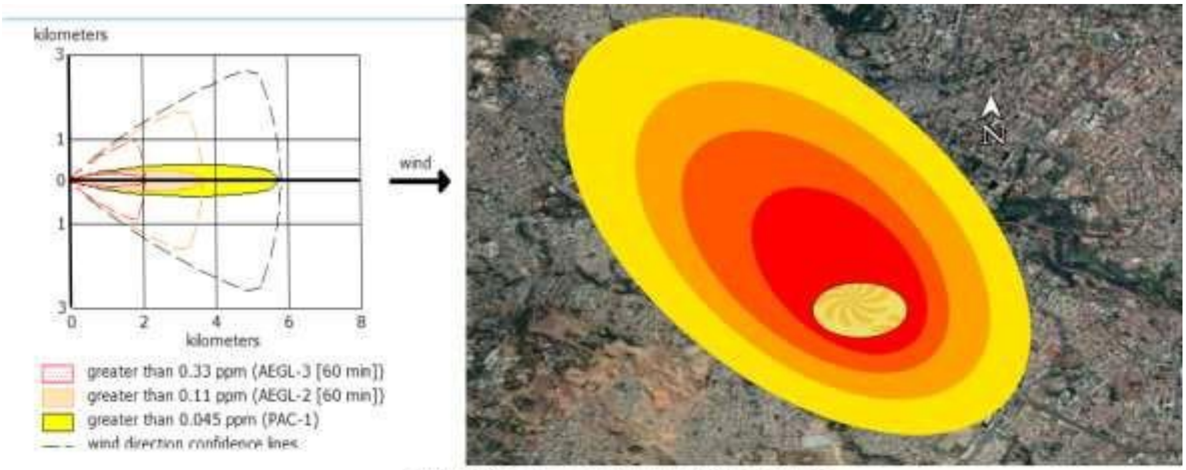


d.Odor impact zone under stability class F.

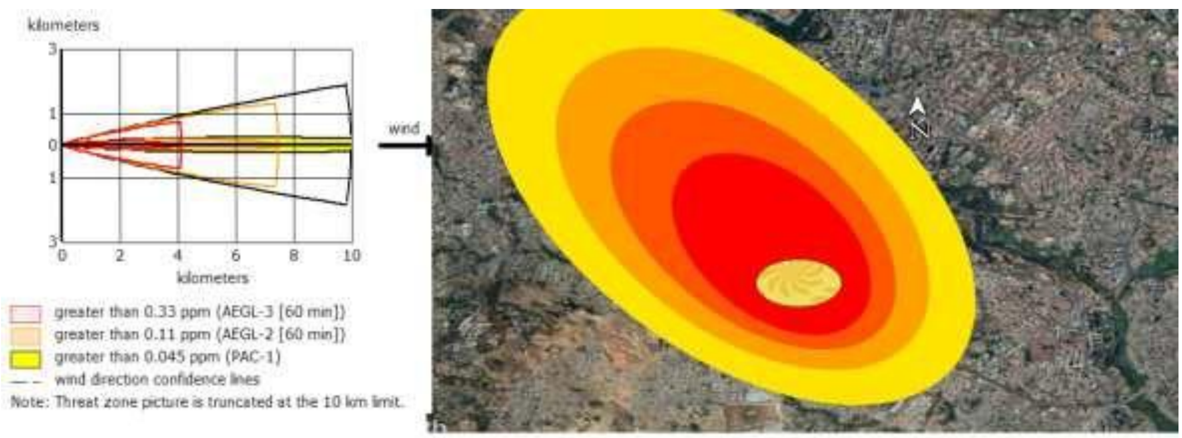
Figure 11. Odor impact zones around Koshe Landfill in April for (a) Koshe landfill (b) stability class B (c) stability class C (d) stability class F



b.Odor impact zone under stability class B.



c.Odor impact zone under stability class C.



d.Odor impact zone under stability class F.

Figure 12.Odor impact zones Koshe Landfill in June for (b) stability class B (c) stability class C (d).stability class F.

Table 5. comparison of the estimated impacted area by odor emissions around koshe landfills for atmospheric stability conditions corresponding to unstable (B), neutral (C), and stable atmospheric conditions (F).

Landfill		Impact Radius (kilometres)			Highest odor strength zone (Kilometre)		
		B	C	F	B	C	F
Koshe	April 15-20,2022	3.3 km	4.2 km	8.4 km	1.2 - 2.1 km	1.5-2.7km	3- 5.6 km
	June 21-26 ,2022	4.6 km	5.5 km	More than 10km	1.6 - 2.9 km	2 - 3.6 km	4 – 7.5 km

Table 6. Percent increase in the impacted area when atmospheric stability changes from B (unstable) to C (neutral) during day time and from B (unstable) during day time to F

Landfill		Odor impact radius (% increase)	
		B to C	B to F
Koshe	April 15-,2022	90	322
	June 21-26,2022	90	540

The color shade in the figures is due to the curvature of the odor dispersal profile - i. e. an elliptical or nearly elliptical shape centered at the source. In unstable atmospheric conditions (typically in the afternoon; conditions B and C), the mixed layer is larger; Therefore, the odor gases released would be mixed by the vertical movements of the air, keeping the impact radius smaller. However, under stable atmospheric conditions (typically at night, condition F), the mixing depth is less; As a result, the air moves closer to the ground and odorants can betransported greater distances. However, for stability condition F, the odor intensity would decrease by as the air would be diluted to a larger volume. Table 3 compares the odor impact radii for Koshe landfill under different atmospheric stability conditions.

Stability conditions are representative of daytime (B unstable and C neutral) and nighttime (F stable) conditions. It should be noted that the dispersion properties of odorous substances in the air depend on both the atmospheric conditions and the distance downwind from the landfills. During the daytime hours, the odor exposure radius would be smaller; however, during the nighttime hours, the odor exposure radius can be four to six times larger. (Table 4). Koshe landfill has the most affected population due to residential land use (i.e. high population density) around the site. It would be more appropriate to conduct odor impact assessments for conditions that are prevalent during the rainy season, as the potential for odor release during these conditions would be higher. Releases of LFG from landfills can be reduced by separating waste, mulching it daily, incorporating odor-neutralizing (or odor-absorbing) materials into the daily mulch, and limiting exposure to rain and wind during the day as little as possible.

4.1.3. Community perception of odor

Out of a total of 192 sample sizes, only 147 responses were collected from the distributed questionnaire within a 1.5 km radius of the landfill during April 2022. The respondents (sensitive recipients) of the study concerned exclusively residents in the study area. Respondents fill the questionnaire near their homes during the survey to determine perceived odor exposure inside their houses.

General background

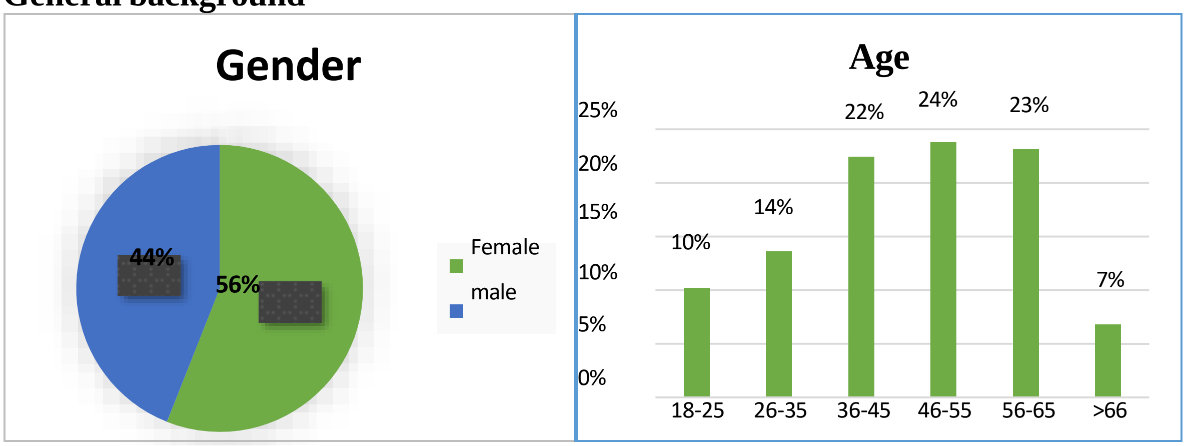
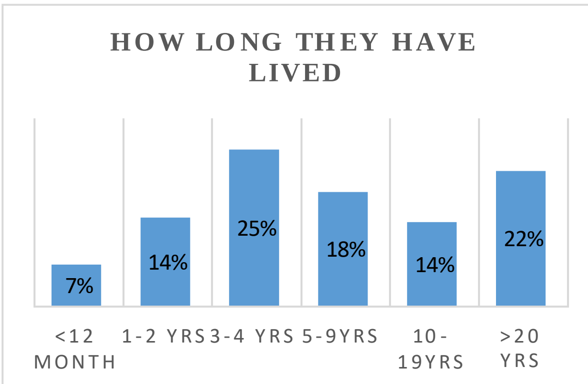


