The Impact of Improper Solid Waste Management on Public Health of African Cities. The Case of Addis Ababa City, Ethiopia.

by

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ABSTRACT

THE IMPACT OF IMPROPER SOLID WASTE MANAGEMENT ON PUBLIC HEALTH OF AFRICAN CITIES. THE CASE OF ADDIS ABABA CITY, ETHIOPIA.

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Many African cities are generating an ever-increasing amount of waste and the effectiveness of their solid waste collection and disposal systems is currently declining. Therefore, research has been striving to develop a sustainable and integrated solid waste management system that fits the current challenges facing the local environment.

The objective of this study is to analyze the impact of improper solid waste management that affects the air and water quality of the near Koshe open dump site and around the Addis Ababa City, and their adverse effect on the public health living around them. The rapid increase of population in Addis Ababa, combined with a deficiency of resources to deliver basic facilities and urban services have led to a series of difficulties such as the increased generation of waste and improper solid waste management impacting the environment and the community health.

With increasing population, the quantity of municipal solid waste generation in Addis Ababa city has been consistently rising over the years which were collected inefficiently, transported inadequately, and disposed unscientifically. The average annual collection of solid waste over the last ten years (2011-2020) was 1,976,033 cubic meter which was lower than the annual generation of solid waste of 2,511,076 cubic meter indicating that there was insufficient collection rate of solid waste in the city with 23% left uncollected waste.

The composition of Municipal Solid Waste (MSW) is largely organic and plastic waste which together consists of 71.1%-83.9.5%. Organic waste in the city has shown an increasing trend from 65.9% to 74.29 % during the period 2017 to 2021 respectively. Similarly plastic wastes are also shown an increasing trend from 5.2% to 9.61% during the year 2017 to 2021 respectively. On the other hand, solid waste composition for glasses, paper and textile wastes are showing a declining trend during the year 2017 up to 2021.

The ambient air quality of Addis Ababa city were collected by Aroqual series measurement and has been analyzed. The result showed that, the eight-month average fine PM2.5 emissions of Addis Ababa city was 56.6μg/m^3 which is more than three times the standard set by WHO limit of 15μg/m^3 but below the standard set by EEPA of 65μg/m^3. Whereas the result of Koshe dump site showed PM 2.5 emissions of 204 μg/m^3 which is more than thirteen times the standard set by the WHO limit of 15μg/m^3 and more than three times the standard set by EEPA of 65μg/m^3. PM2.5 concentration in Addis Ababa city average was found to be higher during Dry season (November 2022, December 2022 and January 2023 resulted in 98μg/m^3 ,53μg/m^3 and 79μg/m^3 respectively). During the dry seasons the concentration of PM2.5 is relatively higher than the wet season due to lower average temperature, lower precipitation, and higher wind speed.

Similarly, the trends of PM10 concentration in Koshe dump site during Summer/wet season (August 2022 and October 2022) were 156μg/m^3 and 224μg/m^3 respectively with lower results than the dry season.PM10 concentration of Koshe dump site during winter/dry season (November 2022, December 2022, and January 2023) were 587μg/m^3, 393μg/m^3 and 490μg/m^3 respectively with very much higher results than wet season. This is because of lower average temperature, lower precipitation, and higher wind speed was recorded during dry season. Higher concentration of PM2.5/PM10 has negative impact on the communities living around Koshe open dump site. Moreover, the CO, SO_2 and NO_2 concentration of Koshe dump site during winter or dry season of the Months exceeded above the limit of WHO standard and below the limit of EPA standard. These may be due to the presence of Waste to Energy (or incineration) facility near the Koshe dumpsite.

Water pollution near Koshe open dump site area and the downstream Little Akaki river of Addis Ababa city have been analyzed and the laboratory result for BOD, COD and TDS at the downstream of Akaki river during dry season were higher and exceeding the permissible limits of EEPA and WHO standards.

The COD and BOD values of the wastewater after it was Mixed with the Akaki River (Lower stream) during August 2022 were 416mg/L and 97mg/L, respectively which were below the WHO Permissible limit of 500mg/L. After it was Mixed with the Akaki river (Lower stream) during August 2022, the TDS values of the wastewater were 800mg/L, above the recommended values of WHO Permissible limit of 500 mg/L. The reason is that high rainfall and water flow dilute the pollutants during the dry season, contributing to higher concentrations of TDS.

The BOD values of the wastewater after it were Mixed with Akaki river (Lower stream) during the month of February 2023 were 139mg/L which were below the recommended values of WHO Permissible limit of 500 mg/L. The COD values of the wastewater after it were Mixed with Akaki river (Lower stream) during the month of February 2023 were 806mg/L which were above the recommended values of WHO Permissible limit of 500 mg/L. The higher value of COD implies a greater amount of oxidized organic material in the sample that reduces dissolved oxygen level and endangers the surface water bodies/river life. The TDS values of the wastewater after it were Mixed with Akaki river (Lower stream) during the month of February 2023 were 742mg/L which were found to be above the recommended values of WHO Permissible limit of 500 mg/L.

The study further identified that the laboratory results of heavy metal concentration for Nickel, Mercury, Lead and Chromium at downstream of Akaki river during rainy season were exceeding the permissible limits of WHO standards. Moreover, the laboratory result for wastewater during the dry season indicated that heavy metal concentration of the Nickel, Mercury, Lead and Chromium after the Leachate is Mixed with Akaki water river were exceeding WHO permissible limit.

The health prevalence of the community living around the Koshe open dump site has been analyzed during the study period considering the Alert Hospital as the case study area and Menelik Hospital as the control Hospital. Hence, out of the total patient card diagnosed in Alert Hospital and Menelik Hospital, the data analysis has shown that more patients in Alert Hospital were

identified to have a more significant number of patients with solid waste-related diseases than in Menelik Hospital. The study has further identified air and water pollution-related diseases that were more aggravated in Alert Hospital, where solid waste-related diseases affect the communities living near the dump site.

The unit cost of medication for solid waste related disease during wet season (August 2022) was 1.43 USD and 2.43 USD for Government pharmacy and private pharmacy respectively. Whereas the unit cost of medication for solid waste related disease during dry season (February 2023) was 75.13USD and 125.88USD for Government pharmacy and private pharmacy respectively. Hence, the unit cost of medication for solid waste related disease during dry season (February 2023) was found to be very much higher than the cost of medication for solid waste related disease during wet season (August 2023).

The present study can be helpful for the government, municipalities, researchers, and policy makers as there are limited studies specific to the impact of improper solid waste management in Addis Ababa city.

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CHAPTER ONE

Introduction

1.1 Background

Human activities create waste, and it is the way these wastes are handled, stored, collected, and disposed of, which can pose risks to the environment and to public health. (Zurbrugg, C. 2002). Access to improved sanitation contributes to human health, dignity, security, and wellbeing of people (Sida, 2012). Improper Municipal Solid Waste Management (IMSWM) is one of the most accurate indicators of environment and health-related problems in the world. (Prasad, 2013).

This implied that the process of solid waste generation, collection, processing, and final disposal still represents a problem in many low-middle income regions due to its improper management. Unfortunately, many cities, especially in developing countries, are grappling with high volumes of solid waste and face vast inadequacies in their management (Gutberlet et al., 2017). Increasing rates of waste generation due to rapid urbanization, population growth, changing lifestyles, and consumption patterns continue to contribute to the challenges facing solid waste management (Sharholy et al., 2008).

The world generates 2.01 billion tonnes of municipal solid waste annually, and this number is expected to grow to 3.40 billion tonnes by 2050 under a business-as-usual scenario. At least 33 percent of 2.01 billion tonnes of municipal solid waste are mismanaged conservatively in an unsafe manner. Unlike low-income countries, high-income countries have a full capacity to manage solid waste from generation up to disposal sites properly. (Kaza et al., 2018.)

The amount of MSW generation in the world has significantly increased in the few decades and is rising faster than the rate of urbanization. For instance, in the early 2000s, there were 2.9 billion urban residents generating around 0.68 billion tonnes per year; a decade after, these amounts increased to about 3 billion residents generating 1.3 billion tonnes per year. In addition, by 2025, urban residents are projected to likely increase to 4.3 billion, generating about 2.2 billion tonnes per year. (Hoornweg & Bhada-Tata, 2012; Wilson et al., 2015)

Waste in Sub-Saharan Africa is predominantly openly dumped, primarily organic, with 40 percent being food and green waste. The overall waste collection rate in Sub-Saharan Africa is about 44 percent. However, the rate is much higher in urban areas than in rural areas, where waste collection services are minimal, and about 69 percent of waste is improperly managed and openly dumped. (Kaza et al., 2018.) The use of open dump sites for the final disposal of solid waste is widespread in all urban areas and towns of Sub-Saharan Africa, including Ethiopia.

Research findings have indicated that an insufficient city solid waste management system may have significant adverse health and environmental impacts, such as air pollution, water pollution, and transmittable diseases due to this contamination of air, land, water, and harm to biodiversity. Das and Bhattacharyya (Das & Bhattacharyya, 2015) in their study stated that solid waste collection ranges from 40% to 70% in developing countries. In contrast, according to Tan (2012), the collection rates in developing countries range between 30 and 50%, and the collected waste is disposed of through improper management, uncontrolled landfilling, and open dumping.

This is factual in Addis Ababa City because only 70% of the waste generated (792 tons/day out of a total of 1132 tons/day generated) is collected and transported and deposited at the country's largest landfill. The remaining 30% is left uncollected and burned, buried, or disposed of informally in a way that pollutes the environment. These wastes are improperly dumped in non-alloy spaces, like exposed areas, channels, drains, roads, streets, sides, rivers, sanitary drainage channels, and other unprotected areas, becoming a rising fear in the city's public health **(**Fesseha and Bin F., 2015).

Addis Ababa city, like other developing cities, has a practice of improper solid waste management in that the city's generated solid waste, which amounts to 30%, is not collected, and 70% of the collected waste is also transported to uncontrolled and open-dumping sites called Reppie/Koshe dump site. Such unscientific disposal sites cause an adverse impact on all components of the environment and human health. (Guerrero et al., 2013). The enlarged expansion and population growth in Addis Ababa have led to a series of problems, such as the increased production of waste and inadequate collection, transportation, and dumping of solid waste. This condition has become the main threat to the urban environment and the health of the citizens in Addis Ababa **(**Fesseha and Bin F., 2015).

The health impacts of improper solid waste management can be categorized into infection transmission such as bacterial, viral, and other disease-causing organisms; Physical bodily injuries like cuts, drowning, and blunt trauma; and chemical or radiation injury, which ranges from immediate skin or inhalation burns to longer terms effects like respiratory disease, skin diseases, and cancer; non-communicable diseases and emotional/psychological effects like strong smells and unsightly waste. (Ziraba et al., 2016).

The population residing and working in the vicinity of solid waste processing and disposal facilities is exposed to public health risks. This is due to the emission of toxic gases and air pollutants such as landfill gas containing methane, carbon dioxide, hydrogen sulfide, and other contaminants, including particulate matter or contaminated soil and water. (Mataloni et al.,2016; (WHO, 2021). Communities near landfills and open dumps are susceptible to health impacts associated with exposure to landfill and uncontrolled dump sites. Moreover, across the cities, it is the urban poor that suffer most from the life-threatening conditions deriving from deficient SWM (Zurbrügg, 2003).

Another study showed that human health risk is also faced by waste collector and workers who are constantly exposed to various types of diseases from sharp objects and unknown waste disposed of in bulk by the public (Aminuddin & Rahman, 2015). The impact of solid waste on health is varied and may depend on numerous factors, including the nature of the waste, duration of exposure, the population exposed, and availability of prevention and mitigation interventions (Abd El et al.,2014; Al-Delaimy et al.,2014). The impacts may range from mild psychological effects to severe morbidity, disability, or death.

Waste acts might be immediate, obvious to discern, and directly linkable to solid waste exposure; others may be occult, longer term, and difficult to attribute the effects to a particular type of waste (Brinkel et al., 2009). The literature on the health impacts of solid waste exposure remains weak, and in Sub-Saharan Africa, including Ethiopia for instance, poor disposal practices have aggravated environment and health-related problems (Abul, 2010) which seeks further study and research for the successful implementation of Integrated and sustainable solid waste management system for policy makers and municipalities.

It is on this basis that this research has been proposed to assess, analyze, and evaluate the impact of improper solid waste management affecting the public health of the communities in Addis Ababa city and the communities residing and working in the vicinity of Koshe dump site. Insufficient collection and poor disposal practices generate serious health-related problems for humans and the environment (Loboka *et al.*, 2013). A thematic model of solid waste management is shown in Figure 1.1.

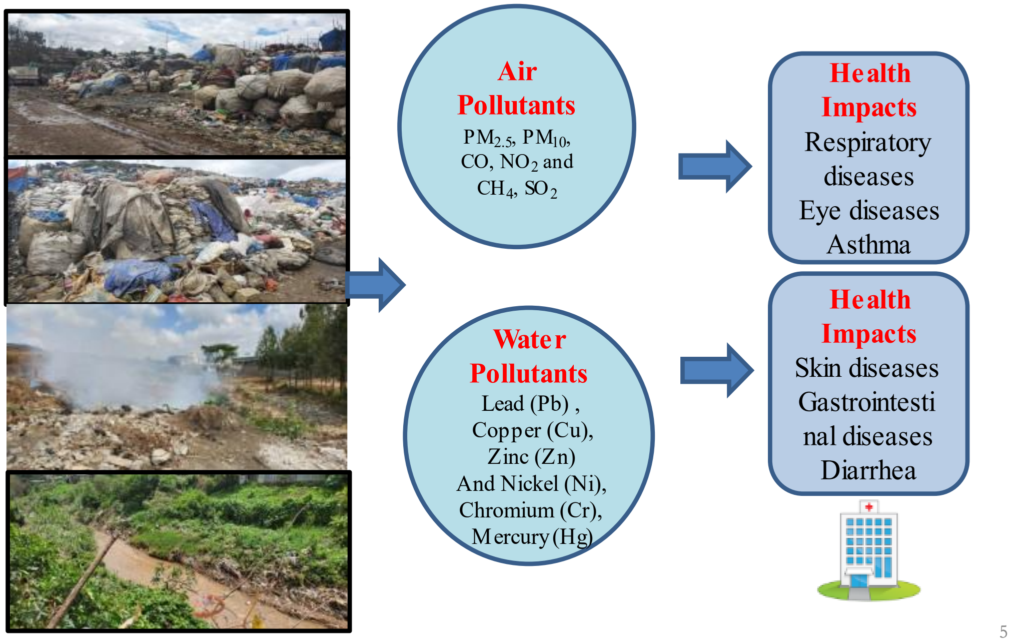


Figure 1.1 Thematic Model of Solid waste Management

1.2 Problem statement

Improper Solid waste management in developing countries represents a dangerous issue due to the practice of uncontrolled dumping and open burning impacting the public health triggered by waste releases in water bodies, soil and air pollutions, which are mostly underestimated by the governments. The mismanagement of this MSW in developing countries emanates from the lack of economic funding, public awareness, technological facilities and know how worsens the situation, giving low hopes of improvement. (Hoornweg & Bhada-Tata, 2012).

Most municipalities in developing cities are currently unable to fulfill their duty to ensure environmentally sound and sustainable ways of dealing with waste generation, collection, transport, treatment, and disposal. The failure of municipal solid waste management by the cities in developing countries can ultimately result in serious health problems.

This will lead to problems such as flooding, air pollution, respiratory and communicable diseases which are directly associated with the practice of municipal solid waste mismanagement (Hoornweg & Bhada-Tata, 2012).Thus, it is clear that particularly in the case of the cities in low- and middle-income countries, improper solid waste management practices are directly correlated with the increasing public health issues and degradation of the environment, being an issue that requires detailed research and urgent attention by decision-makers at all levels (Hyman et al., 2013; Marshall & Farahbakhsh, 2013). However, scientific research on the public health implications of improper solid waste management is negligible.

Like most other developing countries, improper solid waste management is a major challenge in urban areas of Ethiopia in general and Addis Ababa city in particular because of social, political, financial, technological, and infrastructural reasons (Audu et al.,2015). Moreover, the lack of services and infrastructure has often resulted in urban residents being confronted with wastes dumped all over the community in backyards, public spaces, drains, streets, and streams negatively impacting the health and the environment of the surrounding communities (Audu et al.,2015).

Currently, Addis Ababa city lacks efficient and effective municipal solid waste management system, leading to high possibilities of negative short and long-term impacts on human health. This study analyzes the implications of improper solid waste management that affects public health.

Cognizant of this end, the impact of improper solid waste management affecting public health due to open dumping and open burning of wastes has often been overlooked in most parts of the city of developing countries, including Addis Ababa. Moreover, there is a minimal amount of literature, research findings, and studies focusing on improper solid waste management affecting the public health of Addis Ababa city.

Hence this study will focus on evaluating, assessing, and analyzing the impact of improper solid waste management on the public health of Addis Ababa City in general and the community living near the Koshe Open dump site. Further, the study will evaluate and critically analyze air pollution trends in the city and determine the quality of river water near the Koshe dump site, impacting the health of the community.

1.3 Research Objective

The main objective of the current study is to evaluate, determine and analyze the impact of improper solid waste management on the public health of Addis Ababa City. The specific tasks to accomplish the objective of the study include:

a) To analyze the trends of solid waste management at the stage of generation, collection, and disposal at the dump site.
b) To evaluate trends of air pollution status of Addis Ababa city and Koshe open dump site of the city.
c) To determine the water pollution level due to the improper solid Waste management that affects the surrounding river water.
d) To analyze the health prevalence of the communities living around the Koshe open dump site.
e) To develop possible policy measures to minimize the impact of improper Solid Waste management affecting public health.

1.4 Dissertation Organization

Chapter 1 describes the research's background, problem statement, and objectives. It’s the total dissertation “in a nutshell.” Chapter 1 is followed by an extensive literature review presented in Chapter 2. The rest of the dissertation is divided into four major papers.

The first paper describes trends in solid waste management in Addis Ababa City. The second paper focuses on the detailed trend analysis of the air quality of Addis Ababa City and Koshe open dump sites. The third paper focuses on determining the water pollution due to improper solid waste disposal that affects the surrounding river water with an extensive parametric study. The final and fourth papers cover a detailed analysis of the health prevalence of the communities living around the Koshe open dump site due to improper solid waste management. A summary and conclusion follow these papers.

CHAPTER TWO

Literature review

2.1 Introduction

Municipal solid waste management (MSWM) is a multidisciplinary activity that includes administrative activities and solid waste management practices such as the control of waste generation, storage, collection, recycling and transport, processing, and disposal of solid waste (Rada et al. 2013).

Its overall goal is to reduce and eliminate the adverse impacts of waste on human health and the environment and to support economic development and quality of life (USEPA 2020). Hence, effective MSWM plays a significant role in improving the quality of the environment, human health, and socioeconomic activities of local communities. However, according to the United Nations Environment Program (UNEP 2020).

Municipal Solid Waste (MSW) poses a threat to public health and the environment if it is not safely managed through separation, collection, transfer, treatment, and disposal or recycling and reuse. The World Health Organization (WHO) has highlighted the risks associated with the improper disposal of solid waste with respect to soil, water, and air pollution and the associated health effects for populations surrounding the involved areas (WHO, 2015).

Effective waste management is essential for public health and maintaining a healthy, safe, and sustainable environment. If it is not managed correctly, it can pose serious health and environmental problems and cause water and air pollution. Due to the lack of waste management services in many African cities, the burning of waste is frequent. This is a significant contributor to high levels of air pollution. The present chapter provides a comprehensive analysis of the literature that addresses the problem associated with improper solid waste management in the public health of Addis Ababa city.

2.2 Background

Uncontrolled dumping of waste in African cities has the potential to cause significant direct and indirect impacts on communities and receiving environments (Jerie 2016). Residents, particularly those living adjacent to dumpsites, are at risk from the improper disposal of waste, owing to the potential of the waste to contaminate water and food sources, land, air, and vegetation (Kimani 2012).

As a result of uncontrolled municipal solid waste incineration, many pollutant particles, such as Particulate Matters (PM), SO2, CO2, CO, furans, and dioxins, are released into the environment leading to higher air pollution. Exposure to these pollutants may significantly negatively impact the physical and mental health of residents in the vicinity (Roberts and Chen 2006; Silverman and Ito 2010).

Moreover, uncontrolled leachate leaks from landfills drastically increase the concentration of Heavy metals, which can easily enter the water and discharge wastewater into rivers, groundwater, lakes, and streams. The pollution of water by heavy metals like Zinc (Zn), Copper (Cu), Lead (Pb), Chromium (Cr), Mercury (Hg), and Nickel (Ni) brought risks that cause various impacts on the natural environment such as humans, animals, soils, and plants. Literature has revealed that heavy metals aggregate in the water and represent a hazard to human well-being, and some are cancer-causing (Goel 2006).

Various techniques have been reported in the literature to understand the impacts of air pollution and water pollution on public health due to improper solid waste management practices in urban areas of developing countries. By reducing water and air pollution levels, which are the most significant environmental risks to health, governments can reduce the burden of disease from stroke, heart disease, lung cancer, and both chronic and acute respiratory diseases, including asthma (The WHO Air Quality Guidelines, 2021).

This study aims to critically analyze and evaluate the adverse impact of improper solid waste management in African cities that affects public health and communities living in urban areas.