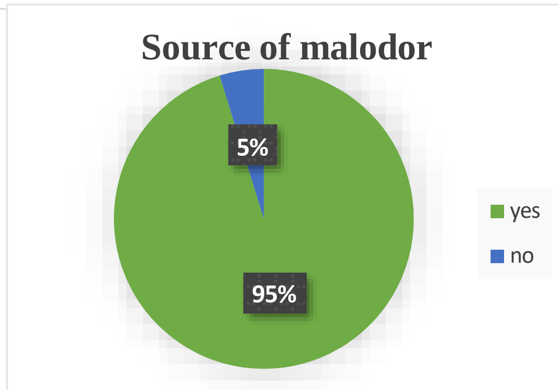
Figure 13.General questions (a) and (b).

In terms of gender, the respondents were 44% male and 56% female. The minimum age of the respondent was 19 years; the maximum age was 79 years. In terms of age group, the 46-55-year-old group was the most represented at 24%, followed by 56-65-year-old (23%), 36-45-year-olds (22%), 26-35-year-olds -year-olds (14%), 18-25 (10%) and older than 66 years (7%). About

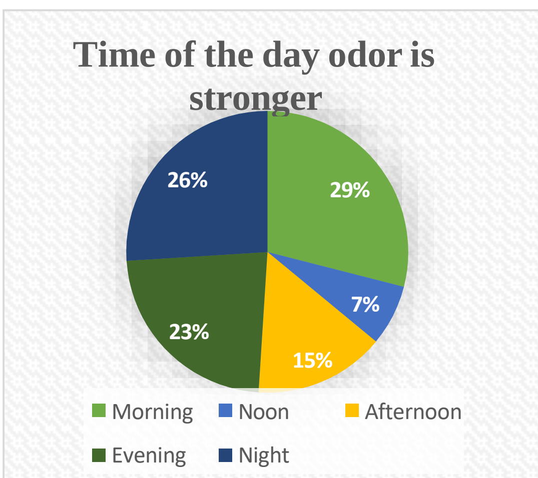
20% of the respondents have completed secondary education, with 18% completing primary school and 17% being illiterate. Respondents who achieved a college degree were grouped into two categories, namely college level, and university level, with an equal representation of 14 %.The rest (11%) completed vocational training **Figure 13.General questions (a) and (b).**

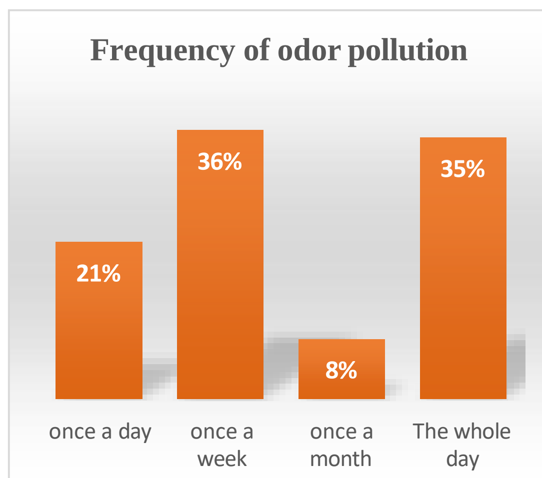
Community perception





(a) (b)



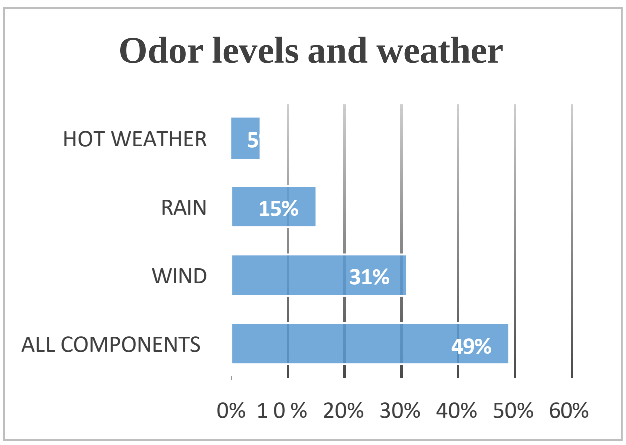


(c) (d)

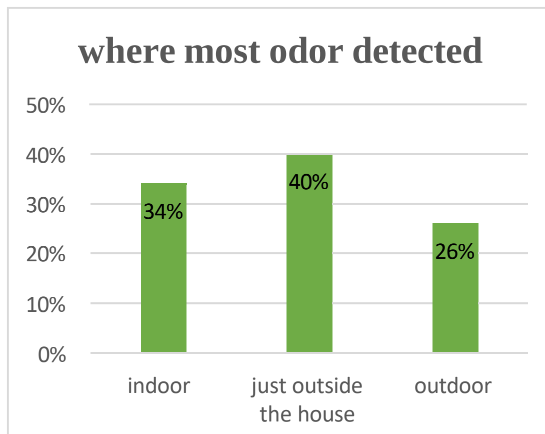
Figure 14. community perception results (a), (b), (c) and (d).

Most of the residents lived 3-4 years (25%), 22% of the respondents lived more than 20 years, 18% 5-9years, 14% of residents lived 10-19 and 1-2 years, and 7% less than 12 months in koshe area **Figure 14.community perception results (a), (b), (c) and (d)** Although 140 (95%) of the respondents agreed that the landfills were the source of malodor and most of them were bothered by the smell only (5%) were unaware of the smell **Figure 14.community perception results (a), (b), (c) and (d)** This study found that the occasions during the day when malodor was detected can be divided into five different periods, i.e. morning (6 a.m. to 10 a.m.), noon (12 p.m. to 2 p.m.), afternoon (2 p.m. to 4 p.m.), evening (5 pm to 7 pm) and night (8 p.m. to 10 p.m.) and the whole day. The survey found that the period when odors were frequently detected was in the morning (29 % of respondents) followed by night (26%), evening (23%), afternoon (15%), and noon (7%) **Figure 14. community perception results (a), (b), (c) and (d)**

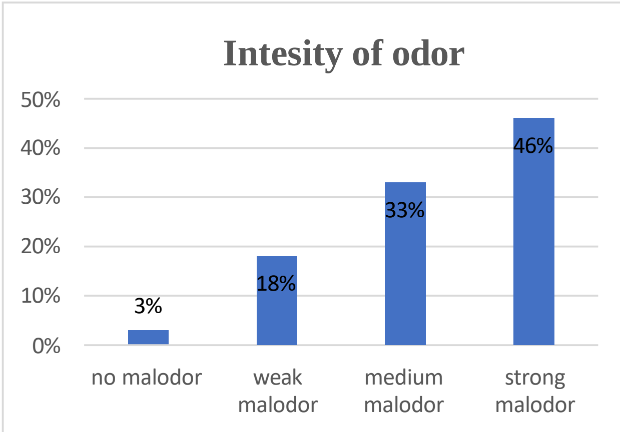
Four main scenarios on the frequency of odor pollution were assessed. They are once a day, once a week, once a month and during the whole day. The survey found out that the smell will eventually disappear but the rate of disappearance was uncertain and perceived by 36% of the respondent as dependent on the general weather situation once a week with 35% thinking the direction of the wind was the main determinant but agreed they detect the smell the whole day while 21% agreed with once a day and 8% said it happened once a month and so. **Figure 14. community perception results (a), (b), (c) and (d)**

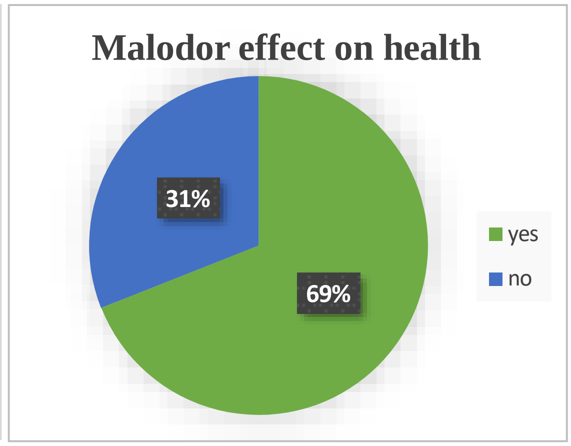


(a)



(b)





(b) (d)

Figure 15. community perception questions (9-12), (a), (b), (c) and (d).

Climate is one of the environmental components that can affect the frequency and intensity of the smell perceived by the respondent. According to Sakawi et al. (2009) (Sakawi et al., 2011), the influence of climates such as wind direction, wind speed, temperature, and humidity can affect the concentration of odor transported from the landfill. The results of this study showed that 88% of respondents agreed that the smell of pollution near the landfill was related to weather conditions. According to the survey, 49% of respondents agreed that it is influenced by factors such as wind, rain, and hot weather. The influence of the wind is felt to be high (31%), followed by rain (15%) and heat with only 5% **Figure 15. community perception questions (9-12), (a), (b), (c) and (d).**

Community perception of detectable odor falls into three areas; indoors, just outside the house, and outdoors (parks, paths, etc.). The results of the study showed that 40% of respondents perceived the worst smell just outside the house, followed by the inside (34%) and outside (26%). The large difference in perceived odor between inside and outside of the home was likely due to the common practice in the community of closing all doors and windows to prevent bad odors from entering their home. The odor was less noticeable when driving through in an air-conditioned car or walking through parks. This was probably the reason for the low odor perception outdoors. Odor Intensity: Regarding odor intensity, the human sense of smell is very important in determining the perceivable odor scale **Figure 15. community perception questions (9-12), (a), (b), (c) and (d).**

According to the survey, the community's perception of odor intensity can be divided into four main classes; no smell, weak unpleasant smell, medium bad smell, and strong bad smell. Strong odor intensity is perceived by 46% of respondents, followed by moderate odor (33%), weak odor (18%), and no odor (3%). **Figure 15. community perception questions (9-12), (a), (b), (c) and d).** shows the odor intensity perceived by respondents. Finally, the study also focused on the perceived impact of odor on human health and the physical environment. The results of the survey showed that 83.7% of the respondents believed that the bad smell had affected the quality of life and that the respondents associated the bad smell with its impact on health. In terms of the physical environment, only 13.2% of respondents attributed the bad odor to the environmental effect. Figure **15. community** perception questions (9-12), (a), (b), (c) and (d). shows the diversity of impacts perceived by the respondent.

4.2. Indoor air concentration of carbon dioxide at sample sites

The researcher divided the site into four regions to simplify the data gathering and assembly process according to their direction. From each region, 48 residential houses were inspected with the digital instrument, within a radius of 500m and 500m- 1.5 km, even though the dispersion distance exceed this time and resources were the constraints that limit the distance up to 1.5km. The raw data collected were presented in the tables and graphs below.

Recorded data for Region 1

Region 1 is located in the northeast direction of Koshe landfill, as shown in (**Table 7**) and the following two figures (Figure 16 and Figure 17) below, the highest concentration of CO2 recorded in this region within the radius of 500m and 500m-1.5km were 854.5ppm and 619.5ppm, respectively. Whereas, the lowest concentration of CO2 recorded were 607 ppm and 351.5ppm within the radius of 500m and 500m-1.5km, respectively.

A. **Region 1 (500m)**

Table 7. (a) Recorded CO2 concentration for Region 1 within the radius of 500m and (b) Recorded CO2 concentration for Region 1 within the radius of 500m -1km.

House ID	**Region 1 (500m)**		**Mean value**
	Result in (ppm)		
	Min	**Max**	
H1	745	892	**818.5**
H2	793	916	**854.5**

H3	686	748	**717**
H4	623	881	**752**
H5	713	811	**762**
H6	659	788	**723.5**
H7	644	909	**776.5**
H8	751	812	**781.5**
H9	588	626	**607**
H10	610	623	**616.5**
H11	712	917	**814.5**
H12	726	801	**763.5**
H13	748	946	**847**
H14	726	802	**764**
H15	602	617	**609.5**

B. Region 1 (500m-1km)

House ID	Region 1 (500m - 1.5km)		Mean value	House ID	Region 1 (500m 1.5km)		Mean value
	Result in (ppm)				Result in (ppm)		
	Max	**Min**			**Max**	**Min**	
H16	509	476	**492.5**	H40	540	351	**445.5**
H17	510	491	**500.5**	H41	502	376	**439**
H18	525	435	**480**	H42	516	339	**427.5**
H19	528	514	**521**	H43	509	381	**445**
H20	632	605	**619.5**	H44	401	376	**388.5**
H21	630	595	**612.5**	H45	391	355	**373**

H22	639	541	**590**	H46	383	327	**355**
H23	532	477	**504.5**	H47	381	342	**361.5**
H24	503	492	**497.5**	H48	387	342	**364.5**
H25	528	456	**492**				
H26	521	402	**461.5**				
H27	504	454	**479**				
H28	514	514	**484.5**				
H29	502	427	**464.5**				
H30	529	355	**442**				
H31	520	346	**433**				
H32	551	402	**476.5**				
H33	518	329	**423.5**				
H34	381	347	**364**				
H35	388	342	**365**				
H36	394	336	**365**				
H37	402	351	**376.5**				
H38	377	326	**351.5**				
H39	511	421	**466**				

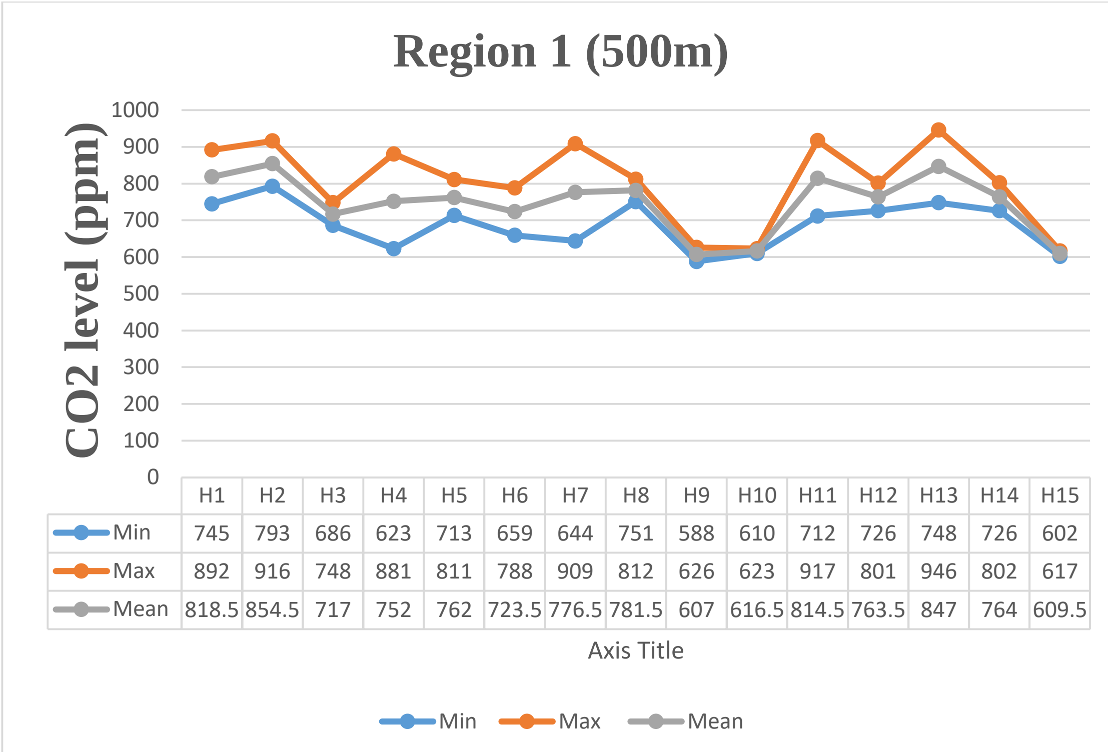


Figure 16. Recorded CO2 level on region 1 within the radius of 500m.