2.3 Municipal Solid Waste Management

Municipal Solid Waste (MSW) can be defined as all refuse, garbage, sludge from a waste treatment plant, water supply, air pollution contrail facility, and other discarded and abounded materials such as solid, semisolid, liquid, or any contained gaseous materials resulting from commercial, industrial, mining, and agricultural operations (Badi and Kridish, 2020).

Moreover, Solid Waste Management (SWM) broadly refers to the material flow stream of waste from generation to ultimate disposal and comprises storage, collection, transportation/transfer, processing (reuse/recycling/composting), and disposal. However, inadequate SWM has resulted in the accumulation of solid waste on open lands, in drains, and the living areas of many people (Ferronato,2019). According to the World Bank, the world generates 2.01 billion MSW annually, with at least 33% of that conservatively not managed in the safest environmental manner. Likewise, waste is generated per person per day worldwide is an average of 0.74 kilograms but ranges from 0.11 to 4.54 kilograms (World Bank, 2020).

Municipal solid waste management has become very vital issue facing both developed and developing nations, and the rate of waste generation has continued to increase due to lifestyle choices, population, technological advancement, and consumption, which have necessitated the need to address the concern (Asase et al., 2009). Municipal solid waste management, also often called municipal reliable waste treatment, is defined by (Ezechi et al., 2017) as the process of collecting, storing, treating, and disposal of municipal solid waste in a way that can be harmless to humans, animals, plans, economy and environment in general. According to (Kaza et al., 2018, Municipal Solid Waste (MSW) is defined as any material from residential, commercial, and institutional activities which is discarded. It is important to note that industrial, medical, hazardous, electronic, construction, and demolition wastes belong to other categories.

2.4 The Impact of Improper Solid Waste Management

Waste affects people and public health differentially; poor waste management involves the poor more than the wealthy. Poor people are more likely to live near garbage, and they are also more likely to be waste workers whose occupation necessarily involves exposure. Solid waste workers tend to have higher injury rates and higher infection rates, as well as higher occupational hazard rates than the baseline population (UN-Habitat, 2010).

Different research findings have analyzed the health effects focusing on people living nearby landfills and incinerators (Mattiello et al.,2013; Ashworth et al., 2014) and gathered data focusing on waste incineration and adverse birth outcomes. (Ncube et al., 2017) considered epidemiological studies related to municipal solid waste management, assembling the results based on the health risk (e.g., cancer, birth weight, congenital malformations, respiratory diseases), but this made a comparison among MSW practices difficult.

A further systematic review recently published (Tait et al., 2020) focused on waste incinerators' health impact, considering studies until 2017. In many cases, the authors suggested that MSW management practices can pose some adverse health effects for the nearby population. However, the current evidence often lacked statistical power, highlighting the need for further investigations. At the same time, with a moderate level of confidence, some authors derived effects from old landfills and incinerators, such as an increased risk of congenital malformation within 2 km of landfills and cancer within 3 km of incinerators (Porta et al., 2009).

2.4.1 The Health Impact of Improper Solid Waste Management

Public Health Protection Proclamation No. 200/2000: Article 12 states that "any person shall collect waste at an especially designated place and in a manner, which does not affect the health of the society" **(**FDRE, Public Health Proclamation, 2000)**.** It prohibits the disposal of solids, liquids, or any other waste in a manner that affects the environment and public health. This proclamation also indicates that any waste generated from hospitals should be handled through disposal procedures that meet public health and environmental standards.

In several community health surveys, a wide range of health problems like skin and blood infection, malaria, diarrhea, cholera, and typhoid resulting from direct contact with waste, irritation of the nose, eye infection resulting from exposure to infected dust, respiratory disease (coughing, asthma, tuberculosis,) resulting from exposure to dumpsite, intestinal infection that are transmitted by flies feeding on the waste, cancers resulting from exposure to dust and hazardous waste have been discovered.

The UNEPA (2019) states that wastes that are not adequately managed, especially solid wastes from households and the community, is a severe health hazard and could spread. The report further states that wet waste that decomposes and releases a foul odor affects the people settled next to the dumpsite, which clearly shows that the dumpsites have severe effects on people settled around or next to them (The UNEPA, 2019)

The population residing and working near solid waste processing and disposal facilities are exposed to public health risks. This is due to the emission of toxic gases and air pollutants such as landfill gas containing methane, carbon dioxide, hydrogen sulfide, and other contaminants, including particulate matter or contaminated soil and water. (Mataloni et al.,2016). In addition, solid waste dumping areas become sources of contamination because of the incubation and proliferation of flies, mosquitoes, and rodents. (Mahler et al., 2016) Apart from that, the practice of open burning results in many harmful public health and environmental effects.

2.4.2 Environmental Impact of Improper Solid Waste Management

The environmental impact of improper solid waste management has direct relation and the basis for the health impact of improper solid waste affecting negatively the surrounding urban community.

Municipal solid waste management disposal is one of the major environmental challenges for all societies (Gallardo et al., 2014) and consists of a multidisciplinary activity, which includes generation, separation, storage, collection, transfer, transport, processing, recovery, and disposal of MSW (Zelenović Vasiljević et al., 2012). Proper MSWM is a major challenge for developing countries (Henry et al., 2006; Saikia and Nath, 2015), where urban agglomerations present challenges for governance, but also opens opportunities for sustainable solutions (Seto et al., 2010; Rada et al., 2013).

Among diverse kinds of environmental degradation caused by humans, solid waste disposal is one of the most impactful, because Municipal solid waste is retained in the same place where it is deposited, even though the waste undergoes chemical and physical transformations over time (Nascimento et al., 2015; Chonattu et al., 2016). Municipal solid waste disposal has a potential to affect the four main spheres of the environment directly and indirectly, which are atmosphere, hydrosphere, lithosphere, and ultimately biosphere (Butt et al., 2016).

The increasing generation and improper Municipal solid waste disposal cause local environmental impacts, such as contamination of soil and water sources, as well as cause for public health impacts (Ma and Hipel, 2016), such as the increase in dengue virus (Bhada-Tata and Hoornweg, 2016). Improper Municipal solid waste disposal can also cause global environmental impacts from emissions of carbon dioxide and methane and numerous trace organic compounds during anaerobic decomposition of the wastes (Hoornweg and Bhada-Tata, 2012; Onyanta, 2016; Zhou et al., 2016).

Another environmental impact that can be caused by improper, ineffective, or non-existing Municipal solid waste disposal is associated with flood events. Improper MSW management is an environmental problem of high relevance for all societies (Gallardo et al., 2014). The environmentally responsible MSWM must go further than an appropriated Municipal solid waste disposal and must have a sustainable point of view, changing production and consumption patterns.

Hence, solid waste’s negative impacts on the environment include water, air, and soil pollution, climate change, and adverse effects on flora and fauna (Yeheyis et al., 2013). Jilani (2007) concluded that proper management of solid waste would help cut down the amount of waste produced as well as furnish a healthy environment and fertilizer material which can be utilized to keep up soil richness and enhance dampness holding limit. Additionally, generating massive quantities of MSW and its mismanagement is a global challenge, posing environmental risks such as soil, water, and air pollution and reduced social wellbeing worldwide (Joshi and Ahmed, 2016). Despite years of globalization, landfilling is unfortunately still one of the most common old-fashioned methods that are not perfectly designed to stop contamination in soil and groundwater through toxic leachate percolation.

On a local scale, improper waste management pollutes water bodies, contaminates air and land, attracts disease vectors, and causes flooding by clogging drains. Open dumping and burning of MSW which is more common in low-income and lower-middle-income countries pollutes the soil, air, and water bodies such as groundwater, rivers, and oceans (Guisti 2009). Solid Waste releases from households, agriculture sites, animal husbandry, and industries accumulate in the MSW landfill, which, finally, affects the surface or groundwater level through leachate percolation. (Anand et al., 2021).

Environmental pollution has inherently been associated with health issues including the spread of diseases, i.e., typhoid and cholera, some of which are largely seen as waterborne diseases (Zhao et al. 2015). There are also Non-Communicable Diseases (NCDs) that are brought about due to environmental pollution, such as cancer and asthma, or several defects evident at birth among infants (Reinhart and Townsend 2018).

The significant adverse effects of environmental pollution on health-related outcomes have largely been evidenced in low-income countries, where an estimated 90% of the deaths are, in fact, caused by that type of pollution. The two most established forms of pollution in low-income countries are those of air and water. This is contrary to the economies that are rapidly developing, where the toxicity of chemicals and pesticides constitutes the main forms of environmental pollution (Xu et al. 2018).

Yang et al. (2018) identified five classes of pollutants: particulates, sulfur oxides, nitrogen oxides (NOx), hydrocarbons, and carbon monoxide (CO). In their study, they reported that in cities and centers, like Karachi and Islamabad, the leading air pollutants included carbon emissions and lead (Pb) (Yang et al. 2018). On the other hand, several types of water pollution exist, resulting in waterborne diseases (Joshi et al. 2016). Some of these waterborne diseases include typhoid, amoebiasis, and ascariasis.

Inorganic pollutants mostly include the Potentially Toxic Elements (PTEs), like mercury (Hg), lead (Pb), and cadmium (Cd). Most of these substances of concern get accumulated within supply chains, thereby largely harming the earth's living organisms (Majolagbe et al. 2017). There are, also, biological pollutants that are anthropogenic derived. The key types of biological pollutants within the environment include viruses, bacteria, and/or several forms of pathogens (Marfe and Di Stefano 2016). Potentially Toxic Elements (PTEs) are regarded as one of the most important environmental pollutants, mainly due to their non-degradability, high persistence, and toxicity (Hahladakis et al. 2013, 2016). In their simplest form, PTEs occur naturally, and they have high atomic weight and density as compared to the one that water.

2.4.3 The Impact of Improper SWM on Sustainable Development Goals (SDGs)

The principles of sustainable development were introduced within the Sustainable Development Goals (SDGs), where 17 Goals were introduced for reducing poverty, decreasing environmental pollution, and ameliorating city livability. In particular, the global waste management goals for improving sustainability at a worldwide level are to ensure, by 2020, access for all to adequate, safe, and affordable Solid Waste collection services; to stop uncontrolled dumping and open burning; to achieve sustainable and environmentally sound management of all wastes, by 2030 (Kaza et al., 2018).

The issue of solid waste management is further elaborated in SDG 3 (health lives and promotes wellbeing); SDG 6 (water and sanitation); SDG 11 (making cities inclusive, safe, resilient & sustainable); and SDG 13 (combating climate change and its impact). SDG 11 specifically has an indicator that relates to solid waste management: "percentage of solid waste regularly collected and well managed." However, in many countries in the developing world, management of solid waste is not mainstreamed, poorly funded, and has always fallen below expectation (SDG, 2015; Tata et al., 2012; Haylamicheal and Desalegne, 2012; Bassey et al., 2006). Hence the SDGs agenda advocates for reduced generation of waste, and increased reuse and recycling.

Another research study further stated in detail that solid waste is dispersed between SDGs 11, 12, and 14, and hence, SDG 11.6 (waste collection and safe management), SDG 12.5 (waste prevention, reduction, recycling, and reuse), and SDG 14.1 (marine litter) recognize the human and environmental threats posed by solid waste. However, many of these waste-related targets and indicators lack definitions, well-defined methodologies for data collection, and reliable baseline data, especially for Low- and Middle-Income Countries (Ekins et al., 2019), result in difficulty to assess progress or ensure governmental accountability (Wilson et al., 2012).

In addition to that, the elimination of open dumping is a necessary stepping stone towards Environmentally sound waste disposal, which is explicitly addressed by target 12.4: "By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water, and soil in order to minimize their adverse impacts on human health and the environment."

The first two *Global Waste Management Goals* are: (1) to ensure, by 2020, access to adequate, safe, and affordable solid waste collection services; and (2) to stop uncontrolled dumping and open burning. Goal (3) takes this one step further, by 2030, to achieve sustainable and environmentally sound management of all wastes, particularly hazardous wastes.

The remaining *Global Waste Management Goals* focus: (4) on ensuring by 2030 a substantial reduction in waste generation through prevention and the 3Rs (reduce, reuse, recycle), thereby creating green jobs; and more specifically, (5) cutting by half, per capita global food waste at the retail and consumer levels, and reducing food losses in the supply chain (Wilson et al., 2015; Latif et al. 2023).

2.5 Africa and Solid Waste Management

Africa is the world's second-largest continent after Asia, with a total surface area of 30,365,000 km2, including several islands. It is bounded by the Mediterranean Sea to the north, the Atlantic Ocean to the west, the Red Sea to the northeast, and the Indian Ocean to the east. Africa's population was estimated at 1.26 billion in 2017 (UNDESA 2017).

The management of waste in Africa is a major challenge that needs serious attention (Mwesigye *et al*. 2009, Okut-Okumu 2012, UN-Habitat 2014, Bello *et al*. 2016). Several regional waste policies and strategies have been developed to address the challenge, in addition to country-specific policies and legislation. Agenda 2063 is a 50-year strategic socio-economic transformation framework for the African continent.

Agenda 2063 Implementation Plan (2014– 2023) outlines specific goals to be achieved during the first ten years, including reference to the expected transformation of waste management (AUC 2015b). Under goal 1 of aspiration 1 (A high standard of living, quality of life, and wellbeing for all citizens), priority area 4 (Modern, affordable, and livable habitats and essential quality services), cities will be recycling at least 50 percent of the waste they generate by 2023.

The urban population in Africa has been rising steadily over time. It was estimated at 455 million in 2014 (UNDESA 2015a, 2015b) and around 472 million in 2015 (Lall *et al.* 2017) and is increasing at a rate of 3.55 percent per year (UNDESA 2015a). This population increase will inevitably mean an increased waste burden on African cities and already strained waste infrastructure (UNEP 2015).

Notably, despite disposal being the least preferred option for waste management in the waste hierarchy (Gertsakis and Lewis, 2003), it is the most prevalent practice in Africa (Waste Atlas,2016). The prevalent use of disposal for managing MSW is a concern since waste disposal tends to magnify the numerous environmental and human health challenges presented by waste and its management. Specifically, open dumps, which are the commonest disposal methods in Africa (Waste Atlas,2016), create the biggest threats to the environment and human health.

The inadequate management of MSW is one of the principal challenges for African cities achieving the ambitious sustainable development goals (SDGs). The subsequent waste hazard created plays a crucial role in slowing down the continent's progress towards sustainable development as waste management is embedded in several targets of the SDGs (UN-SDG, 2018).

To mention but a few, by 2030, it is anticipated that (1) there will be a substantial reduction in the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination; (2) there will be reduction of 'the adverse per capita environmental impact of cities including, paying particular attention to air quality and municipal and other waste management and (3) the respective governments would ensure availability and sustainable management of water and sanitation for all (UN-SDG, 2018). Accordingly, the impact of poor waste management in Africa is not limited to only the directly affected resources but also has severe implications regarding sustainable development.

The trend of ever-increasing waste quantities for disposal in African cities creates an ever-growing need for more land to dispose of the waste. For instance, the Kiteezi landfill of Uganda in Kampala occupied an area of 29 acres when it was established in 1996 but was extended by 6 acres in 2007 (Mboowa et al. 2017; Mugisa et al., 2015) as a short-term arrangement to expand the landfill lifespan for two years (Kampala City Council, 2008). However, the landfill continues to be used beyond its capacity ending up with conditions like an open dump, although it was constructed as a sanitary landfill.

Since the trend of increasing waste quantities for disposal is typical for the EAC, most waste disposal sites are similarly being used beyond their capacities. For example, the Dandora dump in Nairobi and the only municipal landfill located at Nyanza in Kigali (Isugi and Niu, 2016), which were deemed complete in 2001 and 2013, respectively, continue to be used.

Overall, the best practice for the sustainability of waste management in Africa would be the reduction of waste that is eventually disposed of; however, since there are no official transfer stations for waste in most African countries (ISWA,2017), vast amounts of recyclable waste are taken directly to the disposal sites.

Effective waste management is essential for public health and for maintaining a healthy, safe, and sustainable environment. If it is not managed correctly, it can pose serious health and environmental problems and pollute our water, soils, and air. Due to the lack of waste management services in many African cities, the burning of waste is frequent. This is a significant contributor to high levels of air pollution, although it is hard to quantify the exact impact as there are no emissions inventories for African cities. The Organization for Economic Co-operation and Development (OECD) estimates that in 2013 around 712,000 people in Africa died because of dirty air, a 36% increase from 1990 (OECD, 2016). Air pollution mainly affects Africa's urban areas.

2.5.1 Solid Waste Generation in Africa

The average per capita waste generation in Africa in 2012 was 0.78 kg per day, which is much lower than the global average of 1.24 kg per day (Scarlat *et al*. 2015). However, there are considerable spatial differences in the amount of waste generated (Figure 2.1), which range from as low as 0.09 kg per day (Ghana) to as high as 2.98 kg per day (Seychelles).

Sub-Saharan Africa is projected to be the world's fastest-growing region for waste by 2050, during which waste generation will peak (Hoornweg et al, 2013). Moreover, urbanization in Africa is poorly planned (Onibokun and Kumuyi, 1999), further limiting the efficiency of managing MSW.

The impacts of improper waste management only get worse with the increasing population, which generates more waste. Therefore, the increased rates of MSW generation in Africa are expected to translate to more significant environmental impacts in a region that is already struggling to manage its existing waste. Yet, challenges are faced at every level of the waste management chain (Mohee and Simelane, 2015).

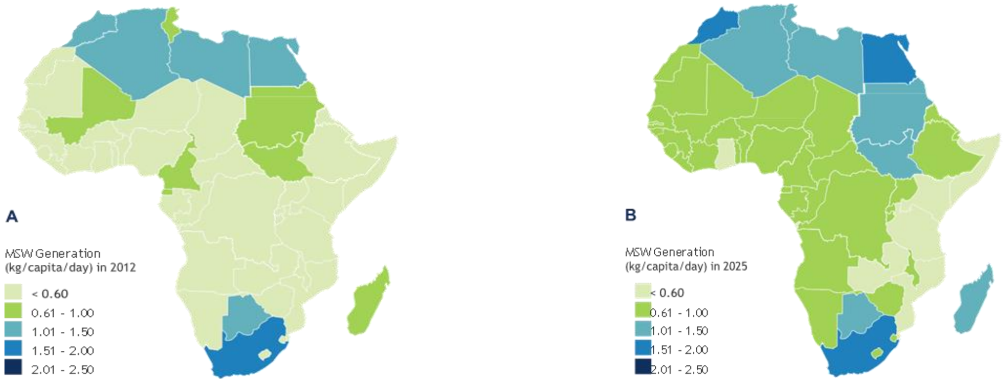


Figure 2-1 Spatial distribution of kg/Capita/day waste generation of African countries in 2012 (A) and 2025 (B) (Kawai and Tasaki (2016)

Eastern and Western Africa are the two most rapidly urbanizing sub-regions in Africa (UNEP, 2018). As the population grows and urbanization increases, so does the amount of waste. In 2015 the annual waste generation for urban Africa was 124 million tonnes. By 2040, it is expected to reach 368 million tonnes (UNEP, 2018). In other words, urban waste will increase by nearly 200%

by 2040. Several studies have also identified a correlation between a rise in income, leading to a surge in consumption, and a consequent rise in the amount of municipal solid waste generated (UNEP, 2018). In Africa, the amount of waste is therefore expected to rise as it has a growing middle class (UNEP, 2018) and the majority of African countries aim to achieve ‘middle income status’ by 2025. The waste generatation rates of Sub-Saharan Africa Region is shown in Figure 2.2

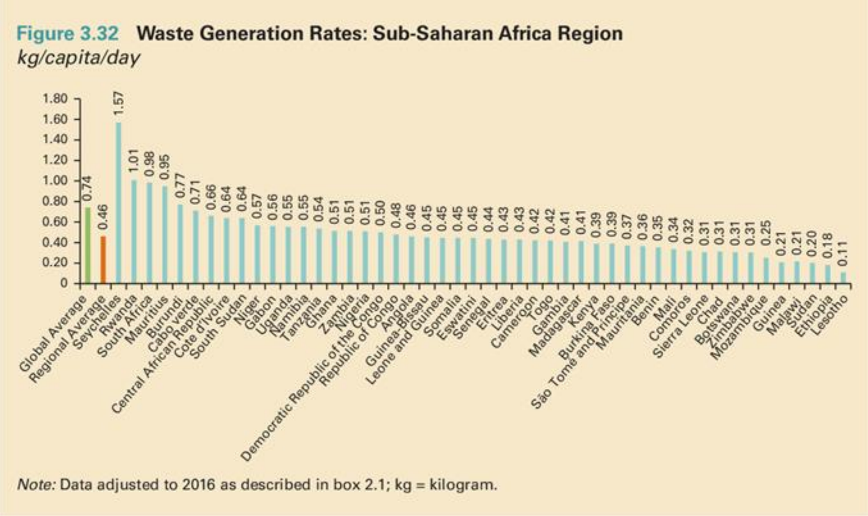


Figure 2-2 Waste Generation Rates in Sub-Saharan Region, (Adapted from Kaza et al. 2018)

Table 2-1 Estimated Urban Population and Waste Generation in Africa (UNDESA (2014, 2017a, 2017b), UNEP (2018) and Hoornweg et al. (2015)

Estimated Urban Waste in Africa	2015	2020	2025	2030	2035	2040
Population statistics for Africa	470,151,015	557,921,020	657,131,025	768,302,030	891,549,035	1,027,128,040
Waste Generation in Africa (in millions, in tonnes)	123.7	165.1	210.9	258.1	309.4	367.7
Waste Generation in Sub-Saharan Africa Kg/Cap/ Year	263	296	321	336	347	358

Currently, the amount of waste generated in Africa is less than in developed countries. The average per capita waste generation in 2012 was between 0.78 kg and 0.8 kg of solid waste per capita/day compared to the global average of 1.39 kg/capita/day (UNEP, 2018). The daily waste generation per capita is much higher in North African Countries and South Africa than in the rest of the continent (UNEP, 2018). This is primarily due to higher purchasing power and consumption in these countries.