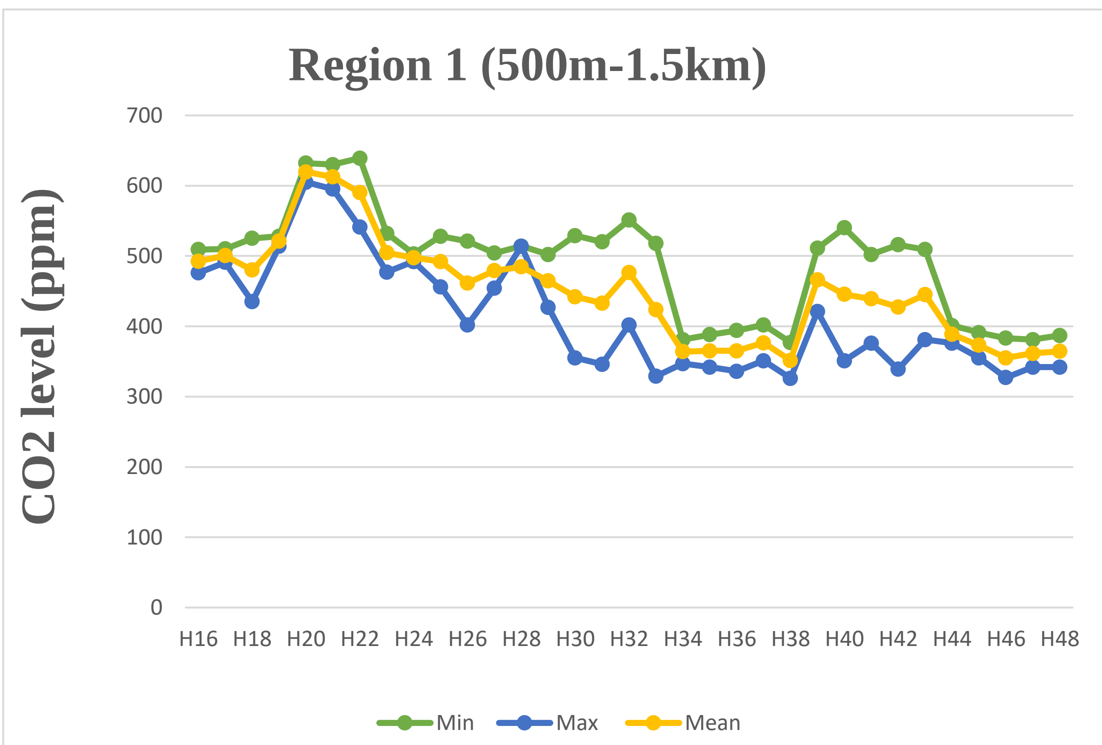


Figure 17. The recorded CO2 level (in ppm) in region 1 within a radius of 500m-1.5km.

Recorded data for region 2

Region 2 is located in the southeast direction of Koshe landfill, as indicated in (Table 8) and the following (Figure 18 and Figure 19) two figures below, the highest concentration of CO_2 recorded in this area within the radius of 500m and 500m-1.5km were 740.5ppm and 445.5 ppm, respectively. Whereas, the lowest concentration of CO_2 recorded were 639.5 ppm and 349.5ppm within the radius of 500m and 500m-1.5km, respectively.

A. Region 2 (500m)

Table 8. (a) Recorded CO_2 concentration for Region 2 within the radius of 500m Recorded and (b) CO_2 concentration for Region 2 within the radius of 500m-1km

House ID	**Region 2 (500m)**		**Mean value**
	Result in (ppm)		
	Max	**Min**	
H1	726	713	**719.5**
H2	688	591	**639.5**
H3	709	711	**710**
H4	750	725	**737.5**
H5	701	672	**686.5**
H6	724	707	**715.5**
H7	731	686	**708.5**
H8	712	592	**652**
H9	708	679	**693.5**
H10	750	731	**740.5**

B. Region 2 (500m -1km)

House ID	**Region 2 (500m - 1.5km)**		**Mean value**	**House ID**	**Region 2 (500m - 1.5km)**		**Mean value**
	Result in (ppm)				**Result in (ppm)**		
	Max	**Min**			**Max**	**Min**	
H11	698	513	**605.5**	H35	522	499	**510.5**
H12	650	614	**632**	H36	502	489	**495.5**

H13	646	621	**633.5**	H37	522	498	**510**
H14	650	641	**645.5**	H38	533	510	**521.5**
H15	521	506	**513.5**	H39	543	489	**516**
H16	527	526	**526.5**	H40	355	344	**349.5**
H17	571	448	**509.5**	H41	402	365	**383.5**
H18	626	547	**586.5**	H42	397	365	**381**
H19	577	538	**557.5**	H43	399	349	**374**
H20	566	516	**541**	H44	388	343	**365.5**
H21	612	621	**616.5**	H45	511	415	**463**
H22	638	588	**613**	H46	549	444	**496.5**
H23	644	626	**635**	H47	525	438	**481.5**
H24	530	499	**514.5**	H48	519	413	**466**
H25	491	448	**469.5**				
H26	359	348	**353.5**				
H27	377	349	**363**				
H28	406	395	**400.5**				
H29	382	354	**368**				
H30	412	409	**410.5**				
H31	511	425	**468**				

H32	518	433	**475.5**
H33	522	425	**473.5**
H34	506	436	**471**

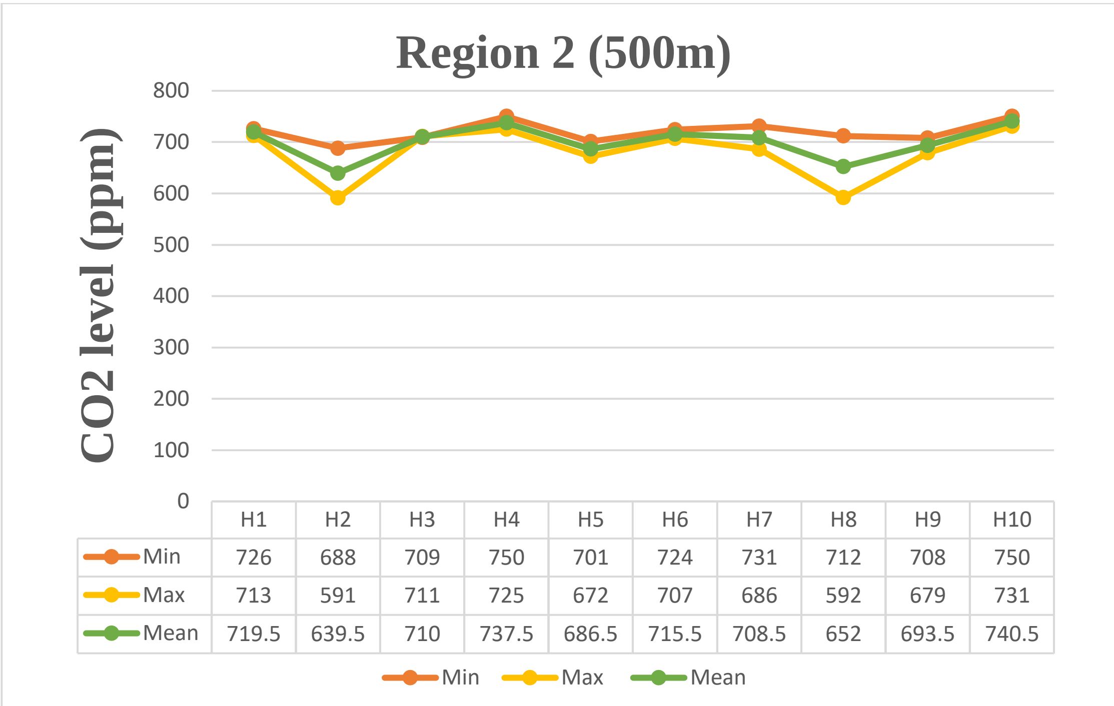


Figure 18. The recorded CO2 level (in ppm) in region 2 within the radius of 500m.

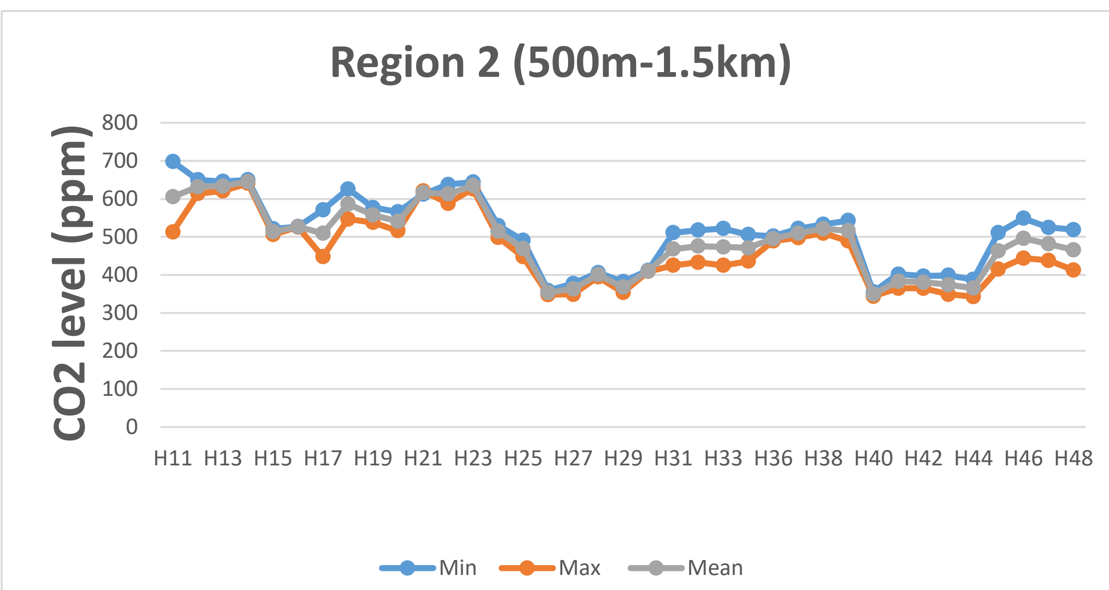


Figure 19. The recorded CO2 level (in ppm) in region 2 within a radius of 500m-1.5km.

Recorded data for site 3

Region 3 is located in the southwest direction of Koshe landfill site, As indicated in (**Table 9**) and the consecutive two figures (Figure 20 and Figure 21) below, the highest concentration of CO_2 recorded in this site within the radius of 500m and 500m-1.5km were 814 ppm and 504 ppm, respectively. Whereas, the lowest concentration of CO_2 recorded were 503.5 ppm and 344 ppm within the radius of 500m and 500m-1.5km, respectively.

A. Region 3 (500m)

Table 9. Recorded CO_2 concentration for Region 3 within the radius of 500m (a). Recorded CO_2 concentration for Region 3 within the radius of 500m-1.5km (b).

House ID	**Region 3 (500m) Result in (ppm)**		**Mean value**
	Max	**Min**	
H1	508	499	**503.5**
H2	529	511	**520**
H3	559	482	**520.5**
H4	522	505	**513.5**
H5	433	381	**814**
H6	546	448	**517**
H7	524	504	**514**
H8	564	494	**529**
H9	527	519	**523**
H10	591	421	**506**

B. Region 3 (500m -1.5km)

House ID	Region 3 (500m - 1.5km)		Mean value	House ID	Region 3 (500m 1.5km)		Mean value
	Result in (ppm)				Result in (ppm)		
	Max	**Min**			**Max**	**Min**	
H11	523	456	**489.5**	H35	477	441	**459**
H12	570	426	**498**	H36	523	398	**460.5**
H13	471	364	**417.5**	H37	394	382	**394**
H14	543	465	**504**	H38	507	429	**468**
H15	593	433	**513**	H39	420	361	**390.5**
H16	490	484	**487**	H40	449	333	**391**
H17	522	480	**501**	H41	411	394	**402.5**
H18	523	448	**485.5**				
H19	499	420	**459.5**				
H20	551	433	**492**				
H21	512	471	**491.5**				
H22	523	418	**470.5**				
H23	520	455	**487.5**				
H24	510	422	**466**				
H25	501	429	**465**				
H26	496	404	**450**				

H27	496	428	**462**
H28	470	430	**450**
H29	415	351	**383**
H30	442	328	**385**
H31	425	355	**390**
H32	385	356	**370.5**
H33	377	319	**348**
H34	456	416	**436**

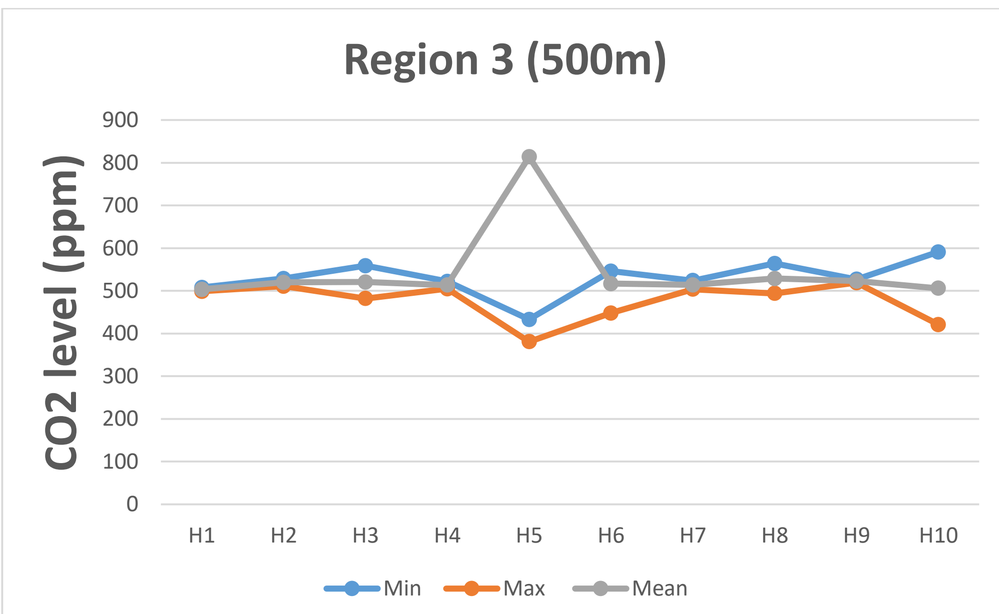


Figure 20. The Recorded CO2 level (in ppm) in region 3 within the radius of 500m.

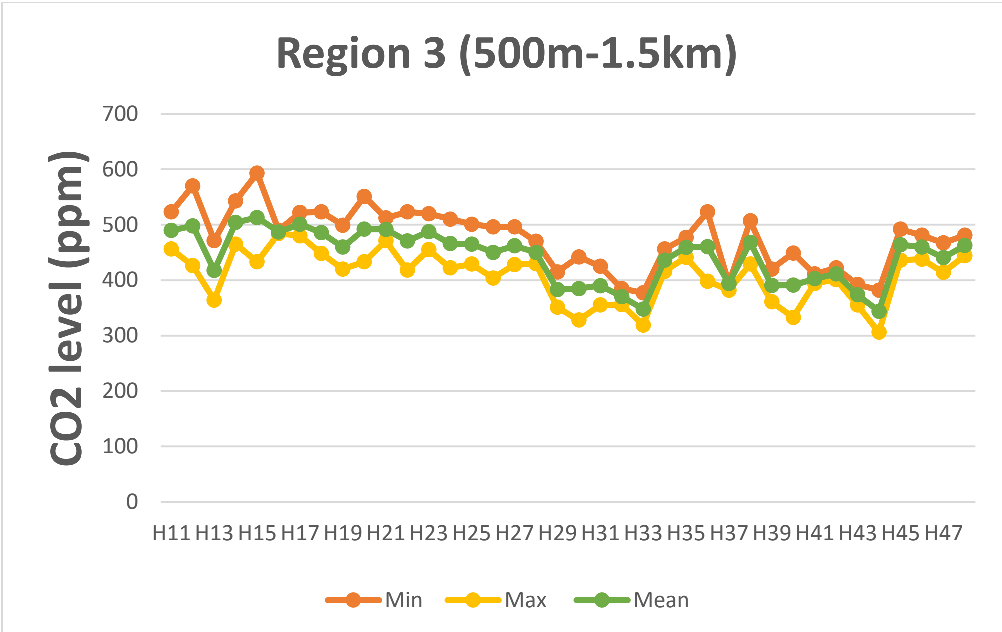


Figure 21. The recorded CO2 level (in ppm) in region 3 within a radius of 500m-1.5km.