2.5.2 Solid Waste Composition in Africa

In sub-Saharan Africa, waste composition is characterized by a high percentage of organic waste due to the preparation of fresh food, and the use of less packaging in goods that are sold (UNEP, 2018). It is estimated that 57 % of waste is organic, 13 % is plastic, 9 % paper or cardboard, 4% glass, 4% metal, and the remaining 13% is other materials (UNEP, 2018). This is very different from the waste composition in high income countries, where only 28% of the waste is organic waste and it is also above the global average of 46% organic waste.

According to Figure 2.3, waste composition in Sub-Saharan Region has been characterized by high organic waste and food waste 40%, paper and cardboard 10.4%, and plastic 8.6%. However, the changing production and consumption patterns in Africa are reflected in slow changes to the composition of waste. The share of organic waste has gone down in recent years, while the share of plastic and paper has gone up. This trend is expected to continue, as income levels are predicted to rise.

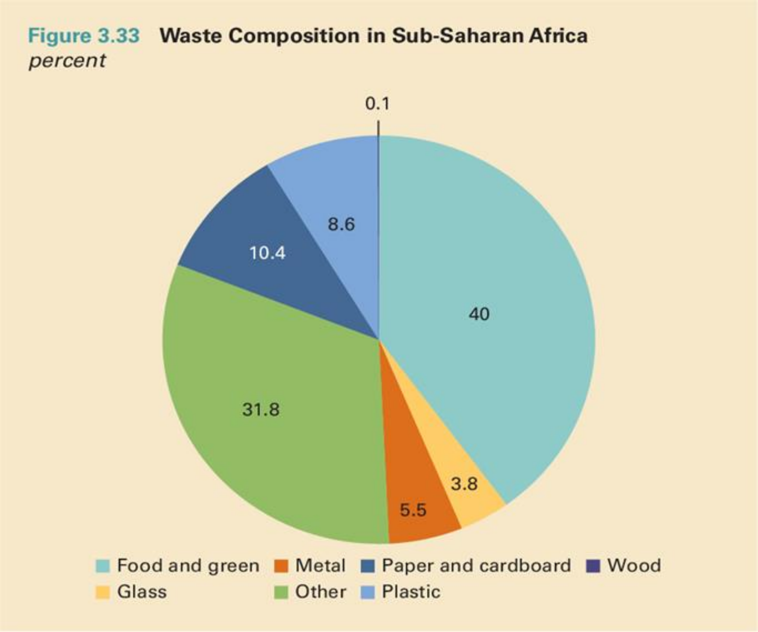


Figure 2-3 Waste composition in Sub-Saharan Region (Adapted from Kaza et al. 2018).

2.5.3 Solid Waste Collection in Africa

The total waste collected in Africa was only 55 % of the total waste generated. In sub-Saharan Africa, the collection rate is very low, with only 44% of waste generated in sub-Saharan Africa being collected. This is striking as over half of the population in Sub-Saharan Africa lives in poor areas, often in informal housing (UN-Habitat, 2016). Consequently, residents are forced to deal with the waste themselves, often leading to illegal dumping and open burning.

The collection coverage varies considerably across countries, regions, and cities and between urban and rural areas. Around 60 percent of Africa's population lives in rural areas (World Bank,2015), but there are hardly any waste management services available outside of the major cities (UNEP, 2018).

Some cities have achieved a very high collection rate. For example, in Sousse, Tunisia, and Lagos, Nigeria, waste collection coverage can be higher than 90 % (UNEP, 2018). Waste collection performance can vary significantly within the same country: for example, the city of Wa in Ghana has a collection rate of 28%, well below the continental average of 55%, while in the capital Accra, coverage is over 80%.

Between 1950 and 2015, about 8300 million tonnes (Mt) of virgin plastics were produced across the globe, generating approximately 6300 million tonnes of plastic waste, of which around 9% have been recycled, 12% incinerated, and 79% accumulated in landfill (Geyer et al. 2017). (Literature Part) Currently, plastic waste poses human and environmental issues globally and especially for African countries, which have a high proportion of mismanaged waste plastics and lack state-of-the-art recycling facilities (Jambeck et al. 2018). Inappropriate use and disposal of waste plastics may result in the release of toxic substances, which is facilitated by the open burning of waste plastics from vehicles and cables (Ionas et al. 2016).

According to Rana and Khwaja (2017), the chemicals in waste plastic do not degrade quickly in the natural environment, and more importantly, the use of plastic in product delivery services could not be banned due to its comfortability, diverse use, and less cost. For these reasons, plastic consumption in Africa in daily life will increase more than indispensable.

Table 2-2 Global Solid waste Collection rates by region by Percentage

No	**Solid waste collection rates by region**	**Percentage**
1	North America	100
2	Europe and central Asia	90
3	Latin America and the Caribbean	84
4	Middle east and north Africa	82
5	East Asia and the Pacific	71
6	South Asia	44
7	Sub-Saharan Africa	44

Source: Adapted from Kaza et al. 2018.

With waste accumulating in open areas near people's houses and in the streets, rivers, and channels or being burned in neighborhoods, there is an increase in dangerous emissions that harm people and the environment. In Africa, a lack of waste collection and disposal facilities has compelled many communities to use watercourses such as rivers and canals for waste disposal. The problem is compounded by the attitude of communities that do not responsibly participate in waste management and is further aggravated by the inability of local councilsto enforce existing waste management laws (Majale- Liyala 2011).

According to the Addis Ababa Solid Waste Management Agency AASWMA (2020b), most of the waste produced per household is food waste. Household waste is collected by Small and Micro Enterprises (SMEs). In contrast, private organizations, industries, and institutions utilize private companies for collection.

The trends of solid waste collection rates in most cities in African countries require urgent attention from the government, researchers, policymakers, and the mayor of the respective cities. For instance, the annual solid waste collection rate in selected cities in Africa compared with Addis Ababa city has been presented in Figure 2.4.

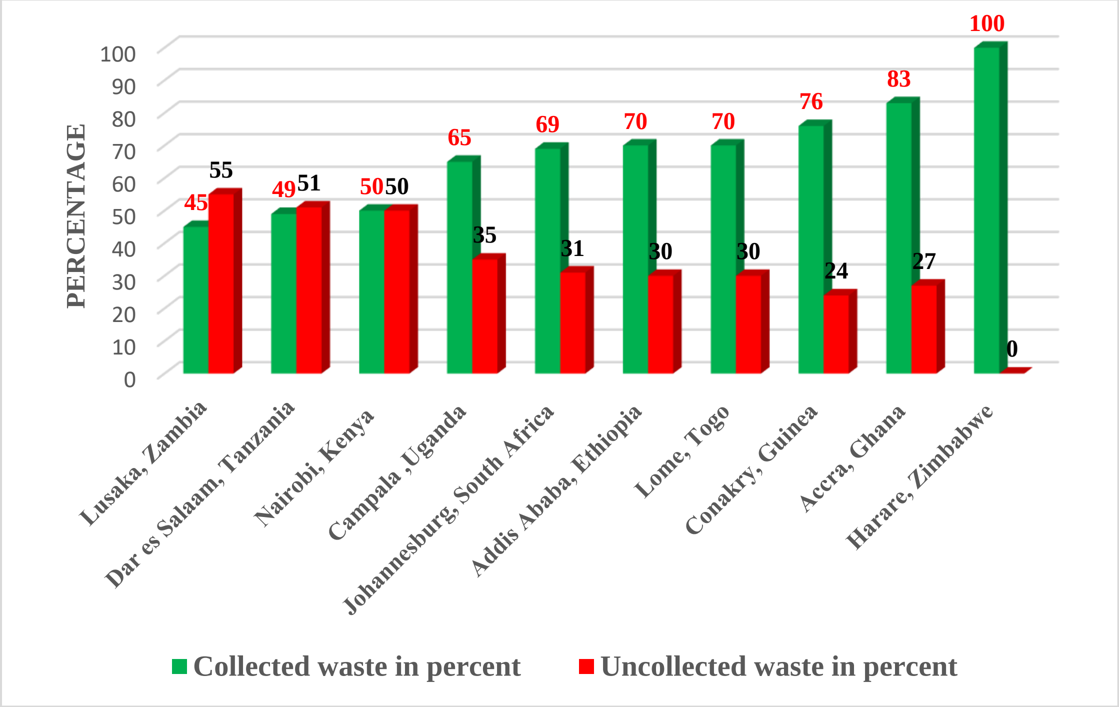


Figure 2-4 Collected and uncollected Waste in cities of African Countries (Kaza et al. 2018)

According to Figure 2.4, most of the African cities' solid waste collection coverage is very low, ranging from 45% in Lusaka, 70 % in Lome, and 76% in Conakry, except for Accra and Harare where the solid waste collection coverage ranges from 83% to 100% respectively.

Government workers collect waste from the street. Overall, waste in the formal sector is collected by workers who are very poorly paid. Additionally, a large but unknown number of people engage in informal recyclable waste collection, such as plastic and scrap metal recycling. (Karadimitriou et al., 2021) After collection, waste is transferred to way stations before final transportation to the landfill. Waste collection rates in sub–Saharan Africa cities are shown in Figure 2.5.

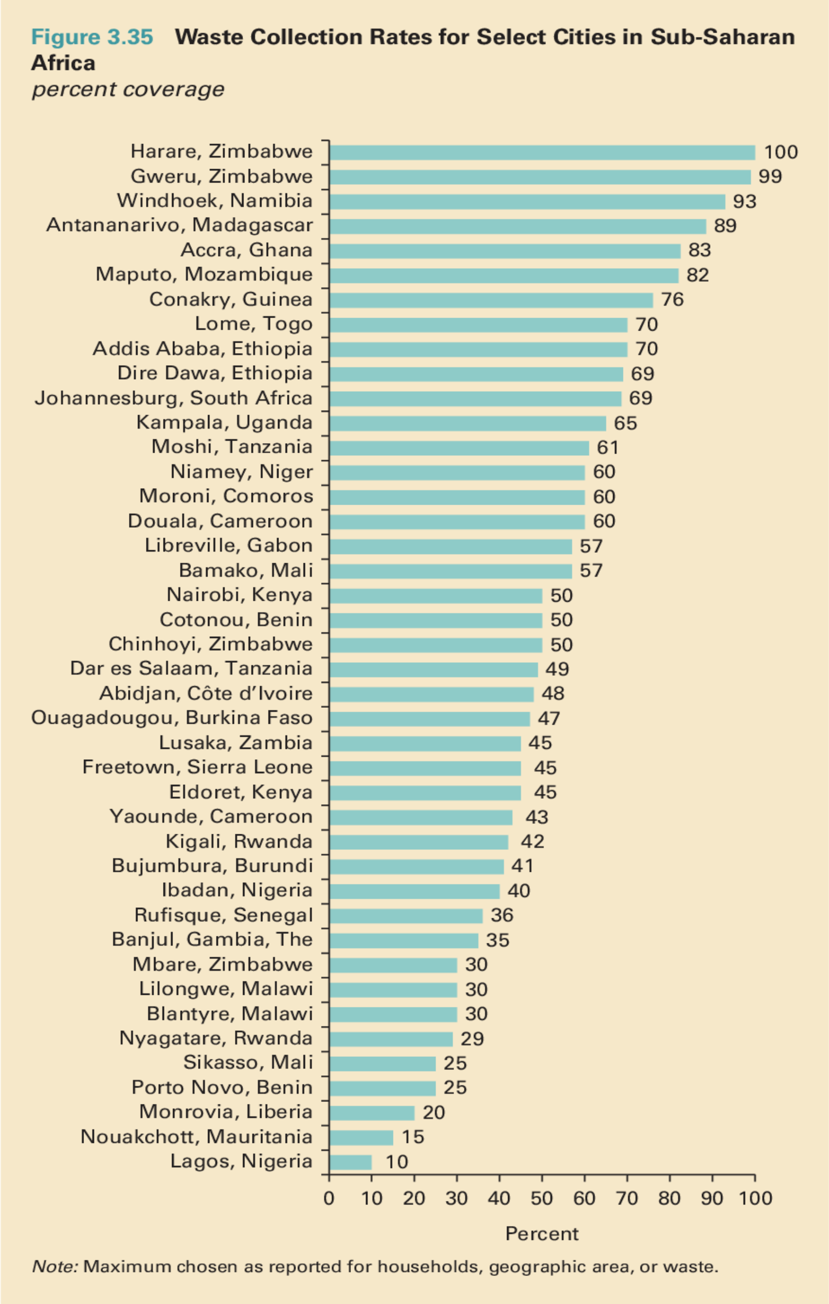


Figure 2-5 Waste collection rates in sub–Saharan Africa cities (Adapted from Kaza et al. 2018)

2.5.4 Solid Waste Recycling in Africa

The average Municipal Solid Waste recycling rate in Africa is only 4 percent, lower than the average recycling rate of most countries of the Organization for Economic Cooperation and Development (OECD), which was 30 percent in 2013 (OECD 2015a, 2015b). There are only a few formal recycling systems in sub-Saharan Africa. Different rates of recycling have been achieved in selective cities of the African countries, which in Nairobi/Kenya (24%), Moshi/Tanzania (18%), Addis Ababa/Ethiopia (10%), and Lusaka/Zambia (6%). (UN-Habitat 2010, CSIR 2011).

Concerns are that the global waste crisis will disproportionately impact the African continent. In Nigeria, the country with the continent's largest population and a fast-growing economy, annual plastic waste is about 2.5 million tonnes and with a low recycling rate of about 12 percent (Babayemi et al. 2018). By 2050, the World Bank projects a 197 percent increase in waste in Sub-Saharan Africa, with much of this being plastics (Kaza et al., 2018). Plastics and packaging have been identified as a key sector for Africa's circular economy transition (African Circular Economy Alliance 2021.

As per the report published by UNPD, the world produces around 300 million tonnes of plastic waste; only 9% of the generated plastic waste is recycled, 14% is collected for recycling, while the rest reaches the ocean annually (Plastic Recycling: An Underperforming Sector Ripe for a Remake, 2019). According to World Population Review (2019), the per capita plastic consumption in Africa in 2015 was 16kg for a population of 1.22 billion, and based on this fact, the estimated plastic consumption for the entire continent for 2015 was 19.5 million tons.

Research showed that a large proportion of East African Countries' solid wastes are unsustainably landfilled or dumped; another proportion is thrown in inappropriate places, while only a very small proportion is recycled (Lederer et al., 2017). This is mainly due to their low income, poor living standards, lack of SWM prioritization by governments, inadequate knowledge on SWM, and the effects of its improper management (Das et al., 2019).

2.5.5 Solid Waste Disposal in Africa

In Africa, open dumping is by far the most common one. Open dumping refers to the unplanned dumping of waste without the involvement of environmental protection mechanisms. Almost half of Africa’s waste is estimated to end up in (controlled and uncontrolled) open dumps. Another 30% of the waste is estimated to be disposed of in formal landfill sites, while open burning is another frequently used mechanism to get rid of waste (UNEP, 2018)

Open dumping involves indiscriminate disposal of waste with no plans for environmental protection (Johannessen and Boyer 1999). The waste in open dumps is left untreated, uncovered, and unsegregated, with no groundwater protection or leachate recovery (Mwesigye *et al.* 2012, Mohammed *et al.* 2013).

While no official data is available, uncontrolled dumping is a common mechanism to get rid of waste. In Lagos, Nigeria, there are about 5000 illegal dump sites. (Adegboye, K,2018). In Nairobi, Kenya, there are over 70 illegal dumpsites scattered throughout the city, where most private waste collectors dump collected waste (Njoroge et al. 2014). In Dar es Salaam, Tanzania, 70% of the waste is either disposed of informally or illegally dumped into waterways, fields, or burned (Palfreman, 2015). In Freetown, Sierra Leone, less than half of the total waste output is disposed of at one of the two major dump sites. Almost 127 tons remain uncollected and are dumped informally, posing a major health and safety threat to communities and the environment UN Human Rights Council, 2018). Sub-Saharan Africa and Global solid waste disposal coverage in percentages are shown in Figure 2.6.

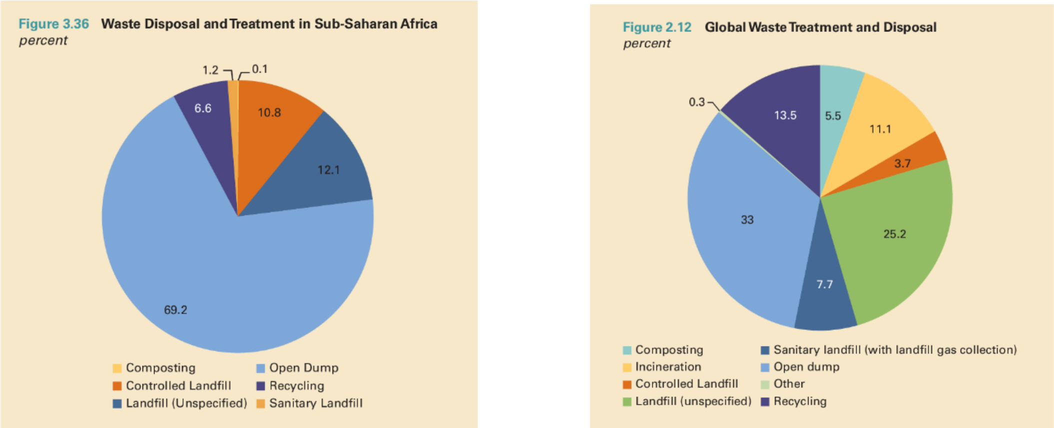


Figure 2-6 Sub-Saharan Africa and Global solid waste disposal coverage in % (Kaza et al. 2018)

2.5.6 Solid Waste Landfills in Africa

Many African cities have only one official landfill site for the whole city, which is often overflowing and a severe health and safety concern. For instance, in Abidjan, Ivory Coast, the only existing landfill site for many years was Akouedo (constructed in 1965). It badly polluted the surrounding area and is due for closure. Two new ones are being built to take its place. The first, in Kossihouen, is a privately-operated landfill site and is up and running. The second one, at Attiekoi, is a publicly operated landfill and is not yet functional. (Yapo et al., 2019).

Many countries have large numbers of illegal or informal landfills. For instance, in South Africa, out of 203 general waste landfill sites, only 524 are registered. Even those that are properly registered are generally not properly managed according to the required regulatory standard. (Madubula & Makinta, 2013). The site of the landfill can also be a problem and can generate conflict between municipalities and local communities. In many cities, it is located within the city, close to residential areas. Even when it is located outside the city, it can encroach on land that could otherwise be used for more socially productive purposes, such as farming. The Repi landfill site (also known as "Koshe") in Addis Ababa, Ethiopia, is an example of the conflict that can result from the location of landfill sites.

When this landfill site became operational in 1968, it was outside the city. Over the years, however, Addis Ababa has grown, and Repi is now located within the city. The plan was to close it and send the waste to another landfill site in Sendafa, outside Addis Ababa. Sendafa is home to the country's largest ethnic group, the Oromo, who already feel marginalized by the government (Ahmed & Fortin, 2017). In 2015 local communities protested vigorously against the location of the landfill site at Sendafa, blocking trucks from dumping waste.

The protests stemmed from the fact that local farmers had been evicted to establish the landfill. The farmers claim they were not adequately compensated, and the promised jobs from the new development have not materialized (Berhane,2016). Eventually, Repi had to be brought back into use. The continuous use of Repi has had fatal consequences. In March 2017, part of the landfill collapsed, killing 113 people. Around 500 informal waste workers are believed to work at the landfill. The waste workers and the communities around the landfill are exposed to great health risks due to the contamination of water (Environmental Justice Atlas, 2017).

The construction of a sanitary landfill for the city of Bishoftu, Ethiopia, was completed in 2013 but was not yet operational in 2016 owing to budget limitations and the lack of skilled manpower required to run the facility (Veses *et al.* 2016). One solution is to outsource landfill operations to the private sector, which can overcome municipal administrative challenges while allowing the municipality to impose strict minimum operating requirements on the private operator.

Senegal does not have a fully functional landfill site. There are four landfill sites where waste is dumped - in Saint-Louis, Sindia (near Dakar), Mbeubeuss, and Thies, but all of them face difficulties in functioning fully. The site in Saint Louis was not properly operated and has been turned into a large unregulated dumpsite. This landfill site was not completed due to a lack of resources. The Sindia site was meant to replace Mbeubeuss, an old landfill site and one of the largest open dumps in the world.

It is regarded as a significant environmental, health, and safety hazard, and the government has come under strong pressure from environmentalists to close it down. However, an estimated 3500 workers make a precarious living from salvaging, selling, and recycling material from this landfill site. The city attempted to close down Mbeubeuss in 2008, but this was strongly opposed by the site’s workers, and the site was left open (Beard and Nadia,2016; The World Bank,2017).