Recorded data for Region 4

Site 4 is located in the North West direction of Koshe landfill site, As indicated in (**Table 10**) and the consecutive two figures (Figure 22 and Figure 23) below, the highest concentration of CO2 recorded in this site within the radius of 500m and 500m-1.5km were 533.5 ppm and 482.5 ppm, respectively. Whereas, the lowest concentration of CO2 recorded were 475.5 ppm and 322.5 ppm within the radius of 500m and 500m-1.5km, respectively.

A. Region 4 (500m)

Table 10. Recorded CO2 concentration for Region 4 within the radius of 500m (a). Recorded CO2 concentration for Region 4 within the radius of 500m-1.5km (b).

House ID	Region 4 (500m)		Mean value in (ppm)
	Result in (ppm)		
	Max	Min	
H1	518	477	**497.5**
H2	561	422	**491.5**
H3	541	502	**521.5**

H4	495	448	**471.5**
H5	532	509	**520.5**
H6	536	467	**501.5**
H7	522	481	**501.5**
H8	527	499	**513**
H9	546	521	**533.5**
H10	503	498	**500.5**
H11	524	458	**491**
H12	541	522	**531.5**
H13	533	488	**510.2**
H14	482	469	**475.5**
H15	521	436	**478.5**

B. Region 4 (500m-1.5km)

House ID	**Region 4 (500m - 1.5km) Result in (ppm)**		**Mean value in (ppm)**	**House ID**	**Region 4 (500m 1.5km) Result in (ppm)**		**Mean value in (ppm)**
	Max	**Min**			**Max**	**Min**	
H16	501	429	**465**	H40	422	308	**365**
H17	490	433	**461.5**	H41	428	427	**426.5**
H18	496	431	**463.5**	H42	413	396	**404.5**
H19	461	443	**452**	H43	336	320	**328**
H20	495	429	**462**	H44	382	317	**349.5**
H21	474	438	**456**	H45	466	431	**448.5**

H22	512	453	**482.5**	H46	454	429	**441.5**
H23	452	448	**450**	H47	454	418	**436**
H24	503	417	**460**	H48	466	381	**423.5**
H25	529	337	**433**				
H26	459	399	**429**				
H27	402	392	**397**				
H28	336	325	**330.5**				
H29	372	333	**352.5**				
H30	406	396	**401**				
H31	398	375	**386.5**				
H32	361	317	**339**				
H33	338	307	**322.5**				
H34	416	409	**416**				
H35	422	408	**415**				
H36	466	354	**410**				
H37	510	321	**415.5**				
H38	386	470	**428**				
H39	340	391	**365.5**				

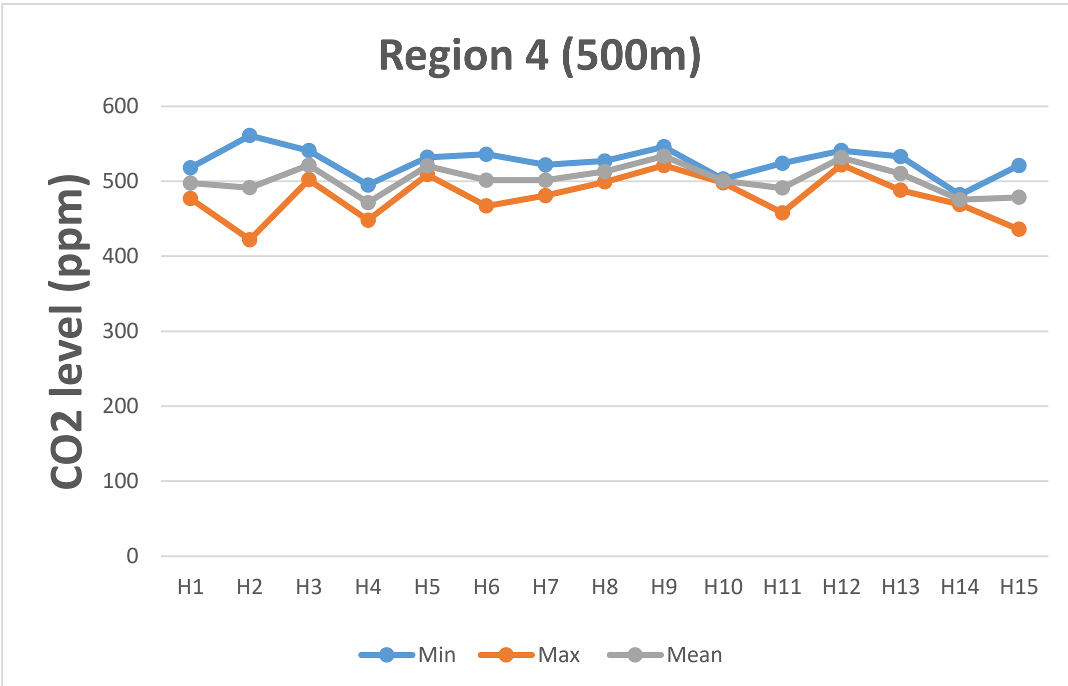


Figure 22. The Recorded CO2 level (in ppm) in region 4 within the radius of 500m.

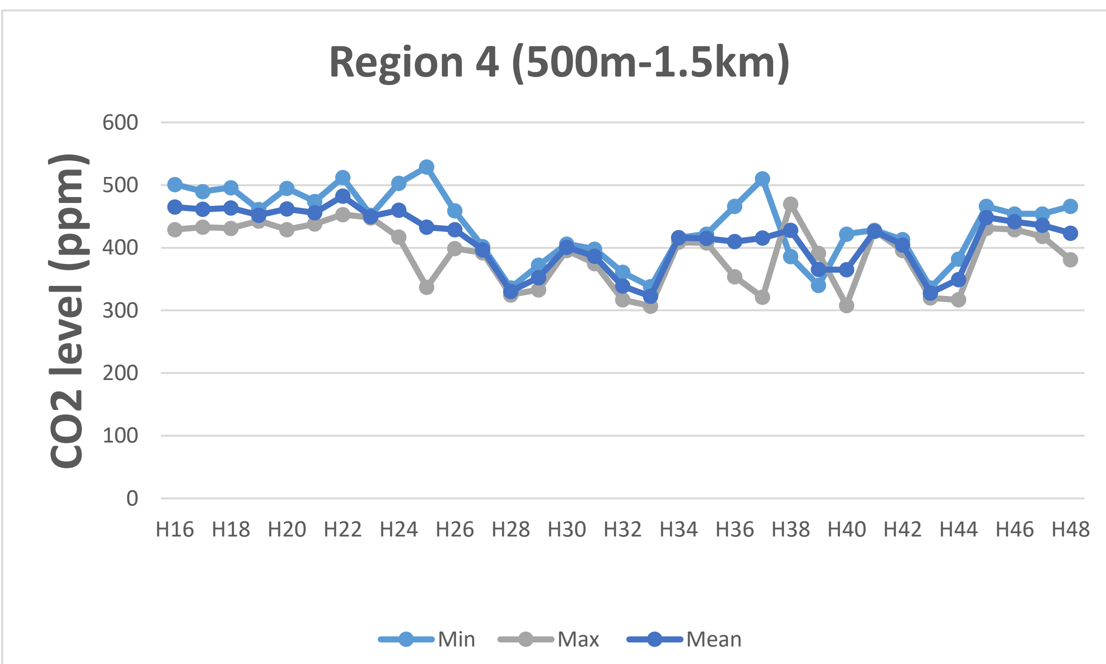


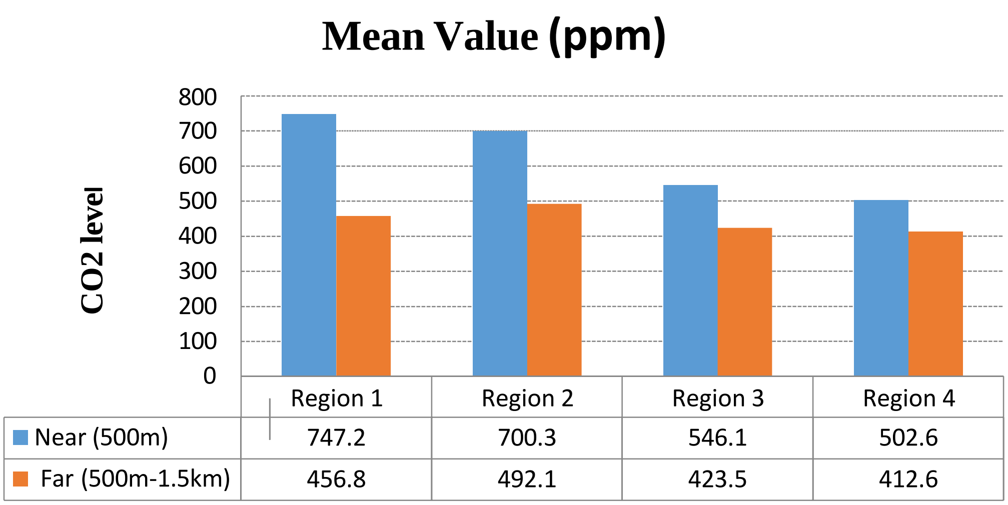
Figure 23. The recorded CO2 level in (ppm) in region 4 within a radius of 500m-1.5km.