The Islamic Development Bank is currently supporting the development of three new landfill sites -in Tivaouane, Touba, and Kaolack. The World Bank has also lent money to the Senegalese government to improve the provision of solid waste management services, particularly in Dakar. The focus of the grant is 16 to gradually close the Mbeubeuss site and establish another treatment and disposal site. The plan is to develop this new landfill site as a public-private partnership (The World Bank, 2017). Nairobi's only legal dumpsite, Dandora, was declared full in 1996. More than 30 years later, it is still operating. Dandora is an open landfill surrounded by residential areas. The dumpsite puts the health of the people living around it at risk. According to the Ministry of Environment and Natural Resources and UNDP 2016 report, the Nairobi River, running right across the dumpsite, carries polluted water downstream, where it is used for irrigation of food products and for drinking water.

In Freetown, Sierra Leone, a 2014 assessment of the two major dumpsites showed that people living in and near the sites were exposed to diseases and contamination of their air, soil, streams, and sea. The waste is burnt without first being sorted, leading to toxins being released into the atmosphere and severe air pollution (UN Human Rights Council, 2018)

In some cities, landfill sites are managed directly by the municipality, while in other cities, private companies have been given a contract to manage the site. As the examples above illustrate, many landfill sites, whether operated by the municipality or a private company, are poorly managed, struggle to cope with the amount of waste they receive and are a constant source of health and safety hazards. The unsafe conditions of many landfills and dumps in Africa are environmental and public health damage illustrating the urgent need for a revised and integrated waste management system.

Community attitudes to landfill sites have at different times and places, resulted either in opposition to closing a particular landfill site because of the living it gives to informal waste workers or opposition to a landfill site being established because of the environmental impacts or because it will use farming land. This shows the importance of consulting workers and residents before initiating large construction projects.

Table 2-3 Methods of Municipal Solid Waste disposal in Africa (Hoornweg and Bhada-Tata (2012), Periou (2012)

No	**Methods**	**Percentage**
1	Open dumping	47
2	Sanitary landfill	29
3	Open burning	9
4	Recycling	4
5	Incinerations	2
6	Composting and others	9
7	Total	100

Proximity to open dumps has been significantly connected with the upsurge and spread of pathogenic infections, including cholera and other diseases, in various African cities (Abul 2010, Jerie 2016, Suleman *et al*. 2015).

A study of the Dandora municipal waste dumping site in Nairobi, Kenya, for example, showed high levels of heavy metals not only within the dumpsite but also in adjacent soils, well above the control sample taken from a residential area on the outskirts of Nairobi (Waithaka) and reference values in soil standards (Kimani 2007, 2012). The risks from waste disposal at Dandora are further complicated in that the Nairobi River flows close to the dumpsite, and waste from the dump ends up in the river. This creates additional potential risks to downstream communities that use this water for domestic and agricultural purposes (Kimani 2012).

Through various routes of exposure, pollutants from uncontrolled dumping can directly impact human health. A medical evaluation of children and adolescents living and schooling close to the Dandora dumpsite reported respiratory, gastrointestinal, and dermatological illnesses such as upper respiratory tract infections, chronic bronchitis, asthma, fungal infections, allergic and unspecified dermatitis (Kimani 2012). Blood samples collected from children near the Dandora dumpsite showed that half of the children examined had blood lead levels equal to or exceedingly internationally accepted toxic levels of 10 µg/dl.

A study focusing on the spatial dependency of cholera prevalence in Kumasi, Ghana, showed a direct spatial relationship between cholera prevalence and the density of refuse dumps and an inverse spatial relationship between cholera prevalence and distance to refuse dumps. A GIS-based buffer analysis showed that the minimum space for the sitting of refuse dumps from community centers is 500 meters. The study concluded that the proximity and density of open dumps play a contributory role in cholera infection in Kumasi (Osei and Duker 2008).

According to Yirgalem et al. (2011), four vegetable farms (Akaki, Goffa, Kera, and Peacock) in Addis Ababa City that were irrigated with contaminated waters exhibited increased concentrations of metals both in the soils and the vegetables grown on them. But it was noticed that different vegetables accumulate and translocate variable amounts of metals from the soil into their tissues. Without regard to bioavailability, the vegetables Ethiopian kale, Swiss chard, lettuce, and cauliflower grown in these farms showed Cd and Pb at levels that could raise health risk concerns to consumers. A landslide at Koshe landfill, Addis Ababa, Ethiopia is shown in Figure 2.7.

Figure 2-7 A landslide at Koshe landfill, Addis Ababa, Ethiopia, Africa Waste Management Outlook (2018)

2.5.7 Open Burning in Africa

Open burning of waste is widely practiced across Africa. It provides a means of reducing the volume of accumulated waste where waste collection services do not exist or managing waste in dumpsites (UNEP 2015). Typical emissions associated with open burning of waste include dioxins, polycyclic aromatic hydrocarbons, and black carbon, which are highly toxic, carcinogenic, and powerful short-lived climate pollutants respectively (UNEP 2015). Open burning is often the result of a lack of awareness of alternative disposal options, high levels of poverty, and lack of environmental regulation or enforcement (Narayana 2009, Hilburn 2015, Jerie 2016).

Families with inconsistent waste collection services in Accra, Ghana, who were forced to burn their waste as a management solution, for example, were found to be vulnerable to respiratory diseases. The burning of waste was the suspected cause of their symptoms. Children and women, the main people involved in the burning process, were found to be the most vulnerable in the community to respiratory diseases (Surjadi 1993). Open burning of agricultural waste, particularly rice straw, is a common practice in Egypt that causes a host of allergic reactions and lung infections in many residents (Safar and Labib, 2010). Furthermore, the black clouds of smoke caused by the burning process are heavily laden with greenhouse gases (GHGs). Open burning of waste and the decomposition of high volumes of organic waste in uncontrolled dumpsites generates many atmospheric pollutants. According to Hoornweg and Bhada-Tata (2012), methane from landfills represents 12 percent of total global methane emissions.

Open burning is a major source of black carbon, one of the short-lived climate pollutants, a group of pollutants that have a particularly high impact on climate change (Hansen *et al*. 2010) (Figure 2.8). Eliminating uncontrolled dumping and open burning of waste in Africa and diverting organic waste away from landfill towards alternative waste treatment technologies, such as composting and anaerobic digestion, have the potential to create significant positive benefits for Africa, including reduced GHG emissions.

Figure 2-8 Open burning of waste at dumpsite in Nairobi, Africa Waste Management Outlook (2018)

Open burning is frequently used to deal with undisposed waste, especially in areas where waste collection is non-existent. The consequences on the health of local communities are severe: for example, in Accra, Ghana, there is a high incidence of respiratory disease among the families who burn their waste due to the lack of formal waste collection services. Children and women are often the most affected, mainly responsible for household waste open burning. Open burning also severely harms the environment and future generations by increasing greenhouse gases, thus contributing to climate change, clearing land, and contributing to high levels of pollution (UNEP, 2018).

2.5.8 Waste to Energy in Africa

Waste-to-energy, a process that generates energy in the form of electricity, heat, or fuels from organic and inorganic waste, is spreading fast worldwide. Burning waste with incinerators to generate energy is a profitable business opportunity. According to recent market research, the global waste-to-energy market was valued at approximately $24 billion in 2014 and is expected to increase to $36 billion by 2020 (Market Research Store, 2016) For the African Development Bank, as well as a range of international aid agencies, waste to energy fits in well with their commitment to extend access to electricity across the continent.

In Africa, this sector is only just beginning to grow but is expected to grow fast. At the beginning of 2018, the Ethiopian capital Addis Ababa opened Africa’s first waste-to-energy plant at Addis Ababa’s only landfill, Koshe (also known as Repi). A consortium of private companies runs the plant: Cambridge Industries Limited (Singapore), China National Electric Engineering (China), and Ramboll, a Danish engineering firm.

The consortium aims to set up a series of waste-to-energy facilities in major cities across the region (Africa News, 2017). The waste-to-energy plant is expected to incinerate 1 400 tons of waste per day, which is about 80 percent of Addis Ababa’s waste and is predicted to serve 30 percent of the city’s households' electricity needs. The incineration is set up to meet European standards on air emissions (Belgium Ethiopian embassy, 2018). The waste-to-energy facility will be owned by the state power utility company Ethiopian Electric Power Corporation (EEPCo) and is expected to provide 100 skilled jobs in Addis Ababa (Environmental Justice, 2017). A gas project (methane capture and flaring) has also been constructed at Repi (Ahmed & Fortin, 2017).

2.6 Biochemicals Parameters

Aquatic organisms depend on the oxygen in water or Dissolved Oxygen (DO) for their respiratory needs. The amount of DO in a water body depends on water temperature, the quantity of sediment, the amount of oxygen taken out from the system, and the amount of oxygen put back into the water. Respiration and decaying of organisms take oxygen out of the system, and photosynthesizing organisms, aeration, and stream flow return oxygen to water. (Lakna, Panawala. 2017)

The main difference between BOD and COD is that BOD (Biochemical Oxygen Demand) is the amount of oxygen which is consumed by bacteria while decomposing organic matter under aerobic conditions, whereas COD (Chemical Oxygen Demand) is the amount of oxygen required for the chemical oxidation of total organic matter in water. (Lakna, Panawala. 2017)

BOD refers to the Biochemical Oxygen Demand, which measures the amount of Dissolved Oxygen (DO) required by aerobic organisms to break down organic material in each water sample at a given temperature and specified time. Since BOD is a biochemical process, it is not a precise quantitative test. But BOD is a widely used test method, indicating the organic quality of water. BOD is determined by incubating a sealed water sample for five days and measuring the loss of oxygen from the beginning of the test of incubation at 20 °C. BOD directly affects the DO of rivers and streams. (Lakna, Panawala. 2017)

The sources of BOD are leaves, woody debris, topsoil, animal manure, food-processing plants, wastewater treatment plants, feedlots, failing septic systems, urban stormwater runoff, and effluents from pulp and paper mills. The oxygen consumption rate depends on the temperature, pH of microorganisms, and the type of organic material in water. The greater the BOD in a particular water body, the lesser oxygen is available for the aquatic life forms in that water body. Marine life forms would be stressed, suffocate, and ultimately die due to high BOD. (Lakna, Panawala. 2017)

COD refers to the chemical oxygen demand, which measures the amount of DO required by the decomposition of organic matter and the oxidation of inorganic chemicals like ammonia and nitrite. Total Dissolved Solids (TDS) are the amount of organic and inorganic materials, such as metals, minerals, salts, and ions, dissolved in a particular volume of water; TDS is essentially a measure of anything dissolved in water that is not an H_2O molecule. (Lakna, Panawala. 2017)

The sources of total dissolved solids come from many sources, both natural and artificial. Natural sources of TDS include springs, lakes, rivers, plants, and soil. For example, when water flows underground in a natural spring, it absorbs minerals from rocks, such as calcium, magnesium, and potassium. On the other hand, the effects of human activity can also produce total dissolved solids in water. (Lakna, Panawala. 2017)

Total Dissolved Solids (TDS) are measured as a volume of water with the unit milligrams per liter (mg/L), otherwise known as parts per million (ppm). According to the EPA secondary drinking water regulations, 500 ppm is the recommended maximum amount of TDS for your drinking water. Any measurement higher than 1000 ppm is an unsafe level of TDS. If the level exceeds 2000 ppm, then a filtration system may be unable to filter TDS properly. Whereas the acceptable TDS concentrations for turfgrass irrigation range from 200 to 500 mg/L. TDS concentrations higher than 2,000 mg/L can damage turfgrasses. (Lakna, Panawala. 2017)

The acidity or basicity of irrigation water is expressed as pH (< 7.0 acidic; > 7.0 basic). The normal pH range for irrigation water is from 6.5 to 8.4. High pH's above 8.5 are often caused by high bicarbonate and carbonate concentrations, known as alkalinity. High carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution.

2.7 The Concept of Heavy Metals

The term "heavy metals" refers to any metallic element that has a relatively high density and is toxic or poisonous even at low concentrations (Lenntech, 2004). "Heavy metals" is a general collective term that applies to the group of metals and metalloids with an atomic density greater than 4 g/cm 3, or 5 times or more, greater than water (Garbarino et al., 1995, Hawkes, 1997).

Heavy metals are natural constituents of the earth's crust and are persistent environmental contaminants since they cannot be degraded or destroyed. To a small extent, they enter the body system through food, air, and water and bio-accumulate over a period of time. (Lenntech, 2004; UNEP/GPA, 2004)

Although some heavy metals are essential trace elements, most of them can be toxic to all forms of life at high concentrations due to the formation of complex compounds within the cell. Unlike organic pollutants, heavy metals cannot be biodegraded once introduced into the environment. They persist indefinitely and cause pollution of air, water, and soil. However, being a heavy metal has little to do with density but concerns chemical properties. Heavy metals include lead (Pb), cadmium (Cd), zinc (Zn), mercury (Hg), arsenic (As), silver (Ag), chromium (Cr), copper (Cu) iron (Fe), and the platinum group elements.

Trace amounts of heavy metals in water are essential to normalize metabolism. However, their higher concentration may be poisonous and pose health threats. An increasing number of heavy metals in the environment is a concern since many industries are releasing metal-containing effluents into water without or with insufficient treatment. It was observed that the main harmful contents of water pollution are heavy metals (both in chemically combined and elemental form).

Heavy metals aggregate in the human body at low concentrations; they are nonbiodegradable, which can be dangerous and may cause severe illnesses, for example, nervous system damage, cancer, and other diseases, at high concentrations (Men et al. 2018). Water containing heavy metals can cause severe harm to the central nervous system, liver, lungs, kidneys, and other fundamental organs. The long-term display may bring about harm to muscular, neurological, and physical degenerative that copy Parkinson's disease, muscular dystrophy, Alzheimer's disease, and numerous types of sclerosis. Moreover, long-term exposure to heavy metals may cause various types of cancers and allergies (Saha et al. 2017).

The biotoxin effects of heavy metals refer to the harmful effects of heavy metals on the body when consumed above the bio-recommended limits. Although individual metals exhibit specific signs of their toxicity, the following have been reported as general signs associated with Chromium, Lead, Mercury, Zinc, Nickel, and Copper poisoning: gastrointestinal (GI) disorders, diarrhea, stomatitis, tremor, hemoglobinuria causing rust–red color to stool, ataxia, paralysis, vomiting, and convulsion, depression, and pneumonia when volatile vapors and fumes are inhaled (McCluggage, 1991).

Leachate is the liquid produced when water percolates through solid waste and contains dissolved or suspended materials from various disposed materials and bio-decomposition processes. It is often a high-strength wastewater with extreme pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD), inorganic salts, and toxicity. Its composition differs over the time and space within a particular landfill, influenced by a broad spectrum of factors, namely waste composition, landfilling practice, and landfill age(Kamaruddin et al. 2017)

2.8 The Impact of Heavy Metals on Public Health

The consumption of heavy metal-contaminated food can seriously deplete some essential nutrients in the body that are further responsible for decreasing immunological defenses, disabilities associated with malnutrition, and the high prevalence of upper gastrointestinal cancer rates. (Singh and Kalamdhad, 2011) .

Moreover, the plant uptake of heavy metals from soils at high concentrations may result in a great health risk taking into consideration food-chain implications. The utilization of food crops contaminated with heavy metals is a major food chain route for human exposure. The food plants whose examination system is based on exhaustive and continuous cultivation have a great capacity for extracting elements from soils. The cultivation of such plants in contaminated soil represents a potential risk since the vegetal tissues can accumulate heavy metals (Jordao et al., 2006). Heavy metals become toxic when they are not metabolized by the body and get into the soft tissues (Sobha et al. 2007).

Chronic level ingestion of toxic metals has undesirable impacts on humans, and the associated harmful impacts become perceptible only after several years of exposure (Khan et al. 2010). The biotoxic effects of heavy metals refer to the detrimental effects of heavy metals on the body when consumed above the bio-recommended limits. These are Zinc (Zn), Copper (Cu), Lead (Pb), Chromium (Cr), Mercury (Hg), and Nickel (Ni).

Zinc (Zn) is a shiny blue–white metal that occurs in nature in the form of willemite, sphalerite, smithsonite, franklinite, zincite, and so forth. Zinc metal is used in the galvanization of steel and some alloys, in the construction of the cathodic plate in electrical batteries, and as a pigment in scanners, plastics, cosmetics, inks for printing backdrop, and so on. Zinc metal is incorporated into most single tablets and is recognized as having antioxidant characteristics that protect the muscles of the body and skin from aging (Hubicki and Koodynsk 2012).

Zinc is relatively non-toxic, especially if taken orally. However, excess amounts can cause system dysfunctions that result in impairment of growth and reproduction. The clinical signs of zinc toxicosis have been reported as vomiting, diarrhea, bloody urine, icterus (yellow mucus membrane), liver failure, kidney failure, and anemia (Duruibe et al., 2007). Zinc is a fundamental metal and is the major component of the human diet as its day-by-day prerequisite ranges from 10 to 20 mg and is necessary for carbohydrate and protein metabolism; however, a high amount of zinc dosage causes various diseases resulting in a type of dermatitis known as “zinc pox” (Neetesh and Lal 2018).

Copper (Cu) is an essential element in mammalian nutrition as a metalloenzymes component, acting as an electron donor or acceptor. Conversely, exposure to high levels of Cu can result in several adverse health effects. Exposure of humans to Cu occurs primarily from consuming food and drinking water. Acute Cu toxicity is generally associated with accidental ingestion; however, some members of the population may be more susceptible to the adverse effects of high Cu intake due to genetic predisposition or disease (Stern et al. 2007).

Excessive human intake of Cu may lead to severe mucosal irritation and corrosion, widespread capillary damage, hepatic and renal damage, and central nervous system irritation followed by depression. Severe gastrointestinal irritation and possible necrotic changes in the liver and kidney can also occur. The effects of Pb exposure vary from skin irritation to damage to the lungs, nervous system, and mucous membranes (Argun et al. 2007).

Copper is usually found in the earth’s crusts as sulfides, for example, chalcopyrite, bornite, covellite, and chalcocite. Even at low concentrations, copper is a harmful transition metal and copper-polluted water must be processed before releasing into the atmosphere. Copper is released in water from various sources such as mining, metal refining, plastic and electroplating industry, smelting operations, plating baths, paints and pigments, petroleum refining, brass corrosion, fertilizers, printed circuit board production, and wood pulp (Al-Saydeh et al. 2017).

Although copper is a fundamental metal, it can still lead to poisonous impact along with gastrointestinal tract disturbances and liver damage, for example, Wilson’s disease and cirrhosis, which are characterized by a gathering of granules of copper inside the liver. Moreover, absorption of copper causes blockage of the nasal mucosa, diarrhea, sore throat, gastritis, inflammation, corneal opacity, lung damage, conjunctivitis, ulceration, itching, nasal congestion, and nasal septum. According to the World Health Organization, the maximum amount of copper in industrial effluents should not exceed 1.3 mg/L. Similarly, the World Health Organization expressed that copper ion content in drinking water should not surpass 2.0 mg/L (Al-Saydeh et al. 2017).

Lead (Pb) is physiologically and neurologically toxic to humans. Acute Pb poisoning may result in a dysfunction in the kidney, reproduction system, liver, and brain, resulting in sickness and death (Odum et al. 2000). Pb heads the threats even at extremely low concentrations (Kazemipour et al. 2008). Other chronic effects include anemia, fatigue, gastrointestinal problems, and anoxia. Lead can cause difficulties in pregnancy, high blood pressure, muscle and joint pain. (Ogwuebgu and Muhanga, 2005). Lead is the most significant toxin of heavy metals, and the inorganic forms are absorbed through ingestion by food and water and inhalation (Ferner, 2001).

Other effects include damage to the gastrointestinal tract (GIT) and urinary tract resulting in bloody urine, neurological disorder, and can cause severe and permanent brain damage. While inorganic forms of lead typically affect the CNS, PNS, GIT, and other biosystems, organic forms predominantly affect the CNS. Lead affects children: particularly in the 2-3 years old range, by leading to the poor development of the grey matter of the brain, thereby resulting in poor intelligence quotient (IQ). (Duruibe et al. 2007).

Lead is a widespread pollutant currently ranked #2 on the United States Environmental Protection Agency’s (EPA, Washington, DC, USA) Toxic Substances and Disease Registry List of Hazardous Substances (ATSDR,2020). In addition, the FDA has classified Pb as a Class I contaminant (FDA, 2022), reflecting that Pb can potentially cause severe toxicities, especially with chronic exposure.

Lead can cause neurological, psychological, cognitive, behavioral, reproductive, developmental, immunologic, cardiovascular, and renal effects (ATSDR,2020). These effects most likely result from the ability of Pb to induce oxidative stress and mimic or antagonize the effects of essential metals such as Ca, Fe, and Zn (ATSDR,2020). The CNS effects may be especially serious or even fatal in children aged five and younger due to the damaging effects of Pb on the blood–brain barrier (Gu et al., 2020).

Lead is utilized to produce pigments, fuels, leaded glass, matches, photographic materials, explosives, and batteries (Goel 2006). Various industrial wastewater effluents, like those from ceramics, lead–acid batteries, mining, leaded gasoline, electroplating, mobile batteries, bangle industry, lead smelting, petrol-based materials, electronic waste, brass corrosion, paints, metal finishing, pesticides, and coal-based thermal power plants, release critical amounts of lead ion in water bodies (Kimbrough 2009).

Lead is a lethal and cancer-causing metal in nature. Inorganic compounds of lead affect the central nervous system, gastrovascular cavity, kidneys, reproductive system, and gastrointestinal tract. A severe impact of lead poisoning is its teratogenic impact. Lead poisoning inhibits the ability to produce hemoglobin and triggers hematological damage, anemia, kidney dysfunction, and damage to the central nervous, cardiovascular, and reproductive systems (Goel 2006). Chronic contact to lead causes extreme liver, lung, kidney, and spleen sores. As per the World Health Organization standards, its extreme level in water is 0.01 mg/L, and the most significant release limit is 0.5 mg/L (Raouf and Raheim 2016; Hubicki and Koodynsk 2012).

Chromium (Cr) is the 10th most abundant element in the earth's mantle and persists in the environment as either Cr (III) or Cr (VI). Cr (VI) is toxic to plants and animals, being a strong oxidizing agent, corrosive, soluble in alkaline and mildly acidic water, and toxic and potential carcinogens (Shaffer et al. 2001; Huang et al. 2009). The toxicity of Cr (VI) derives from its ability to diffuse through cell membranes and oxidize biological molecules carcinogens (Shaffer et al., 2001. Chromium is a steely dark gray, hard, lustrous, and among the most harmful, highly cancer-causing heavy metals. Chromium is a fundamental component for carbohydrate metabolism in small quantities, such as glucose or starch digestion and fat and protein metabolism, yet it becomes dangerous at higher concentrations.

Chromium is observed to be too toxic because of its cancer-causing nature, which are significant pollutant in soil and surface waters, it has risen enormously owing to industrialization, which impacts the geochemical cycle (Berihun 2017). Clinical indications of serious harm by chromium compounds are described as vomiting, abdominal pain, kidney damage, gastrointestinal ulceration, and bloody diarrhea (Hubicki and Koodynsk 2012).

The permissible level of chromium in groundwater is 0.02 mg/L. The upper limit of chromium in drinking water is 0.05 mg/L (Goel 2006). Adsorption strategy is a well-known encouraging method and is regarded to be highly strong financially and operationally extremely powerful to expel heavy metals from wastewater, particularly cheap and high productivity adsorbents.

Mercury (Hg) is toxic and has no known function in human biochemistry and physiology. Inorganic forms of mercury cause spontaneous abortion, congenital malformation, and gastrointestinal disorders. Poisoning by its organic forms, which include monomethyl and dimethylmercury, presents with erethism (an abnormal irritation or sensitivity of an organ or body part to stimulation), acrodynia (Pink disease, which is characterized by rash and desquamation of the hands and feet), gingivitis, stomatitis, neurological disorders, total damage to the brain and CNS and are also associated with congenital malformation. (Duruibe et al. 2007).

Mercury is toxic and has no known function in human biochemistry and physiology. Inorganic forms of mercury cause spontaneous abortion, congenital malformation, and GI disorders (like corrosive esophagitis and hematochezia). Poisoning by its organic forms, which include monomethyl and dimethyl mercury, presents with erethism (an abnormal irritation or sensitivity of an organ or body part to stimulation), acrodynia (Pink disease, which is characterized by rash and desquamation of the hands and feet), gingivitis, stomatitis, neurological disorders, total damage to the brain and CNS and are also associated with congenital malformation (Ferner, 2001; Lennetech, 2004).

Mercury or quicksilver is a silvery white liquid metal, and it is a highly toxic metal that usually occurs in the form of mercuric sulfide. Mercury is incorporated into wastewater via different sources, such as in industries like chlor-alkali plants, fluorescent lamps, household products, hospital waste (sphygmomanometers, barometers, damaged thermometers), thermal power plants, adhesives, paints, and electrical appliances. Among these, the most threatening source to fresh water and aquatic life is in chlor-alkali industry. Volcanoes are among the naturally occurring sources of mercury that produce practically 50% of the atmosphere.

The Clean Water Act established a mercury limit at a level of 0.001 mg/L or 1.0 ppb for discharge of mercury to protect human health, fish, and wildlife (Ekinci et al. 2002). The naturally occurring level of Mercury in surface water and groundwater is less than 0.5 μg/L. A small number of shallow wells and groundwaters surveyed in the Unites States were revealed to have mercury levels that surpassed the maximal impurity level of 2 ppb or 2.0 μg/L set by the US Environmental Protection Agency for drinking water (Tzanetakis et al. 2003; Okpalugo et al. 2005).

Nickel (Ni) is a comparatively less toxic metal than other heavy metals. It is commonly found in the earth's crust, water, soil, food, and air. Nickel has a wide range of applications in stainless steel, and electroplating represents 11% of the total nickel processing (Djaenudin et al. 2017). The wastewater produced from nickel processing still contains a significant amount of nickel that should be expelled before the final release into the environment (Djaenudin et al. 2017).

Nickel sources are industrial methods like plastics manufacturing, connector, pigments, galvanization, nickel-cadmium batteries, lead frame, tableware, metal finishing, electroplating, super phosphate fertilizers, paints, thermal power plants, smelting operations, burning of coal, diesel fuels and mining and metallurgical operations.

Major diseases caused by nickel are kidney and lung cancers, vomiting, nausea, gastrointestinal tract disorders, diarrhea, asthma, pulmonary fibrosis, renal edema, conjunctivitis, and skin irritation, aggregated for the most part in bones, the heart, and different organs, are caused by ingestion of nickel in higher concentration through the water. Since nickel is a poisonous element, it was suggested that it is essential for animals, plants, and human nourishment. The nickel concentration in river water is expected to be around 1 μg/ dm3. A lot of nickel is transferred from municipal wastewater to surface water, where the concentration surpasses 3000 ppm (Hubicki and Koodynsk 2012).

2.9 The Impact of Landfill Leachate on Water Pollution

Gas and leachate generation, mainly due to microbial decomposition, climatic circumstances, refuse features, and landfilling activities, are unavoidable implications of the practice of solid waste disposal in landfills. In both current and new installations, the migration of gas and leachate away from landfill limits and their release into the atmosphere poses severe environmental concerns. These issues result in fires and explosions, vegetation harm, unpleasant odors, landfill settlement, groundwater pollution, air pollution, and worldwide warming, in addition to potential health risks (Sharif et al. 2016)

The by-products of solid waste dumped in landfills have negative consequences on the environment and people living near disposal sites, including odor nuisance, breathing problems, impacts of flies and mosquitoes, water contamination, issues due to illegal burning, and health-related problems, during rainfall, the dumped solid wastes receivers' water and the by-products of its decomposition move into the water through the waste deposition. The liquid containing innumerable organic and inorganic compounds is called 'leachate.' This leachate accumulates at the bottom of the landfill and percolates through the soil, and reaches the groundwater (Mor et al., 2018).

The impact of landfill leachate on the surface and groundwater has given rise to several studies in recent years and gained major importance due to the drastic increase in population (Saarela, 2016). A dump is considered an opening in the ground that is used for burying trash (Gavrilescu et al., 2015). On the other hand, a landfill is seen as a structure properly designed and built into or on the top of the ground. It is through a landfill that the necessary isolation of waste from the surrounding occurs. A controlled landfill ensures that waste is buried in an engineered manner, isolated from the ground water, while mostly maintaining the waste in a dry form (Indelicato et al. 2017b).

A landfill is an engineered pit, mainly designed for receiving compacted solid waste and equipped with a specific covering to dispose of the waste. There is a lining at the bottom of the landfill to ensure that the waste does not pollute underground water. The design of landfills is such that they accept concentrated wastes in compacted layers to lower the volume.

Waste landfills have also been associated with air pollution across the world. For instance, it is projected that about two-thirds of landfills are made of organic materials that are biodegradable. The decomposition of these materials results in the release of CH4 gas (Babayemi et al. 2016). This CH4 gas helps in trapping heat in the atmosphere since it is regarded as GHG. The leachate conveys a significant pollution load that mainly consists of toxic metals, organic matter, and a significant community of pathogenic organisms: it causes organic, bacteriological, and toxic metal pollution of soil, surface water, and groundwater by leaching and ground infiltration.

In addition, the operations carried out at the landfills have been associated with contamination of the underground water sources through the produced landfill leachate. This occurs particularly when the liners within the landfills are not as adequate as required. There are also odors coming from landfills that pollute the air, especially for those living in nearby areas. Other pollutants associated with landfills include dust, liter, and rodents (Ilankoon et al. 2018).

Furthermore, Rezapour et al. (2018) found that uncontrolled leaks of leachate from landfills drastically increased the concentration of various PTEs in the soil, which interacted with the crops grown there. They reported that a few metals were found in moderate quantities, and this study illustrates the extent of landfilling-generated pollution. The PTEs could interact with the soil system and enter the food chain, thus causing harmful effects on the human population (Rezapour et al. 2018).

According to Hossain et al. (2014), landfill pollution is traditionally classified into several aspects. Maybe the most common categories are those that deal with the receiving air (emissions), water (effluents), and soil (dumps and disposals). Conte et al. (2018) examined the influence of landfills on air pollution with reference to Italy. It was found that landfills result in air, land, and water pollution to a large degree (Conte et al., 2018).

Table 2-4 Literature review on trends of heavy metals concentration from selective African open dumping sites from 2011-2018.

Open dumping site	Source	Age of the sites	Pb (Mg/lt)	Ni (Mg/lt)	Cr (Mg/lt)	Zn (Mg/lt)
Addis Ababa Waste Disposal Site (Ethiopia)	Beyene and Banerjee (2011)	47 years	0.1714	0.1437	0.86091	0.15
Addis Ababa Waste Disposal Site (Ethiopia)	Beyene and Banerjee (2011)	47 years	0.04532	0.1258	0.21928	0.23
Addis Ababa Waste Disposal Site (Ethiopia)	Beyene and Banerjee (2011)	47 years	0.420	0.3009	0.6244	0.52
Lapite dumpsite – Ibadan (Nigeria)	Oketola and Akpotu (2015)	50 years	0.13	0.19	-	1.61
Olusosun dumpsite-Lagos (Nigeria)	Oketola and Akpotu (2015)	47 years	2.2	0.39	-	11.8
Staoueli’s landfill, Algiers (Algeria)	Azzouz et al. (2018)	8 years	0.005	-	-	0.017
Jebel Chakir landfill, Tunis (Algeria)	El Ouaer et al. (2017)	15 years	0.48	0.3	0.92	0.47
Permissible limit		-	0.010	0.020	0.050	3.000

Table 2-5 Literature review on trends for COD and BOD Concentration from selective African open dumping sites from 2011-2018.

Open dumping site	Source	Age of the site	COD (Mg/lt	BOD5 (Mg/lt
Rephi, Addis Ababa (Ethiopia)	Woldeyohans et al. (2014)	50 years	6581.54	684
Rephi, Addis Ababa (Ethiopia)	Woldeyohans et al. (2014)	50 years	7845	720
Lapite dumpsite – Ibadan (Nigeria)	Oketola and Akpotu (2015)	50 years	3520	1910
Olusosun dumpsite-Lagos (Nigeria)	Oketola and Akpotu (2015)	47 years	8530	2620
Staoueli’s landfill, Algiers (Nigeria)	Azzouz et al. (2018)	8 years	10,500	5500
Jebel Chakir landfill, Tunis (Tunisia)	El Ouaer et al. (2017)	15 years	23,926	2841
Permissible limit (WHO)	-	-	250-500	500

2.10 Existing Literature on Landfill Exposure

The WHO definition of landfill exposure defines exposure as within a 2 km radius of the landfill (WHO, 2016). The distance of 1 to 2 km is conceptually supported by the WHO definition of landfill exposure, as the transmission of chemicals and microbiological agents mainly through water and air pathways is presumed within a radius of 2 km (WHO, 2016).

Love Canal is one of the most widely acknowledged landfills located in New York. During the periods of the 1930s to the 1940s, a huge volume of toxic materials was deposited. This was followed by establishing residential houses and learning institutions around this landfill in the 1950s. As of the mid-1970s, several chemicals were detected to have leaked into the nearby streams and sewers. This has resulted in various studies being carried out to explore how this affects human health. Most of the studies carried out have revealed that landfilling has, indeed, been associated with health issues because of emissions of pollutants into the air. (Ayesha et al., 2021).

In Italy, studies have been carried out to reveal any effects associated with living closer to areas where there is landfilling. It was revealed that hydrogen sulfide (H2S) was associated with lung cancer and other respiratory health issues. The most affected part of the population was the children. Vrijheid (2000) reported on the health issues that are related to people living closer to landfilling. The trigger point for this study was the fact that some specific forms of cancer and defects at birth as well as low birth weight, have been linked with individuals that live closer to landfilling areas. It was shown that living closer to landfilling areas is associated with respiratory diseases like asthma. This is largely attributed to the emissions of gases in the air that affect the health outcomes of individuals (Vrijheid 2000).

Mattiello et al. (2013) sought to determine how disposing of solid waste in landfills affects health outcomes. The study systematically reviewed the available information on the subject under consideration. It was shown that the health issues linked with landfills include respiratory diseases and possible hospitalization, especially among children (Mattiello et al. 2013). Maheshwari et al. (2015) focused on landfill waste and its influence on health outcomes. The review of information showed that landfills are associated with air, water, and land pollution problems around the world.

These forms of pollution have an adverse influence on people, especially children who have weak immunity systems. Pollution of the environment through dumping of waste is associated with health issues on a long-term basis. The gases that are emitted from landfills result in environmental pollution, and they are also associated with several issues related to cancer (Maheshwari et al., 2015).

Xu et al. (2018) conducted a study to find out the correlation between air pollutants associated with land filling on the respiratory health of children living in the proximity of a particular landfill in China. They reported that CH_4, H_2S, CO_2, NH_4, and other air pollutants were released with anaerobic decomposition of waste in the MSW landfills. These gases have been associated with respiratory health challenges and specific types of cancer, e.g., lung cancer.

While the concentration of these pollutants has been published to be lower than regulatory limits, any exposure to landfill gases (LFG) such as those of H_2S and NH_4, even at lower concentrations, had a negative impact on the respiratory system and the general immunity of children living near the landfill.

Triassic et al. (2015) conducted a study on the environmental pollution from illegal waste disposal and health effects. Improper landfill management and illegal waste shipments can have adverse ecological and public health effects. Different handling and disposal operations may result in adverse effects arising in land, water, and air pollution. Insufficiently disposed or untreated waste can trigger severe health issues for communities surrounding the disposal zone. Waste leakages can contaminate soils and streams of water and cause air pollution by, i.e., emissions of Potentially toxic elements (PTEs) and POPs, thereby eventually creating health risks.

Other studies conducted by various researchers showed that there was an increased risk of malformation of babies among women who lived close to hazardous landfill sites in Washington state, and the risk increased among those living in urban areas compared to rural areas (Kuehn et al. 2007).

Giusti (2009) stated that the ways of exposure that result in health effects associated with waste landfilling are inhalation, consumption, and the food chain. He also noted that the health risks associated with individuals directly involved in the waste management system are much higher due to their proximity to the hazard and that the cases of adverse effects are higher among workers than the residents near the landfill. Moreover, he underpinned the fact that the waste management industry has the highest occupational accidents of other professions. For populations living near landfills, the risk of birth defects and cancer increases (Giusti 2009).

Sharif et al. (2016) performed a risk assessment on sediment and stream water polluted by toxic metals released by a MSW composting plant. Solid waste disposed of in landfills is generally subjected to complicated biochemical and physical procedures, producing both leachate and gaseous emissions. When leachate leaves the landfill and reaches water resources, it can lead to pollution of surface water and groundwater.

2.11 Ambient (Outdoor) Air Pollution

The lower the levels of air pollution, the better the cardiovascular and respiratory health of the population will be, both long- and short-term. In 2019, 99% of the world's population was living in places where the WHO air quality guidelines levels were not met. Outdoor air pollution is a major environmental health problem affecting everyone in low-, middle- and high-income countries. Ambient (outdoor) air pollution in both cities and rural areas was estimated to cause 4.2 million premature deaths worldwide per year in 2016; this mortality is due to exposure to fine particulate matter of 2.5 microns or less in diameter (PM2.5), which cause cardiovascular and respiratory disease, and cancers.

People living in low- and middle-income countries disproportionately experience the burden of outdoor air pollution, with 91% (of the 4.2 million premature deaths) occurring in low- and middle-income countries and a tremendous disadvantage in the WHO South-East Asia and Western Pacific regions. The latest burden estimates reflect air pollution's significant role in cardiovascular illness and death. More and more evidence demonstrating the linkages between ambient air pollution and cardiovascular disease risk is becoming available, including studies from highly polluted areas. (The WHO Air Quality Guidelines, 2021).

WHO estimates that in 2016, some 58% of outdoor air pollution-related premature deaths were due to ischaemic heart disease and stroke, while 18% were due to chronic obstructive pulmonary disease and acute lower respiratory infections, respectively, and 6% were due to lung cancer. Some deaths may be attributed to more than one risk factor at the same time. For example, both smoking and ambient air pollution affect lung cancer.

A 2013 assessment by WHO’s International Agency for Research on Cancer (IARC) concluded that outdoor air pollution is carcinogenic to humans, with the particulate matter component of air pollution most closely associated with increased cancer incidence, especially lung cancer. An association also has been observed between outdoor air pollution and increased urinary tract/bladder cancer.

Most outdoor air pollution sources are well beyond individuals' control and demand concerted action by local, national, and regional level policymakers working in sectors like transport, energy, municipal solid waste management, and urban planning. Policies and investments supporting cleaner transport, energy-efficient homes, and better municipal solid waste management would reduce key sources of outdoor air pollution. (The WHO Air Quality Guidelines, 2021). Most cities have polluted air, but the type of pollution varies from place to place. It's a simple fact: Most urban residents worldwide are breathing unhealthy pollution levels. Research suggests that NO2 exposure is linked to the aggravation of asthma symptoms and the development of asthma in children. Comparing levels of these pollutants in cities around the world reveals strikingly different geographic patterns. PM2.5 pollution tends to be highest in low- and middle-income countries, whereas NO2 levels are high across countries of all income levels. Global PM2.5 Concentration is shown in Figure 2.9.

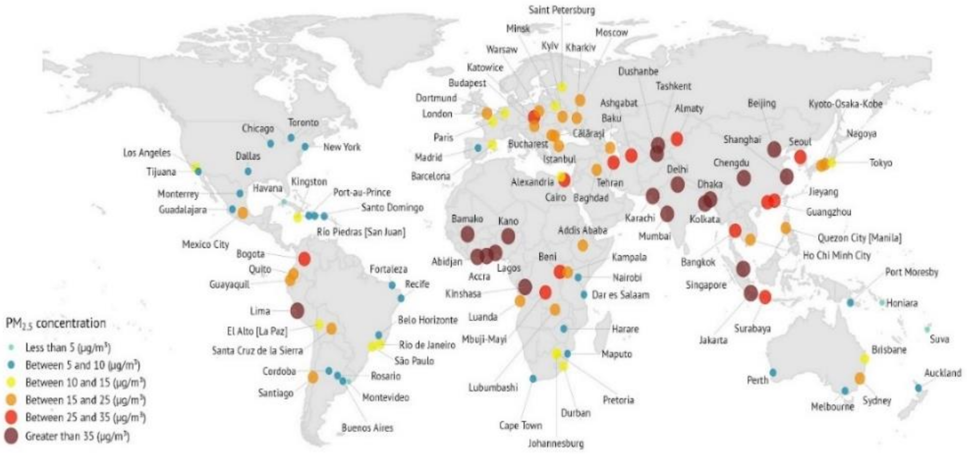


Figure 2-9 Global PM2.5 Concentration (World Health Organization 2018).

2.12 Parameters of Air Quality

The WHO Global air quality guidelines (2021) offer global guidance on thresholds and limits for key air pollutants that pose health risks (Table 2.6). The Guidelines apply worldwide to both outdoor and indoor environments. They are based on expert evaluation of current scientific evidence for particulate matter (PM2.5/10), Nitrogen dioxide (NO2), Sulfur dioxide (SO2), and Carbon monoxide (CO).

Table 2-6 Pollutants Annual mean 24-hour mean standards (WHO Air Quality Guidelines, 2021)

Pollutants	Annual mean in µg/m3	24-hour mean in µg/m3
PM 2.5	5	15
PM 10	15	45
CO	-	4
NO_2	10	25
SO_2	-	40

2.12.1 Particulate Matter (PM2.5/10)

Particulate matter (PM) is a mixture of solid and liquid particles with aerodynamic diameters less than 25 µg/m3 (PM2.5) and between 2.5 and 10 µg/m3 (PM10–2.5), which are referred to as fine and coarse particles, respectively (Wei et al. 2019). In 2015, pollution-related diseases caused an estimated 9 million premature deaths worldwide, accounting for 16% of all deaths—three times the number of deaths caused by AIDS, tuberculosis, and malaria (Münzel Daiber 2019).