4.2. Mean average concentration of carbon dioxide (CO_2)

As indicated in (**Table 11**) below, the highest mean concentration of CO2 recorded for region 1, region 2, region 3, and region 4 were 747.2 ppm, 700.3 ppm, 546.1 ppm, and 502.6 ppm within the radius of 500m respectively. Whereas, the lowest mean concentration of CO2 recorded for region 1, region 2, region 3, and region 4 were 456.8 ppm, 492.1 ppm, 423.5 ppm, and 412.6 ppm within the radius of 500m- 1.5km respectively.

Table 11. Mean (average) level of CO2 for all regions.

	Region 1	Region 2	Region 3	Region 4
Near (500m)	747.2 ppm	700.3 ppm	546.1 ppm	502.6 ppm
Far (500m-1.5km)	456.8ppm	492.1 ppm	423.5 ppm	412.6 ppm



As it can be seen from the mean values the concentration of CO2 increases in residences near the landfill site which is within a radius of 500m, as we go further away from the Koshe landfill the amount of CO2 decreases. These values were only related to carbon dioxide emitted from the Koshe landfill, and other carbon dioxide sources such as vehicles and industries were not considered. All the values with both radiuses compared to OSHA Field Safety and Health Manual are less than 1000ppm (OSHA, 2015) but all results are greater than the atmospheric level of CO2 this can indicate the contribution of koshe landfill to the increase of CO2 in the indoor air quality of the surrounding and atmospheric area.

4.3. Total Mean (average) concentration of carbon dioxide (CO2)

(Figure 25) below shows the total mean values for all residential areas near Koshe landfill site. The highest total mean concentration of carbon dioxide was 602ppm, 596.2ppm, 484.8, and 457.6 for regions 1, region 2, region 3, and region 4 respectively. As the result shows all values are greater than the atmospheric concentration of CO2 Which must be 314ppm according to the OSHA Field Safety and Health Manual (OSHA, 2015). There is no clear standard that is set in Ethiopia so the researcher cannot compare the results with contextual standards. According to OSHA Field, Safety and Health Manual (OSHA, 2015) people cannot sense the side effect of carbon dioxide until the limit reached beyond 1000ppm, but the results indicate the contribution of Koshe to the indoor air quality in terms of CO2 level is greater unless it is controlled.

Table 12. Summary of Mean concentration of CO2 in (ppm) in all regions.

	R-1 (500 m)	**R-1 (500m-1.5km)**	**R-2 (500m)**	**R-2 (500m-1.5km)**	**R-3 (500m)**	**R-3 (500m-1.5km)**	**R-4 (500m)**	**R-4 (500m-1.5km)**
Mean (ppm)	747.2	456.8	700.3	492.1	546.1	423.5	502.6	412.6
Total mean (ppm)	**602**		**596.2**		**484.8**		**457.6**	

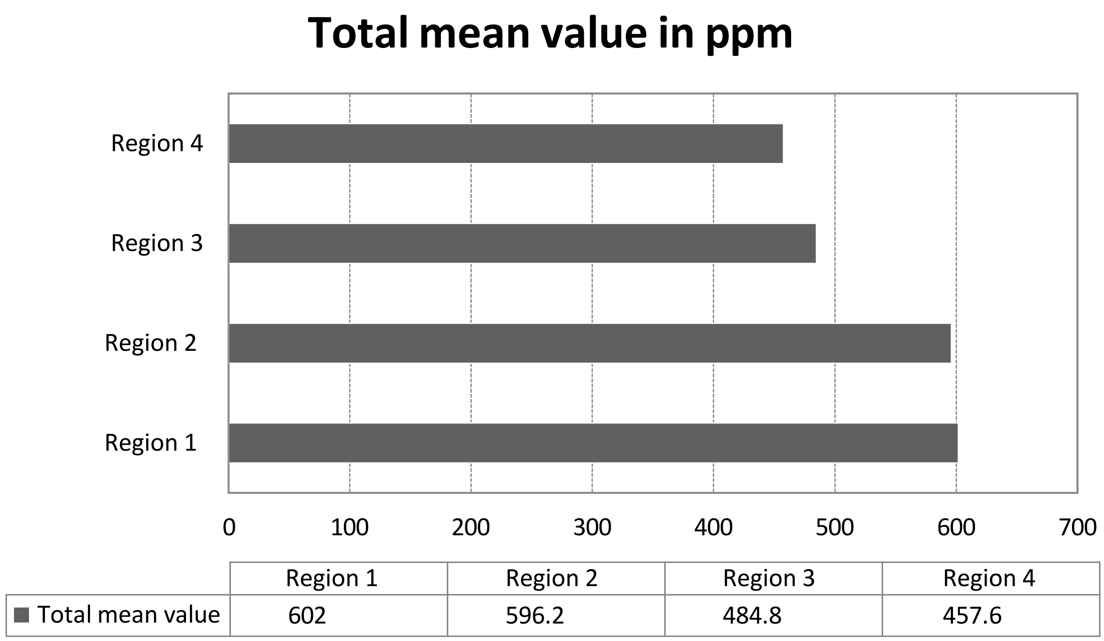


Figure 25. The total mean concentration in (ppm) **of CO_2 in sample sites.**

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This chapter will conclude the study by summarizing the key research findings concerning the research aims and research questions, as well as the value and contribution thereof; it will also review the limitations of the study and purpose opportunities for future research.

This study aims to evaluate the indoor air quality in terms of CO2 level and odor dispersion status in residential buildings neighboring to Reppie (Koshe) landfill site, Addis Ababa Ethiopia. By interactively coupling ALOHA and ArcGIS software, a simple methodology was developed to delineate odor and carbon dioxide (CO2) zones of influence around the Koshe landfill. The analyzes carried out using the developed methodology showed that the properties of the land use in the vicinity of the landfill have a significant influence on the dispersion properties and the impact radius of the odor Atmospheric stability conditions (e.g. day and night conditions) can also have a significant impact on the properties of the odor and carbon dioxide (CO2) dispersion. For example, stable atmospheric conditions at night (Condition F) would result in a larger impact radius; however, the strength of the odor would be lower because the air would be diluted in a larger volume. It should be noted that the dispersion model used (ALOHA) has some limitations as it was developed for spill emergency response. Corrections and modifications should be considered based on knowledge and experience of regional conditions (e.g. prevailing wind direction), landfill operating conditions, and the potential for outgassing in the vicinity of landfills. Considering the prevailing wind direction (day and night and different seasons), the allocation of adequate buffer zones as well as leeward landscape policies should be considered to mitigate the impact of possible odor nuisance. This study has clearly shown that the bad odor emanating from the landfill is detrimental to the daily life of the communities. First of all, the odor is a constant nuisance that affects indoor and outdoor activities in communities. Odor spikes are most commonly perceived at night, requiring communities to close all windows and doors to reduce odor detection. The study also showed that the periods and intensity of bad odor can be influenced by weather, particularly wind direction.

To analyze the concentration of carbon dioxide Cross-sectional study was conducted from April 15- 20, 2022. A total of 192 sample residential houses were selected from four different regions, 96 sample houses were investigated within a radius of 500m distance and 96 within a radius of 500m-1.5km distance surrounding the landfill site. indoor CO2 concentrations were measured with electronic instruments in all sample regions. According to the main findings of the research, the total mean average concentration of CO2 concentration in 500m radius and 500m-1.5km radius of the landfill were 574.84ppm and 414.92 ppm respectively. As the result indicated overall total mean average value from all sample houses was 494.88 ppm. as the result implies the level of CO2 within a 500m radius of Koshe landfill was greater than the average values of samples taken within the radius of 500m-1.5km this indicates that koshe landfill has a contribution to the increase of CO2 level to the indoor environment. Indoor Carbon dioxide concentrations in all regions were within the specified limits set by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) guidelines for comfort (<1000 ppm) (ASHRAE, 2001). All in all, the researcher concludes that Koshe landfill site has contributed to the increasing level of CO2 and malodor impact on the indoor environment of residential buildings close to the landfill. if it remains uncontrolled the level may increase and affect the overall environment.