PM is a standard proxy indicator for air pollution. It affects more people than any other pollutant. The significant components of PM are sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust, and water. It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air. While particles with a diameter of 10 microns or less (≤ PM10) can penetrate and lodge deep inside the lungs, the even more health-damaging particles are those with a diameter of 2.5 microns or less (≤ PM2.5). PM2.5 can penetrate the lung barrier and enter the blood system. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases and lung cancer. For instance, PM10 is a source and a marker of traffic emissions and other combustion and non-combustion sources (Adebayo et al., 2022).

Air quality measurements are typically reported in terms of daily or annual mean concentrations of PM10 particles per cubic meter of air volume (m3). Routine air quality measurements describe PM concentrations in micrograms per cubic meter (µg/m3). When sufficiently sensitive measurement tools are available, concentrations of fine particles (PM2.5 or smaller) are also reported. (The WHO Air Quality Guidelines, 2021).

Ambient PM2.5 comes from vehicle emissions, coal-burning power plants, industrial emissions, improper solid waste management like open dumping, and other sources. Because of their size – 2.5 micrograms or smaller – these tiny particles can quickly get into the lungs and, in some cases, the bloodstream and impact our health in various ways. According to Kim et al. (2015), it is stated that PM2.5 can suspend in the environment for weeks and travel up to 1000 km compared to PM10, which persists in the air only for hours and disperses about 10 km only. Detail evaluation and characteristics of fine Mode particles (PM2.5) versus coarse Mode Particles (PM10) were explained in Table 2.7.

Table 2-7 Basic evaluation properties of fine PM2.5 and coarse PM10 particles (Kim et al. (2015).

Characteristics	Fine Mode Particles (PM2.5)	1. Coarse Mode Particles (PM10)
Diameter	Less than 2.5 µm	Less than 10 µm
Composed of	Sulfate, SO2-4; nitrate, NO-3; ammonium, NH+4; hydrogen ion, H+; elemental carbon, C; organic compounds; PAHs; metals, Pb, Cd, V, Ni, Cu, Zn; particle-bound water, and biogenic organic	Resuspended dust, soil dust, street dust; coal and oily fly ash; metal oxides of Si, Al, Mg, Ti, Fe, CaCO3, NaCl, sea salt; pollen, mold spores, and plant parts.
Sources	Combustion of coal, oil, and gasoline; transformation product of NOx, SO2, and organics, including biogenic organics, e.g., terpenes; high-temperature processes; smelters and steel mills.	Resuspension of soil tracked onto roads and streets; suspension from disturbed soils, e.g., farming and mining; resuspension of industrial dust; construction, coal and oil combustion, and ocean spray.
Lifetimes	Days to weeks	Minutes to hours
Travel distance (KM)	Up to 1000	Up to 10

Long-term exposure to PM10 can result in different respiratory diseases, such as respiratory tract inflammation, lung cancer, and asthma (Guo et al., 2017; Salami, 2022).PMs are generated in dumpsites because of human actions by mechanical processes, which include sorting, tipping, and waste compaction by bulldozers, stock piling of soil, and movement of vehicles and dustcarts overpast deposited waste. PMs are also generated when materials of altered and decomposed wastes are dispersed by wind (Chalvatzaki et al., 2010). Previous works of scholars have also shown exposure to PMs leads to cardiovascular problems (Long et al., 2020). The findings from the work of Guo et al. (2017) revealed that an increase of 10 ugm/3 PM2.5 and PM10 may increase circulatory disease mortality and cardiovascular problem by 1.22% and 0.55%, respectively.

PMs have a high impact on the central nervous system of humans (Mostafa et al., 2016). In 2018, the World Health Organization (WHO) report indicated that 93% of children were exposed to PM2.5 at a concentration more than the guideline level, out of which 630 million were under the age of 5 years and 1.8 billion under 15 years.

The WHO (2006) concludes that the evidence on airborne particulate matter (PM10) and its public health impact is consistent with the adverse health effects presented by urban populations that experience exposure in both developed and developing countries. The health effects are numerous, but the ones that predominate are those related to the respiratory and cardiovascular systems.

2.12.2 Carbon Monoxide (CO)

Carbon monoxide (CO) is a pollutant that threatens human health and is widespread around the environment. Exposure to CO is related to high rates of cardiovascular disease (CVD) worldwide (Cohen et al., 2017; McRae et al., 2019). The characteristics of CO include it being colorless, tasteless, and odorless, which causes death from unwitting poisoning.

The sources of CO gas had been identified from the household items, generally heating equipment, such as portable generators, open burning of solid waste, charcoal grills, gas fires, and burning of fossil fuels like coal, oil, and natural gas. Exposure to improper installation of exhaust vents is also a source of CO poisoning. Researchers have found that low levels of CO are produced by the human body (Brazier, 2017).

2.12.3 Nitrogen Dioxide (NO_2)

The current WHO guideline value of 10 µg/m3 (annual mean) was set to protect the public from the health effects of gaseous nitrogen dioxide. NO_2 is the primary source of nitrate aerosols, which form an essential fraction of PM2.5 and, in the presence of ultraviolet light of ozone. The primary sources of anthropogenic emissions of NO_2 are combustion processes (heating, power generation, and engines in vehicles and ships).

Nitrogen dioxide comes from vehicle emissions, coal-burning power plants, industrial emissions, improper solid waste management like open dumping, and with vehicle traffic being a primary source of NO2 in urban areas. (The WHO Air Quality Guidelines, 2021). The health effect of NO2 in Epidemiological studies has shown that bronchitis symptoms in asthmatic children increase in association with long-term exposure to NO2. Reduced lung function growth is also linked to NO2 at concentrations currently measured (or observed) in Europe and North American cities. (The WHO Air Quality Guidelines, 2021).

2.12.4 Sulfur Dioxide (SO_2)

Studies indicate that some people with asthma experience changes in pulmonary function and respiratory symptoms after exposure to SO_2. Health effects are now known to be associated with much lower levels of SO_2 than previously believed. More protection is needed. Although the causality of the impact of low concentrations of SO_2 is still uncertain, reducing SO_2 concentrations is likely to decrease exposure to co-pollutants.

SO_2 is a colorless gas with a sharp odor. It is produced from the burning of fossil fuels (coal and oil) and the smelting of mineral ores that contain sulfur. The main anthropogenic source of SO2 is the burning of sulfur-containing fossil fuels for domestic heating, power generation, and motor vehicles. (The WHO Air Quality Guidelines, 2021). In many cities, NO2 is a marker of traffic pollution, while SO2 may point to power plant emissions and other fossil fuel combustion sources (Adebayo et al., 2022).

The health effects of SO_2 are indicated on the respiratory system and the lungs' functions and cause eye irritation. Inflammation of the respiratory tract causes coughing, mucus secretion, aggravation of asthma, and chronic bronchitis and makes people more prone to respiratory tract infections. Hospital admissions for cardiac disease and mortality increase on days with higher SO_2 levels. When SO_2 combines with water, it forms sulfuric acid; this is the main component of acid rain which is a cause of deforestation. (The WHO Air Quality Guidelines, 2021).

2.12.5 Methane (CH_4)

Methane, one of the most essential gases produced in landfills, contains 60 to 70% of total biogas and contributes to global warming 30 times more than carbon dioxide. Methane is a nontoxic greenhouse gas that has an explosion potential of about 35,310,000 µg/m3 (Talaiekhozani et al., 2016c). Various studies have shown that 5% of greenhouse gases are released from landfills worldwide (Broun and Sattler, 2016).

Methane is an important greenhouse gas with a significant role in global warming. As methane is lighter than air, it moves toward the surface of the landfill. For this reason, its concentration will gradually increase at ground level and can create fire and explosion risks. Methane has the potential to create fire with an intensity of 5% to 15% (Talaiekhozani et al., 2016a). Methane produced in landfills is higher than the methane produced in rice farms and wetlands. The amount of humidity in the disposal area as well as the pH level of the disposed of wastes influences the level of biogas. (Alexander et al., 2005).

Disposal of municipal solid waste which does not follow principles of environmental protection represents a serious risk to the environment and human health. Waste dumps can become dominant sources of deterioration of the air quality due to the emission of methane caused by the anaerobic decomposition of the organic waste parts. (Bogdana et al 2017). One of the first studies on greenhouse gas (GHG) emissions shows that landfills contribute 5-10 % to global methane emissions (Global Warming Potential Values, 2014) and up to 10 % to an anthropogenic carbon dioxide fraction, which implies that waste dumps are significant pollution sources (Bingemer and Crutzen 1987).

Estimating methane emissions from landfills is extremely complex because landfills cover large areas. Besides, emissions may depend on the topography, the type of waste landfilled, the variety of materials used as a covering, etc. Therefore, the methods for estimating the methane emissions from the waste dumps are different.

The amount of generated methane (CH_4) depends on the composition and age of the waste but also the conditions found in the landfill (temperature, moisture, and oxygen content). The potential to generate methane from the waste that has been disposed of in a certain year gradually decreases with time because the amount of degradable carbon is being reduced. Therefore, to achieve a more precise calculation of methane emission in a certain year, it is recommended to use the data on waste disposal for a period of 50 years at least (IPCC, 2006). Additionally, due to the complex degradation process at the landfill, the amount of methane can vary in time and space within a certain waste dump. Research in this area confirms the variability of methane emissions, Lando et al. (2017).

Although methane is represented as one of the most important GHG, allowed concentrations of methane levels in ambient air are not standardized. However, studies suggest that 1,500 mg/m3 of methane has an immediate toxic effect on people, while Dryahina (2010) discusses ambient methane levels of 30 ppm.

2.13 The Effect of Air Pollutants on Public Health

2.13.1 The Effects of PM on Health

The effects of PM on health occur at levels of exposure experienced by many people in urban and rural areas and in developed and developing countries – although exposures in many fast-developing cities today are often far higher than in developed cities of comparable size.

There are severe risks to health not only from exposure to PM but also from exposure to nitrogen dioxide (NO2) and sulfur dioxide (SO2). As with PM, concentrations are often highest, mainly in the urban areas of low- and middle-income countries. PM is a major factor in asthma morbidity and mortality. At the same time, nitrogen dioxide and sulfur dioxide also can play a role in asthma, bronchial symptoms, lung inflammation, and reduced lung function. (The WHO Air Quality Guidelines, 2021).

The health effects of SO2 are also related to the health effects of other pollutants. Previous epidemiology studies revealed exposure to SO2 causes respiratory problems, retardation in the growth of fetuses of the pregnant female gender, and premature death (Chen et al., 2007).

Such health effects of PM indicated a close, quantitative relationship between exposure to high concentrations of small particulates (PM10 and PM2.5) and increased mortality or morbidity, both daily and over time. Conversely, when small and fine particulates are reduced, related mortality will also decrease – presuming other factors remain the same. This allows policymakers to project the population health improvements that could be expected if particulate air pollution is reduced.

The widespread pollution of Particulate Matter (PM) caused by rapid industrialization and urbanization contributed to the decline of human health. Besides, PM tends to amass several harmful substances, such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), and viruses when inhaled. Inhaled heavy metal particles via the respiratory system, such as Copper (Cu), Nickel (Ni), Lead (Pb), and Cadmium (Cd), cause a range of diseases (Kim et al., 2015; Underwood, 2017).

Small particulate pollution has health impacts even at very low concentrations – indeed, no threshold has been identified below, and no damage to health is observed. Therefore, the WHO Global guideline limits aimed to achieve the lowest PM concentrations possible. (The WHO Air Quality Guidelines, 2021).

PM10 is one-fifth the diameter of human hair, while PM2.5 is a quarter of PM10 size. PM comes from various sources such as coal combustion, biomass incineration, fossil fuel burning, fugitive dust, road and construction dirt, cement, and oil (Abdullah et al., 2019). Extreme exposure to PM-associated heavy metals noticeably worsens lung infections and causes symptoms of asthma, emphysema, and lung cancer (Kuo et al., 2006).

In Malaysia, the smoke haze caused by the fires in Indonesia affected the whole country during the 2015 El Nino phenomenon. PM10 concentrations were 45.0 µg/m3 and 47.0 µg/m3 in semi-urban (Muar) and urban sites (Cheras), respectively. During the smoke-haze phenomenon, PM10 concentrations were 358 µg/m3 and 415 µg/m3 for the two sites, indicating a very unhealthy air quality. Local and transboundary smoke-haze has afflicted Malaysia for many years (Che Samsuddin et al., 2018)

2.13.2 The Effects of NO_2 Gasses on Health

NOx gasses are off-gassing post-exposure from the surroundings, such as clothing and other items, and are the greatest concern for possible sources of respiratory irritants that cause asthma. NOx gases include nitric oxide (NO), nitrous oxide (N_2O), and nitrogen dioxide (NO_2), including nitrogenous compounds associated with NO_2, which have oxidizing characteristics in solution and biological tissue (Cheng et al., 2010; Boningari & Smirniotis, 2016).

The source of NOx gases is mainly fossil fuel combustion andlso caused by natural phenomena. Transportation is a major contributor to the total NOx emission, where fuel combustion and transportation accounted for 54.6% and 40.9% of NOx emissions in the United States, respectively. Industrial processes make up 3% and other factors 1.5%. In Europe, traffic, including road traffic, contributes 46%, followed by agriculture (20%), biogenic (14%), power plants (10%), and 5% for both industry and residential fuel combustion for the total NOx emissions. Cesar et al. (2015) found that reducing 3 µg/m3 of NOx concentration leads to a 10% to 18% reduced risk of death. In contrast, a study in Brazil found that a 10 µg/m3 of NO2 rise resulted in increased hospitalizations, particularly among the elderly and children (Negrisoli & Nascimento, 2013). The health effects of NO2 include asthma, inflammatory reaction, and a decrease in lung function (Samoli et al., 2006).

2.13.3 The Effects of CO Gasses on Health

Individuals are usually prone to CO gas exposure due to a lack of awareness of CO’s chemical characteristics and high toxicity. CO gas is inhaled into the lungs through the respiratory system like oxygen (O2) and is directly transferred to the bloodstream. The transfer allows the diffusion of CO with hemoglobin (Hb), forming carboxyhemoglobin (COHb), transported, and deposited to human tissues with an affinity 250 times higher than O_2. Consequently, CO displaces O2 in the tissue, which causes reduced oxygen-carrying and storage capacity of Hb (Shah et al., 2013). The brain and heart are the main organs being affected due to the lack of O2 since they have high requirements of O2 (Rose et al. 2017).

A study over 24 hours mean was conducted In Lanzhou, China, on ambient CO gas of 0.88 mg/m3, and the result shows that 89,484 hospital outpatients were recorded to be afflicted with respiratory diseases such as asthma, bronchiectasis, and pneumonia. Female patients and the elderly were the worst affected by CO gas due to respiratory diseases (Cheng et al., 2019).

CO is a poisonous gas. It combines with hemoglobin in the blood, reducing blood's ability to carry oxygen to the body's organs. According to the California Air Resources Board (CARB, 2022), the health effects of CO are not limited to headaches, fatigue and dizziness, difficulty in breathing, and inadequate supply of oxygen to the brain, which may result in stroke and cardiovascular diseases (Manisalidis et al., 2020).

In Lanzhou, China, a significant impact on cardiovascular disease (CVD) hospitalization due to CO concentration was recorded. Every increment of 1mg/m3 in CO concentration was allied with an 11% increase in total hospitalization because of CVD. The study identified CO gas to be responsible for 62,792 CVD cases. The effects of CO and CVD cause each patient to spend about 5% of their annual salary on treatment (Cheng et al. 2019).

2.14 Impact of Air Pollution at the Global Level

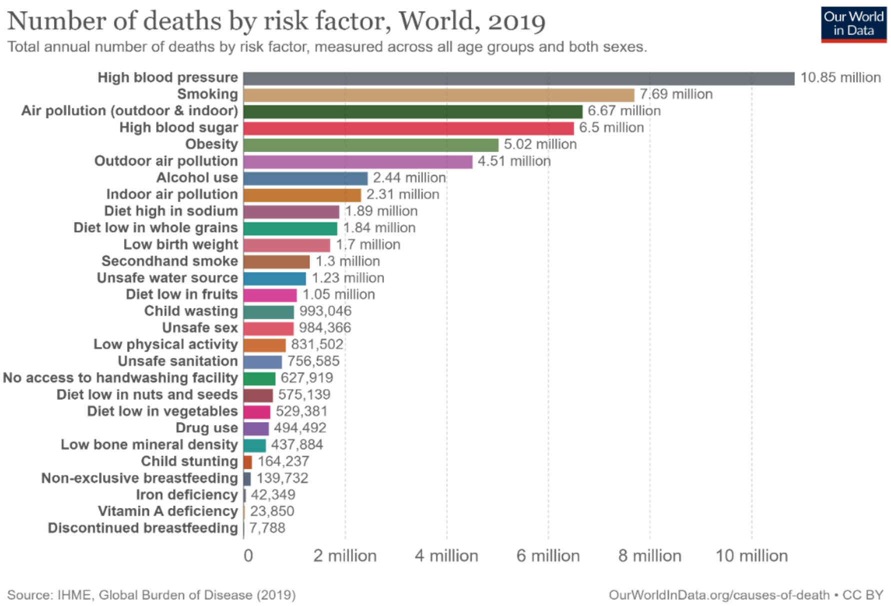
Outdoor air pollution is attributed to millions of deaths yearly and is one of the world’s most significant health and environmental problems. The Global Burden of Disease is a major global study on the causes and risk factors for death and disease published in the medical journal. (Ritchie & Roser, 2020).

According to a Global Burden of Disease study, Outdoor air pollution was attributed to an estimated 4,506,193 deaths in 2019. This means outdoor air pollution was responsible for 7.8% of global deaths. In some countries, it accounts for 10% of deaths or higher. When we compare the share of deaths attributed to outdoor air pollution over time or between countries, we are not only comparing the extent of outdoor air pollution but its severity in the context of other risk factors for death. (Ritchie & Roser, 2020).

Outdoor air pollution is a risk factor for several of the world’s leading causes of death, including stroke, heart disease, lung cancer, and respiratory diseases, such as asthma (Figures 2.10 and 2.11).

According to the Global Burden of Disease study, 4,506,193 people died prematurely because of outdoor air pollution in the latest year. (Ritchie & Roser, 2019).

Over 9,657, 245,491, and 4,506,193 people died prematurely from outdoor air pollution in Ethiopia, Africa, and the world in 2019 (Figures 2.10, 2.11, and 2.12).


Number of deaths by risk factor, World, 2019

Total annual number of deaths by risk factor, measured across all age groups and both sexes.

Source: IHME, Global Burden of Disease (2019)

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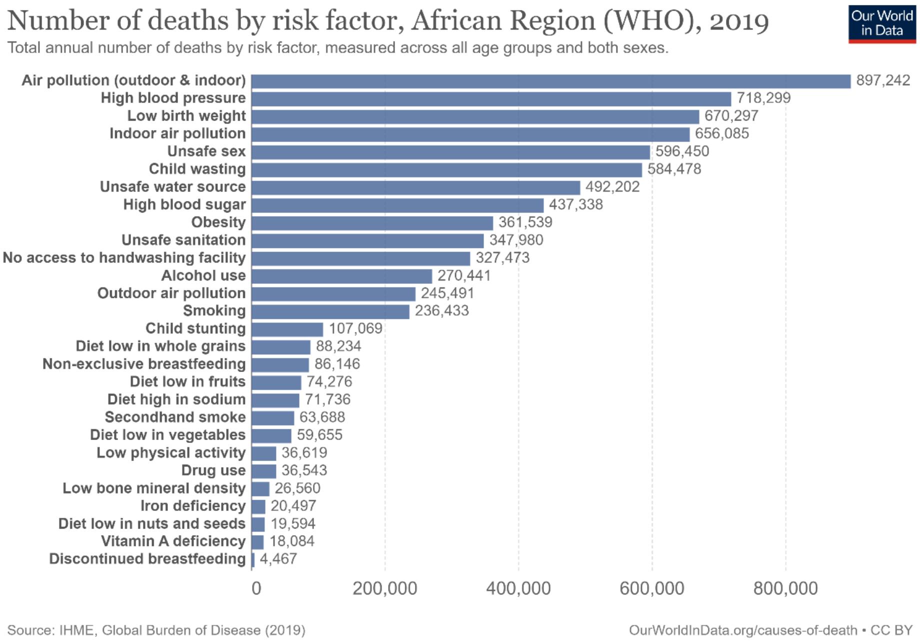
Figure 2-10 IHME, Global Burden of Deaths by risk factors (2019)


Number of deaths by risk factor, African Region (WHO), 2019

Total annual number of deaths by risk factor, measured across all age groups and both sexes.

Source: IHME, Global Burden of Disease (2019)

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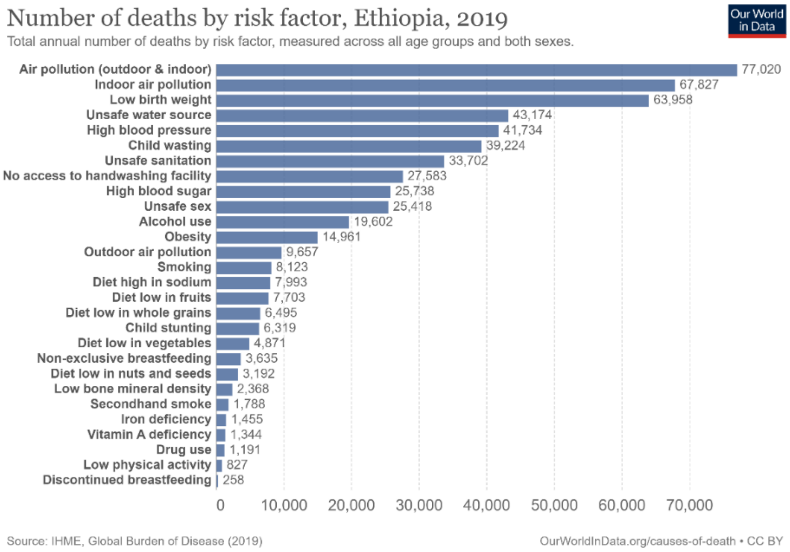
Figure 2-11 IHME, Number of deaths by risk factor, Africa, 2019


Number of deaths by risk factor, Ethiopia, 2019

Total annual number of deaths by risk factor, measured across all age groups and both sexes.

Source: IHME, Global Burden of Disease (2019)

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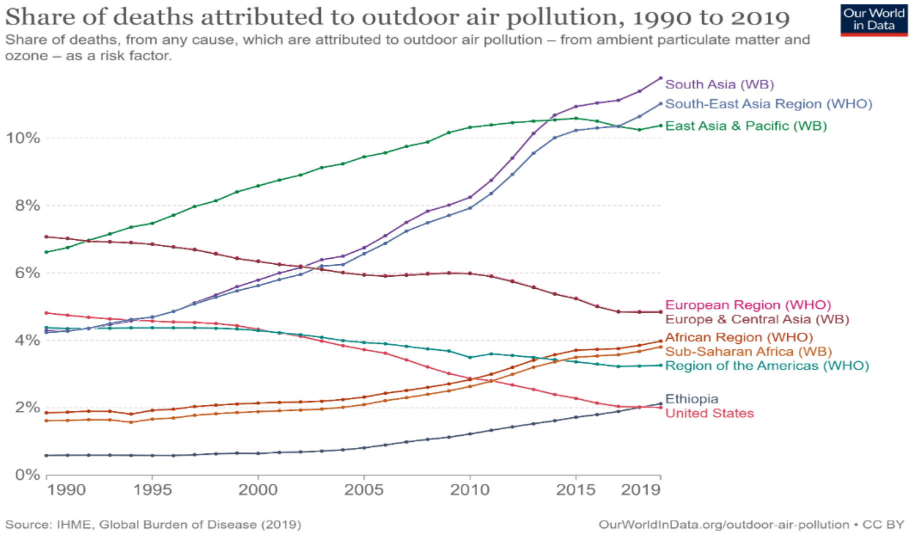
Figure 2-12 IHME, Number of deaths by risk factor, Ethiopia, 2019


Share of deaths attributed to outdoor air pollution, 1990 to 2019

Share of deaths, from any cause, which are attributed to outdoor air pollution – from ambient particulate matter and ozone – as a risk factor.

Source: IHME, Global Burden of Disease (2019)

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Figure 2-13 Share of Deaths attributed to outdoor air pollution, 2019.

The share of deaths attributed to outdoor air pollution in Ethiopia, the African Region, South Asia, Southeast Asia, and the Pacific Region during 1990-2019 has shown an increasing trend, while the share of deaths attributed to outdoor air pollution in the European region and the United States during 1990- 2019 has shown decreasing trends (Figure 2.13).

The study has identified a direct correlation between the level of air pollution and the death rate. The death rate from air pollution is higher in countries with a higher pollution level. There is also an essential regional divide: most European, North American, and Latin American countries cluster near the origin at low pollution and death rates. Nearly all countries with a high death rate or high pollution concentration (or both) are in Africa and Asia. (Ritchie & Roser, 2020).

2.14.1 Death Rates Particulate Matter Pollution

Two critical local air pollutants can have adverse health impacts: ozone and particulate matter. Death rates from particulate matter pollution tend to be higher than ozone. Here, ‘tropospheric ozone’ is ozone in the lower atmosphere, close to the surface, and stratosphere ozone is the ozone layer essential in protecting us from Ultra-violet (UV) radiation. Local ozone close to the surface is often termed ‘bad ozone’ and contrasted with the ‘good ozone’ in the ozone layer. (Ritchie & Roser, 2020).

Outdoor and indoor air pollution often combine ozone and particulate matter pollution death rates. According to global figures, global death rates from total air pollution have risen in recent decades. Most of the total decline is owed to improvements in indoor air pollution. (Ritchie & Roser, 2019). The number of deaths attributed to outdoor particulate matter pollution per 100,000 in the African region and Ethiopia has shown an increasing trend from 1990-2019 (Figure 2.14).

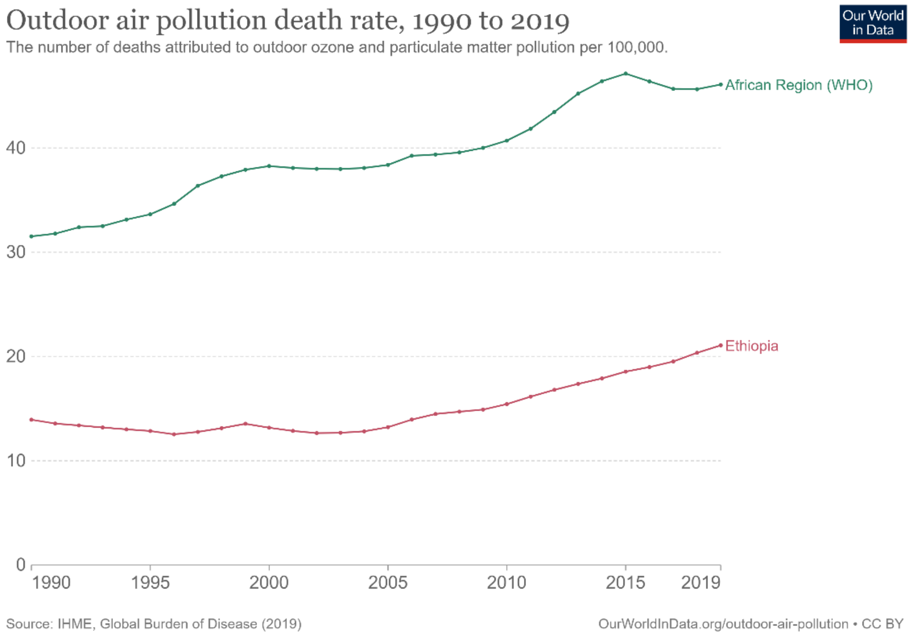


Figure 2-14 Trends of outdoor air polution death rate in Africa and Ethiopia 2019

2.14.2 Concentrations of Air Pollution

The main contributor to poor health from air pollution is particulate matter. In particular, very small particles of matter – termed ‘PM2.5‘, are particles with a size (diameter) of less than 2.5 micrometers (µm). Smaller particles tend to have more adverse health effects because they can enter airways and affect the respiratory system. (Ritchie & Roser, 2020).

PM Pollution exposure is high in many low-to-middle-income countries across Africa and Asia. According to Figure 2.15, concentrations are very high across North Africa, partly owing to drier conditions with more sand and dust sources. Their exposure can reach as high as 200µg per cubic meter. When we compare this with Sweden, where exposure levels are 5 µg/m3, which is 40 times lower. (Ritchie & Roser, 2020).

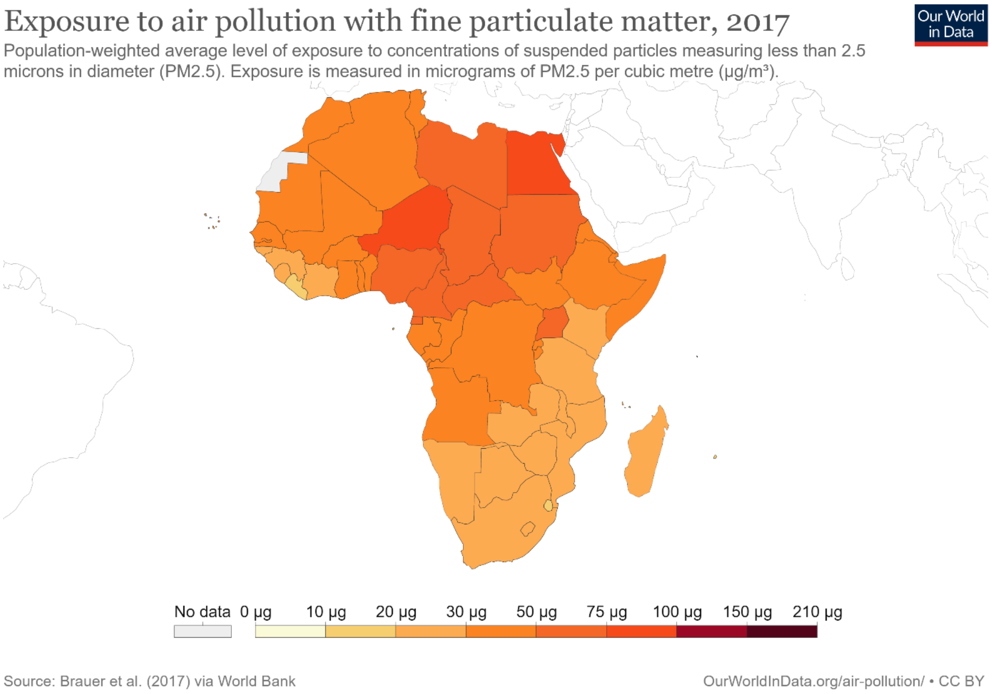


Figure 2-15 Exposure to air pollution with fine PM 2.5 in Africa, Brauer et al. (2017)

2.14.3 Link between Death Rates and Exposure to Air Pollution above WHO Limits

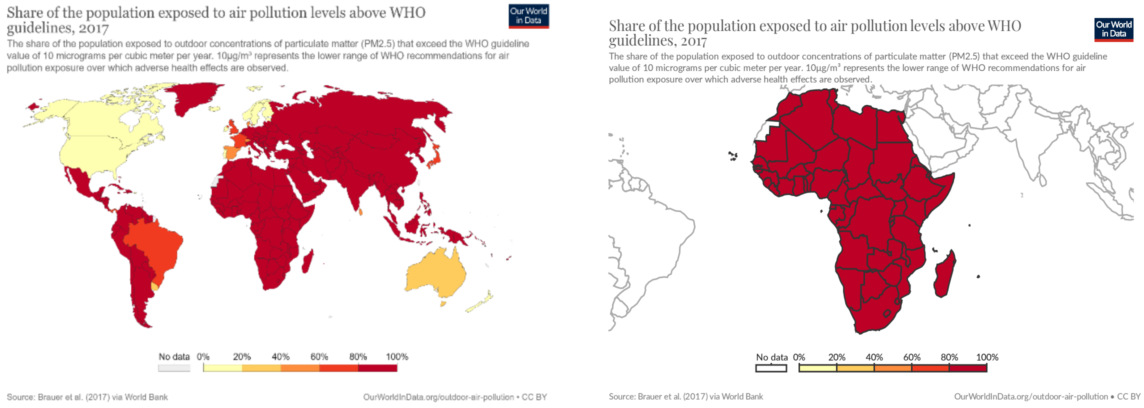
To limit the adverse health impacts of air pollution, the World Health Organization (WHO) lays out clear recommendations for exposure to air pollution – these are its so-called Air Quality Guidelines (AQG). The WHO defines these AQGs for various air pollutants based on an epidemiological assessment of the link between pollution exposure and health consequences.

The negative health consequences of air pollution increase with exposure. There is little evidence that there is a threshold below which no health impacts occur from exposure to PM2.5. In other words, there might not be a “safe limit” where we can expect the health impacts to be zero. The WHO makes clear in its guidelines that limiting exposure to their guideline value cannot guarantee zero health consequences; it will, however, greatly minimize these impacts. (Ritchie & Roser, 2020).

The WHO has set an AQG annual average concentration for PM2.5 of 10 micrograms per cubic meter (10µg/m3). This threshold presents the lower end of the range over which significant effects on survival were observed in the American Cancer Society’s study on the pollution-health relationship. (The WHO Air Quality Guidelines, 2021).

The map indicated in Figure 2.16 below shows the share of world populations exposed to PM2.5 concentrations that exceed this WHO guideline of 10µg/m3, implying that 95% of the world population has a mean annual exposure that This is not only the case for low-to-middle-income countries but also for many high-income countries. In many European countries – the UK, Germany, and France, for example – most of the population is exposed to a level of pollution exceeding this threshold.

The countries where a much lower share of the population is exposed to this level of pollution tend to have a much lower population density – they are high-income countries (where the air is typically less polluted than in low-to-middle-income countries) but also have a smaller percentage of the population living in highly-dense cities like Canada, New Zealand, Australia, Norway, and the United States. (Ritchie & Roser, 2020).


Share of the population exposed to air pollution levels above WHO guidelines, 2017

The share of the population exposed to outdoor concentrations of particulate matter (PM2.5) that exceed the WHO guideline value of 10 micrograms per cubic meter per year. 10µg/m³ represents the lower range of WHO recommendations for air pollution exposure over which adverse health effects are observed.

Source: Brauer et al. (2017) via World Bank

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Share of the population exposed to air pollution levels above WHO guidelines, 2017

The share of the population exposed to outdoor concentrations of particulate matter (PM2.5) that exceed the WHO guideline value of 10 micrograms per cubic meter per year. 10µg/m³ represents the lower range of WHO recommendations for air pollution exposure over which adverse health effects are observed.

Source: Brauer et al. (2017) via World Bank

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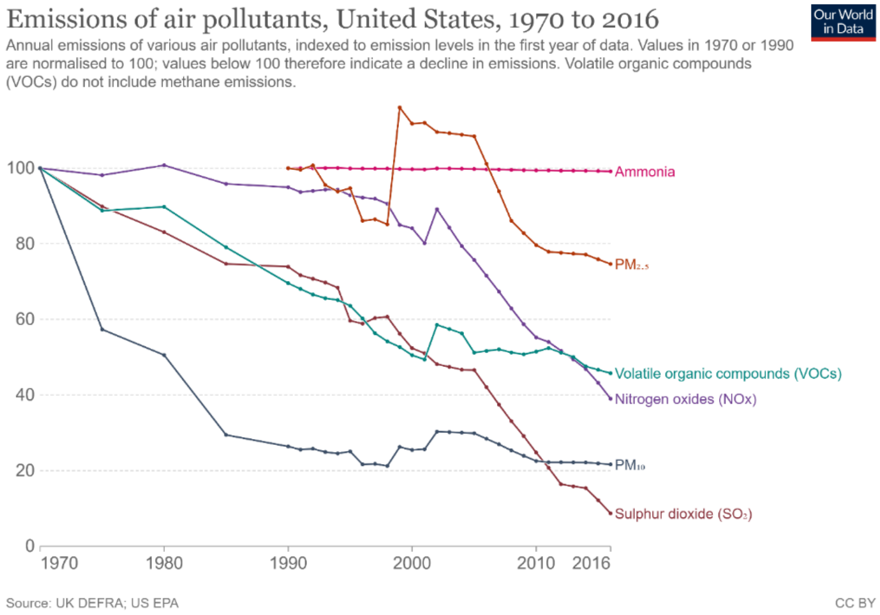
Figure 2-16 Share of population exposed to air pollution above WHO limits in the world and Africa (Brauer et al. 2017)

According to Figure 2.17 below, the US ambient air quality for particulate matter (PM10) shows the relative change in emissions of air pollutants since 1970 (where emissions in the first year of available data are given a value of 100). The US significantly reduced air pollution with Sulphur dioxide, particulate matter (PM10), nitrous oxides, and volatile organic compounds. Data for

PM2.5 did not begin until 1990, but by 2016 emissions had declined by around 25%. (Ritchie & Roser, 2020).


Emissions of air pollutants, United States, 1970 to 2016

Annual emissions of various air pollutants, indexed to emission levels in the first year of data. Values in 1970 or 1990 are normalised to 100; values below 100 therefore indicate a decline in emissions. Volatile organic compounds (VOCs) do not include methane emissions.

Source: UK DEFRA; US EPA

Figure 2-17 Emission of air pollutants in United States, US EPA (2016)

One can easily understand how pollution affects human health by determining the likelihood that a given individual will die prematurely from pollution-related illness. It seems intuitive that the health impacts of air pollution would be strongly linked to the concentration of local pollutants that the exposure.

The following figure 2.18 depicts the death rate from outdoor particulate matter pollution (on the y-axis) plotted against the population-weighted exposure to particulate matter (PM2.5) concentrations (on the x-axis) in Ethiopia.

The number of premature deaths attributed to outdoor air pollution per 100,000 population varies across different ages. Accordingly, the number of premature deaths attributed to outdoor air pollution for populations 70 and above years old per 100,000 was recorded at 197.45. The number of premature deaths attributed to outdoor air pollution for populations 50-69 years old per 100,000 was recorded at 31.9. Similarly, the number of premature deaths attributed to outdoor air pollution for those under five years old per 100,000 was recorded at 16.66. The above data revealed that the number of premature deaths attributed to outdoor air pollution is much more affecting older people and children under five (Figure 2.18).

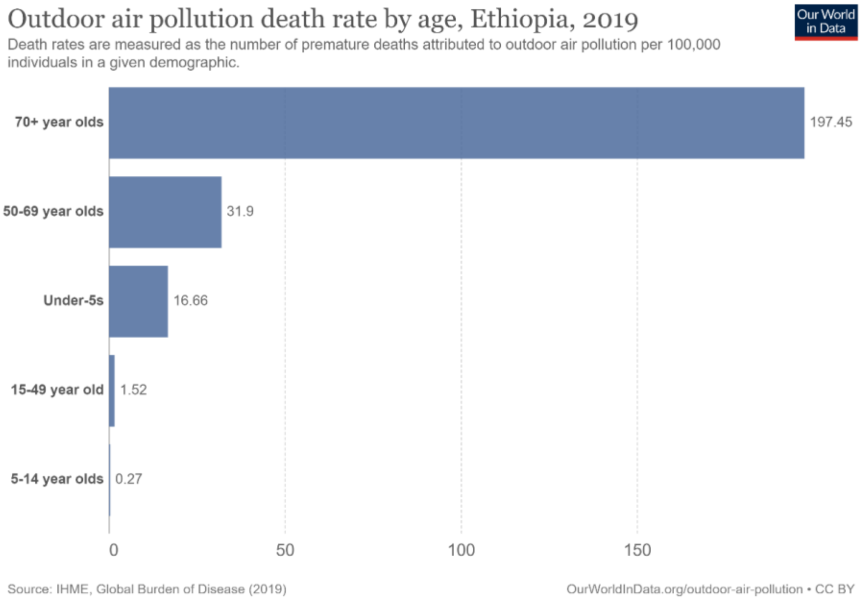


Figure 2-18 Outdoor air pollution death rates by age, Ethiopia, Global Burden of Disease (2019)

2.14.4 Global Air Pollution Monitoring Stations

A robust local air quality monitoring system is essential to managing air quality and reducing exposure. Best practice suggests an integrated measurement network comprising a reference grade ground monitoring station that can improve the accuracy of satellite measurements and integrated with lower-cost air monitors. Such an integrated measurement network would provide the ability both to collect accurate, real-time local ground-level data as well as examine wider areas through satellite measurements (WHO (2018).

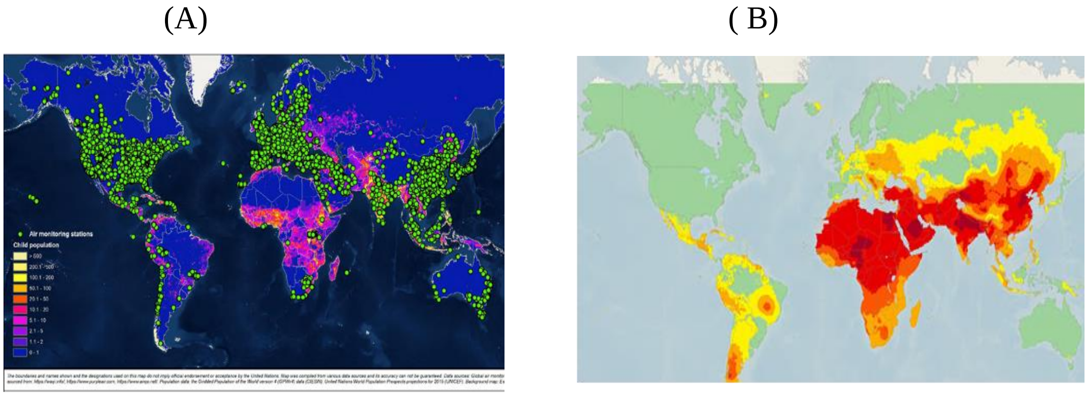


Figure 2-19 Global Air pollution (PM2.5) monitoring stations (A) and Outdoor Air Pollution (B), WHO (2018)

According to one recent study, a 10 µg/m3 increase in PM2.5 is associated with a 9 percent increase in infant mortality (Heft-Neal et al., 2018). Air pollution has been shown to greatly exacerbate the risks of pneumonia and respiratory infections (Darrow et al.2014). Children's respiratory airways are also smaller than adult airways, so infections are more likely to cause blockages than in adults. (Columbia University, 2005). Children breathe twice as fast, taking in more air per unit of body weight, compared to adults. (Agency for Toxic Substances and Disease Registry, 2016)

According to the above Figure 2.19, Modeled annual mean PM2.5 for the year 2016 in µg/m3 for global outdoor results showed that Green = <10, Yellow= 11-15, Purple =16-25, Light Red = 26-35, Red = 36-69 Dark red = >70

Air pollution can also seriously affect the health of the fetus. Pregnant mothers are advised to avoid air pollution – just as they should avoid smoking or breathing secondhand cigarette smoke (WHO,2014). Studies have shown that chronic exposure to high levels of particulate matter (PM2.5 – which consists of particulate matter with a median diameter of fewer than 2.5 microns, approximately one-thirtieth the width of an average human hair) is associated with higher rates of early foetal loss, preterm delivery – and lower birth weight. (Schwartz and Joel, 2016 WHO, 2005).