5.2. Recommendations

To solve the air pollution, effect the government and society should work on the mitigation and implementation policy.

5.2.1. Mitigation measures

Planting green belt as Buffer

Waste disposal sites include waste processing/disposal facilities, which become sources of air, water, soil, and noise, and emit bad odors. Planting trees and shrubs around landfills can disrupt the plume and mix it with prevailing winds to dilute the odor. Therefore, the provision of a buffer zone around these facilities is imperative to protect those living nearby from exposure to such pollutants. The green buffer zone acts as a barrier, absorber, and partly as a corrective measure against fugitive emissions. Fugitive emissions of pollutants released during the handling, storage, and transportation of waste. The green belt around the waste disposal facility can reduce the said annoyance value of the disposal facility, but also strives for an aesthetic upgrade (Central Pollution Control Board (CPCB), 2017).

Criteria for selecting plant species

- The Plant species must grow rapidly
- They must have a dense canopy
- They must have high carbon– CO_2 sink potential
- They must absorb pollutants effectively without significantly affecting their growth

Recommended plant species:

Considering the type of pollutants expected from the landfill, a green belt with a minimum width of 10 meters is recommended and the following plant species can be selected for planting (Central Pollution Control Board (CPCB), 2017):

- Acacia nilotica
- Deldergia Sissoo
- Acacia auriculiformis

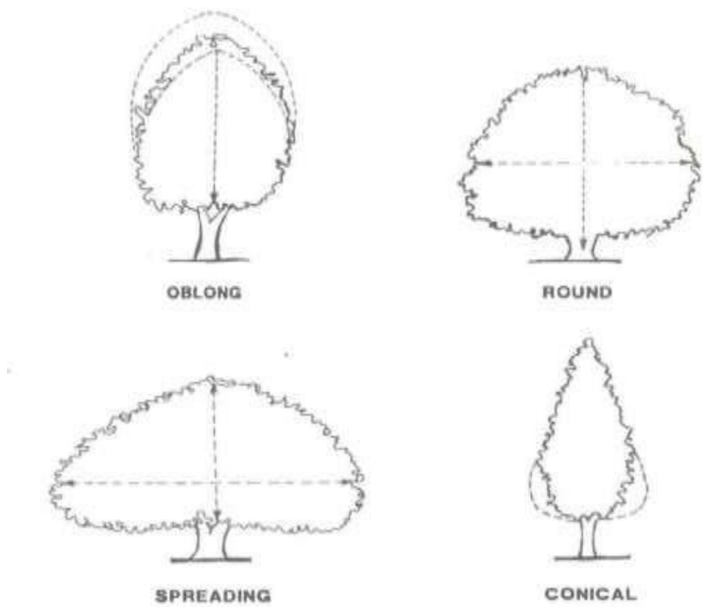


Figure 26. Tree canopy shapes

Figure 27. Green belt design option for Koshe landfill.

Passive solution for residential Buildings

A key strategy for IAQ management is the development of a comprehensive, scientifically sound, and carefully considered plan. This plan must address both new construction and existing buildings.

- Many surfaces in a building absorb pollutants by themselves. This often results in significantly lower concentrations of pollutants indoors than outdoors, particularly in naturally ventilated buildings due to the installation of filters in the air handling system that can absorb certain pollutants. Contaminants entering a space settle on all available surfaces, so the amount that reaches object surfaces can be reduced by ensuring surfaces in the space are large and made of reactive materials such as concrete, brick, stone, plaster, and wood. preferably with zero or porous surface finishes.
- Sealing doors and windows are relatively easy and inexpensive. To seal doors, windows, and cracks in the building fabric from the outside and insert locking doors on the inside. This is a low-maintenance, passive solution suitable for buildings with air conditioning and natural ventilation.
- Increase surface area, and change building layout to include smaller rooms by adding partitions.

- Introduce more absorbent surface finishes.
- Brick and plaster commonly used as indoor surfaces are passive, low-maintenance solutions. Can be made to work with the existing building layout. Other wall coverings, such as carbon-impregnated cloth can be introduced. This approach could be designed into new buildings. (Blades et al., 2000).
- Plants can be used as indoor filters and add an ecosystem service to the decorative purpose. Indoor air quality can be actively improved by a plant based air filtration system. Several studies have demonstrated the ability of plants to absorb and remove pollutants from the air. (Becker et al., 2015). Nature Based Solution (NBS) is essentially a small, plant-filled conservatory that can be placed in a place of a window, thus providing both air filtration services and being a decorative element (Gattringer et al., 2021). Several specific plants act as 'natural air purifiers and have been found to improve IAQ.

Figure 28. Nature based solution to filter unwanted air.

Scope for future work

The modeling tool ALOHA doesn't consider the effects of terrain and other physical barriers on dispersion, therefore further research on this aspect is recommended.

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APPENDIX- I

Household survey Household survey in English

Adama Science and Technology University

MSc in Environmental Architecture

Date………….……… Time: ….………………. Code: ……………………

Dear Resident

I am conducting a household survey in your area as part of a research project at the University of Adama Science and Technology University. My research aims to provide me with a better understanding of residents' odor concerns in the Koshe landfill neighborhoods. It would be appreciated if you would contribute to my research by answering the following questions. It will not take more than 30 minutes of your time. The information you give will be kept confidential, and where necessary, please feel free to answer 'don't know or 'not applicable. If you do not want to participate in the survey, there will be no repercussions for you. Thank you for your participation.

Part 1: General Information (These questions are based on (Studies, 2020)**).**

Please put √ in the appropriate box/ boxes for our answer

1. Sex a) Female ☐ b) Male ☐

2. Please tick your age group in the appropriate answer.

a) 18-25 ☐ b) 26-35 ☐ c) 36-45 ☐

d) 46-55 ☐
e) 56-65 ☐
f) ≥ 66 ☐

3. What is your highest educational level?

a) Illiterate ☐ b) Primary ☐

c) High School ☐ d) College Graduate ☐

e) Vocational Training ☐ f) University Diploma/Degree ☐

g) MA/PhD ☐

Part 2. Subject-related questionnaire (These questions are based on (Perumal, 2015)**).**

4. How long have you lived in this residential area?

a) Less than one year (12 Months) ☐ b) 1-2 years ☐

c) 3-4 Years ☐

e) 10-19 Years ☐

c) -9 Years ☐

f) More than 20 Years ☐

5. Do you think Koshe landfill is the source of malodor to the environment?

(a) Yes ☐ (b) No ☐

6. At which particular times of the day are these odors/smells stronger or more prevalent? (You may tick more than one option)

(a) Morning (6 am to 10 am) ☐

(b)Noon (12 pm to 2 pm) ☐

(c) Afternoon (2 pm to 4 pm) ☐ (d) Evening (5 pm to 7 pm) ☐

(e) Night (8 pm to 10 pm) ☐

7. What is the frequency of odor pollution?

(a) once a day ☐ (b) once a week ☐ (c) once a month ☐ (d) The whole day ☐

8. What time of year are the odors or smells at their worst? (You may tick more than one option)

(a) Spring ☐ (b) Summer ☐ (c) Autumn ☐

(d) Winter ☐ (e) The same all year round ☐ (f) don't know ☐

9. Do you think odor pollution is related to weather conditions (wind, rain, and hot weather)?

(a) Yes ☐ (b)No ☐

If yes which weather factor is influential

(a)wind (b)rain (c)hot weather (d) wind, rain, and hot weather all affect

10. Where do you detect the odor most? (You may tick more than one option)

(a) indoor ☐
(b) just outside the house ☐
(c) outdoor ☐

11. How do you express the intensity of the odor around your environment?

(a) no smell (b) weak unpleasant smell (c) medium malodor (d) strong malodor

12. does Koshe landfill malodor have an impact on your health and physical environment? (a)yes

(b) no

Thank You for your participation!!!