2.15 The Impact of Air pollution in Africa

Many African urban areas do not have sufficient monitoring programs to understand their air quality. Air pollution is a pressing and multi-sectoral development challenge, representing a global health, economic and social threat to cities. It is linked to planning, managing, and living in these cities. Ambient air pollution is a major environmental issue across the world (WHO 2016).

Only seven of 54 African countries have reliable, real-time air pollution monitors, says a 2019 UNICEF report. Ground-based, real-time data helps to capture fluctuations in air quality, which is important to improve public awareness and to help people to alter their behaviors to reduce air pollution and exposure to it. (Makoni, 2020)

Particulate matter (PM) air pollution is a major concern in East Africa because of its impacts on human health (Petkova et al., 2013, Pope et al., 2018). Currently, relatively few air quality monitoring sites and networks are established in East Africa, resulting in a lack of long-term air quality data to understand both air quality trends and their influences on public health.

The UNICEF report says outdoor air pollution deaths increased from 164 000 in 1990 to 258 000 in 2017, and with population, industrial, and consumption growth potentially increasing, pollution levels will subsequently increase. Projections estimate that Africa’s population will double by 2050 from 1·2 billion. More than 80% of that increase will occur in cities, leading to increased traffic and hence air pollution. (Makoni, 2020)

In an east African study, the change in pollution levels from 1974 to 2018 is illustrated. Without quality historic air pollution data, researchers used visibility to estimate the pollution increase in Addis Ababa (Ethiopia), Nairobi (Kenya), and Kampala (Uganda). The significant visibility decrease found estimated that air pollution had increased by 62% in Addis Ababa, 162% in Kampala, and 182% in Nairobi. (Makoni, 2020)

In recent years, a growing body of evidence indicates that ambient air quality in urban African locations is often poor (Petkova et al. 2013, Desouza et al. 2017, Pope et al. 2018, WHO 2018, Kalisa et al. 2019). Moreover, High rates of urbanization and population growth are affecting African air quality (Pope et al. 2018)

The main obstacle to measuring and monitoring the air pollutants in these countries is the high cost of air quality monitoring equipment, including their appropriate calibration and certification (Crilley et al., 2020, Pope et al., 2018). To this end, there are increasing efforts to make air quality monitoring networks in various African countries (Gaita et al. 2014, Desouza et al. 2017, Pope et al. 2018), but historical data is almost non-existent.

Data from the World Health Organization (WHO) shows that 9 out of 10 people breathe air containing high levels of pollutants, with low- and middle-income countries bearing the brunt of poor air quality. Air pollution is the leading environmental risk factor for premature death. In 2019 alone, air pollution globally caused 6.7 million premature deaths, corresponding to about 19 percent of the total premature deaths (IHME, 2020).

Air pollution is a growing challenge for Africa. Deaths in Africa from outdoor air pollution have increased from 164,000 in 1990 to 258,000 in 2017 – a growth of nearly 60%. According to the studies by the United Nations Department of Economic and Social Affairs, *Population Division (2017)*, Population growth, industrial growth, and consumption growth have the potential to increase pollution levels. Africa's 1.1 billion citizens will likely double by 2050; more than 80% of that increase will occur in cities.

In Africa, deaths from indoor air pollution are declining, whereas deaths from outdoor air pollution are increasing. 'Deaths from outdoor air pollution' is the absolute number of deaths by region attributed to ambient (outdoor) air pollution of Particulate Matter (PM). 'Deaths from indoor air pollution' is the annual number of premature deaths attributed to household air pollution from using solid fuels for cooking and heating. 'Solid fuels' includes cropwastes, dung, charcoal, and coal for indoor cooking.

The health impacts of air pollution are also reflected in morbidity levels, loss of income, decreased participation in the workforce, disability, and higher health care costs. Air pollution has also been known to impede cognitive development in children, with long-term implications on human capital development.

Table 2.8 below illustrates the ambient PM2.5 concentrations (µg/m3) and their impact in selected African cities. It shows that the PM2.5 concentration and its effects on health in Addis Ababa are slightly higher than those in other African capitals, namely Cotonou (Benin), Lomé (Togo), and Abidjan (Côte d'Ivoire). At the same time, it is lower than that in very polluted megacities, such as Lagos (Nigeria) and Cairo (Egypt). Reports indicate the number of premature deaths in a year per 100,000 population (urban) due to ambient air pollution was 73 in Cairo, 46 in Lagos, and 35 in Abidjan and Addis Ababa.

Table 2-8 Particulate Matter 2.5 concentration and deaths due to air pollution in selected African cities, Safe to Breathe? (Xie et al., 2021)

Cities	Ambient PM 2.5 concentration (µg/m3)	Deaths due to air pollution	Deaths/100,000 people
Dakar/Senegal	21	270	25
Cotonou/Benin	32	200	32
Lomé/ Togo	32	490	31
Abidjan/Cote devour	32	1,500	35
Addis Ababa/Ethiopia	34	1,600	35
Lagos/Nigeria	68	11,200	46
Cairo/Egypt	76	12,570	73

Urban air pollution is an increasing problem, among others, and threatens public health and local ecosystems. Growing economic activities (e.g., construction and industrial development), unregulated urban sprawl, and improper solid waste management in Addis Ababa have increased pollution emissions, traffic congestion, land and environmental deterioration, and risks to public health (Xie et al., 2021).

Ethiopia's deteriorating air quality undermines its citizens' quality of life, but the country has limited air quality monitoring and management capacity. An analysis of Addis Ababa's visibility data suggests that air quality has been declining since the 1970s, with the average air quality now approximately 1.6 times worse than in the 1970s. (ASAP East Africa, 2019).

Common drivers of ambient air pollution in a city and its surrounding areas include cooking and heating; industries; construction sites; unpaved roads; agricultural activities (especially the burning of agricultural residuals), and solid waste management, including the open burning of trash. Primary air pollutants that put pressure on airsheds include Particulate Matter (PM), Carbon monoxide (CO), Nitrogen Oxides (NOx), Sulfur Oxides (SOx), and Volatile Organic Compounds (VOC). PM is a complex pollutant and is further divided by its aerodynamic diameter in micrometers (µm); most commonly, PM2.5 with diameters less than or equal to a nominal 2.5µm and PM10 less than or equal to 10µm. PM2.5 is considered the most relevant indicator for urban air quality (Cohen et al., 2005) and a significant risk factor for premature death worldwide.

It can pass the barriers of the lung, enter the bloodstream, and destroy the integrity of the blood-brain barrier, thus causing premature deaths, as well as respiratory, cardiovascular, and neurological diseases (Brook et al., 2010; Bowe et al., 2019; Shou et al., 2019; Peeples, 2020). CO, NOx, and VOC are mainly from vehicular or industrial activity emissions, and SO_2 is usually the byproduct of coal and burning fuel. These pollutants also cause respiratory, circulatory system, and heart problems and can be fatal. Moreover, studies recently associated air pollution with increased infections, such as influenza and COVID-19 (Petroni et al., 2020; Zivin et al., 2021).

Air pollution affects lung function and can trigger asthma, among other health conditions, and can lower productivity. Air pollution also has a distinct impact on vulnerable groups, including women and children, as studies have shown that high exposure to air pollution can affect the ovaries and fertility. In Ethiopia, PM pollution is the second leading risk factor for death after malnutrition (IHME, 2020). Residents in urban areas, especially in a large city like Addis Ababa, are at considerable risk of heart and lung diseases and premature death. Several studies have assessed the consequences of ambient air pollution on people's health in Ethiopia (Tefera et al., 2016; and IEC, 2019); however, no economic valuation has been done on the health impacts of air pollution.

The health effects of long-term exposure to ambient PM2.5 include ischemic heart disease, lung cancer, Chronic Obstructive Pulmonary Disease (COPD), lower respiratory infections (such as pneumonia), stroke, type 2 diabetes, and adverse birth outcomes (GBD 2019 Risk Factors Collaborators, 2020).

Several epidemiological studies revealed strong correlations between long-term exposure to PM2.5 and premature mortality (Apte et al., 2015; Cohen et al., 2017; Wu et al., 2020). Recent research associated PM2.5 exposure with mortality related to several other health outcomes: lower respiratory infections; tracheal, bronchus, and lung cancer; ischemic heart disease; stroke; chronic obstructive pulmonary disease; type 2 diabetes mellitus; and adverse birth outcomes (GBD 2019 Risk Factor Collaborators, 2020).

According to the research findings and analysis (Xie et al., 2021) estimates the health damage due to exposure to ambient PM2.5 is about $78 million, or 1.3% of Addis Ababa's GDP in 2019, and Air pollution caused about 1,600 premature deaths a year, on average. Stroke, ischemic heart disease, and lower respiratory infections are the leading causes of PM2.5- related mortality. People between 60-84 years of age are most affected by PM2.5, accounting for about 58% of the total premature deaths.

According to WHO (2018) studies on Air Pollution and Child Health issues, air pollution is one of the biggest threats to children globally. Respiratory tract infections caused by air pollution resulted in over half a million deaths of children under five in 2016. According to the studies by the United Nations Department of Economic and Social Affairs, *Population Division (2017),* Air pollution doesn't just threaten children's survival; it can make them very sick, causing them to miss school and suffer from chronic infections.

2.16 Limitations of the Previous Studies

The literature on health impacts of solid waste exposure remains weak and inconclusive in many cases due to the difficulties encountered in accurately ascertaining exposure, controlling for confounders, accounting for duration of exposure, and inability to follow up those exposed to ascertain outcomes that do not manifest in the short term. (Rushton L.2003). All the existing literature has done studies in detail on the issues of the impact of improper solid waste management on public health and environment, water, and air pollution.

But further investigations and in-depth studies have not been conducted in the areas of the impact of water and air pollution on public health and the cost implication of improper solid waste management on the annual budget of the city administration that affects the urban sustainable development goal.

Furthermore, the current ambient air pollution and heavy metals emission inventories in most of the cities of the developing countries are not providing sufficient information for health risk assessment due to inhalation exposure of Toxic Heavy Metals emitted from Municipal Solid Waste dumpsites. Thus, it was challenging to make intensive research undertakings on the contribution of dumpsite activities to ambient air pollution and heavy metals emissions for its adverse impacts on local and regional air quality. (Peter et al., 2018).

CHAPTER THREE

Trend Analysis of Solid Waste Management in Addis Ababa city

Abstract

In most cities of developing countries and low-income countries, Municipal Solid waste, if not managed properly, has become a challenge and an uncontrolled problem for the city municipalities and government. On the contrary, if implemented sustainably, integrated, and scientifically, municipal solid waste can be one of the untapped opportunities to transform into wealth.

This study assesses the municipal solid waste management in Addis Ababa city during 2011–2020 by analyzing the generation, collection, transportation, and disposal. The study uses secondary data and a literature review on solid waste generation, collection, and disposal methods to critically understand and evaluate the significant challenges of solid waste management in Addis Ababa city. Moreover, quantitative and qualitative data were analyzed through descriptive statistics and trend analysis.

The study result revealed that the population of Addis Ababa city had shown an increasing trend from 3,263,000 in 2011 to 4,794,000 in 2020, with 4.36 and 4.40% growth rates, respectively. Similarly, the solid waste generation rate in Addis Ababa city has increased from 0.25kg/capita/day in 1994 to 0.67 kg/capita/day in 2019. More than 70% of the source of the generated waste in Addis Ababa city constitutes biodegradable organic waste from households, and the trends of this organic waste over the last 5 years have shown an increasing trend from 64% in 2017 to 69% in 2021.

According to the annual report of Addis Ababa city Solid Waste Management Agency, out of 17.41% recyclable solid waste, the recycled amount of municipal solid waste of Addis Ababa city was 4.5-5.0%, and recycling in the city has not been regulated, implying that the solid waste recycling practice and culture in Addis Ababa city remain very low. Very little has been done at the waste-generating sources to reduce the volumes of waste disposal through the processing of domestic waste into compost, as there have been no well-organized and formal composting centers.

The trends of solid waste collection in Addis Ababa city have increased from 1,250,949 cubic meters in 2011 to 3,000,000 cubic meters in 2019, with an annual mean collection rate of 77%. The average annual collection of solid waste over the last ten years (2011-2020) was 1,976,033 cubic meters which was lower than the annual generation of solid waste of 2,511,076 cubic meters, indicating that there was an insufficient and improper collection rate of solid waste in the city with 23% left uncollected waste.

The implication of such improper solid waste management and disposal methods in Addis Ababa city and Koshe open dump site has proven to bring about social, economic, and environmental challenges to the community living around the dump site. The inefficient solid waste collects trends in Addis Ababa city, coupled with increasing population growth, economic growth, industrialization, and increased consumption of goods, will lead to improper solid waste management practices.

The study suggests minimizing waste from its source by reducing generation, applying composting technologies, reusing, and recycling waste in sustainable and integrated systems through locally applicable solid waste management in Addis Ababa city. Finally, the study proposes valuable suggestions that may be beneficial for transforming the current improper solid waste management practice into an integrated and sustainable Municipal solid waste management system in Addis Ababa city.

Key words: waste generation, waste collection, recycling, composting, Koshe dumpsite

3.1 Introduction

Researchers in their study have revealed that about 3.5 million tonnes of waste was generated daily across the globe in 2010, with a daily increase projection to about 6 million tonnes by 2025 (Hoornweg et al. 2012). However, in most developing countries, this increasingly generated waste has been poorly managed and consequently placed a burden on the collection, storage, and disposal of resources and operations (Al-Khatib et al. 2010). The global MSW generation is expected to increase from 2.01 billion tons in 2016 to 3.40 billion tons by 2050, and low- and middle-income countries are projected to have the highest increase rate by at least 40% (Kaza et al. 2018).

Another researcher has also revealed that the waste collection rate for sub-Saharan Africa countries is about 44% (Kaza et al. 2018). The other 56% are disposed to open dumpsites (usually open-burned) or open-burned by the generators. However, there is limited research in the well-planned management of solid waste generated that aids the reduction of the quantity of waste that ends up in landfill, consequently mitigating the environmental effect of uncontrolled landfill sites on the city's human, soil, water, and air quality.

Addis Ababa, like cities of most developing countries, is still facing the challenge of waste management due to the increase in the population, urbanization, industrial activities, and rural-urban migration of the people. However, there is limited focus on urgent attention and action to be taken to combat the repercussion of the increase in the generation rate of waste in the city because the current waste management strategy is inefficient in meeting the collection and disposal needs.

Many researchers have identified that the storage, collection, transportation, and final treatment/disposal of wastes are reported to have become a major problem in urban centers (ADB,2002; Okot-Okumu & Nyenje, 2011). The problem of solid waste generation and the inability to manage it has become a great concern to many countries in Africa, and this global threat of solid waste disposal has affected Africa in many ways especially by causing diseases and increasing the poverty rate. In most rapidly growing cities in developing countries, the major concern issue is inefficient solid waste collection and disposal.

Zurbrugg (1999) noted that the problems of MSWM are of immediate importance in many urban areas of the developing world, and waste management is known as one of the key issues in urban management aside from water and sanitation.

Solid waste management is the process of collecting, storing, treating, and disposal of solid wastes in such a way that they are harmless to humans, plants, animals, the ecology, and the environment generally. The unhealthy disposal of solid waste is one of the greatest challenges facing developing countries (Kofoworola, 2007).

Some authors (Liyala 2011; Oberlin 2011;) identify common causes for poor waste management services as inadequate policy and legislation, lack of political will, lack of public commitment, lack of technical capacity, and poor financing. A different group of authors thinks it is seldom technical (Scheinberg 2011) but rather politics, economics, or institution (Wilson et al.,2010). However, little investment has been made in Municipal Solid Waste Management research, resources, and human capacity development.

A detailed survey conducted in 1986 concluded that only 21.6 percent of waste had been collected (NUPI et al., 1989.) A recent study by the Addis Ababa City Administration shows that coverage has been constantly increasing from 38% in 1993 to 40 % (1994), 53% (1995), and 53.9 % in 1996. It also shows that the amount of waste generated in the city increases by 4 percent. (Hassen, 1998). However, the solid waste collection method is improperly disposed of in open dumping sites resulting in health and environmental impacts.

Improper solid waste disposal causes pollution of air, soil, and water, while indiscriminate dumping of waste contaminates surface and ground water supplies. In urban areas, solid waste clogs drain, creating stagnant water for insect breeding and floods during the rain. Uncontrolled burning of solid waste and improper incineration contributes significantly to urban air pollution.

Many research works, and projects have been undertaken on solid waste management in Addis Ababa, which helped improve the service gradually; however, the provision still lags behind the need. It is evident from Kaseva &Mbuligwe (2005) for Tanzania, Rotich et al. (2006) for Kenya, and Okot-Okumu & Nyenje (2011) for Uganda that urban areas in East Africa have been experiencing serious solid waste management failures. However, there is a very limited study to comprehensively investigate the failures of the short-term and long-term trends in the generation, collection, and disposal of Solid Waste Management.

According to Gemechu et al., 2022 waste management is not only about waste or the environment. But it is also about the economy, society, and institutions. Any changes in one can influence the other and, thus, a waste management system. Consistent with this, introducing the physical driver as one dimension emphasizes that waste should be seen as a part of the whole but not a complete representation of the waste management system.

If waste management was only about waste, Ethiopia has waste generation much below the average for low-income countries, so the waste management problem had to be lesser. However, while the low generation can be an opportunity to ease the required management effort, as it reduces the burden on the environment, economy, human health, and institutional capacities, a lack of understanding of the holistic nature of the waste management system aggravates the problems. (Gemechu et al. 2022)

Sustainable development is “the development that meets the need of the present without compromising the ability of future generations to meet their own needs” (UN, 1987). It means exploiting today’s resources for future generations implying that resource is central to sustainability (Redclift, 1992). Nevertheless, waste is a by-product of resource consumption and the most visible evidence of inefficiency (Ezeah and Roberts, 2014). Thus, sustainability in Waste Management refers to creating a system in which resource conservation is maximized through waste prevention and reduce, reuse, and recycle (3Rs) activities while practicing proper waste treatment and disposal so that social, economic, and environmental balance is maintained for the well-being of the present and future generations. However, developing countries struggle to realize the first two stages, waste collection and controlled disposal (UNEP, 2016).

Waste management is nowadays one of the significant challenges of urban development. It is a major issue in developing countries, especially because of the accelerated growth of the urban population and the emergence of new modes of production and consumption that generate more waste (Ouattara et al., 2019).

SWM in sub-Saharan African countries fails due to insufficient funds and poor waste disposal methods. SWM is an ever-increasing problem in sub-Saharan Africa and has caused many environmental and health concerns due to various unsustainable Solid Waste Management methods (Kubanza 2021).

According to the 2018 World Bank report, only 39% of waste is collected in low, 51% in lower-middle, and 82% in upper-middle, but 96% in high-income countries. About 93% of waste is disposed of uncontrolled in low-income countries, while 66% in the low-middle, 30% in the upper-middle, and only 2% in high-income countries (Table 3.1). In addition, while high-income countries are expected to experience the least waste generation by 2030, the largest growth is expected in low-and middle-income countries due to the upcoming economic growth and urbanization (Kaza et al., 2018).

Table 3-1 Global solid waste collection rate and uncontrolled disposal rate (Kaza et al., 2018)

Country in income level	**Collection rate in %**	**Uncontrolled Disposal rate in %**
Low income	39	93
Lower-middle-income	51	66
Upper-middle income	82	30
High income	96	2

This study aims to investigate the trends of improper solid waste management by the Addis Ababa city government at generation, collection and disposal stage at generation, collection, and disposal stage. Furthermore, the proposed study will focus on the uncontrolled Koshe dump site in Addis Ababa.

3.2 Methodology and Instrumentation

3.2.1 Study Area

Addis Ababa is the capital city of Ethiopia in the Horn of Africa; it was founded in 1887 by Emperor Menelik II. The Global position of the city is located between 8°55' and 9°05' N Latitude and 38°40' and 38°50' E Longitude (Figure 3.1). The temperature is mild afro-alpine and warm temperate weather with an annual average temperature of 19.6°c which ranges between 10°C to 24°C. The lowest temperature occurs (from November to February), and the highest temperature usually occurs (from March to May). The average annual rainfall is 1200 mm. (Diriba and Meng, 2021)

The average annual rainfall of the city is 1200 mm. From this, about 80% of the rainfall occurs in July and August, only 3% fall during the dry months, the rest falls in the remaining months, and slight rain occurs between March and May. The city's average elevation is estimated at 2500 meters above sea level ranging from 2000-2800 meters above sea level. The size of the city covers around 540 square kilometers (54000 hectares). Addis Ababa is a seat for the Oromia National Regional State Government and the Federal Democratic Republic of Ethiopia (FDRE), Oromia National Regional State. It has eleven sub-cities and about 119 districts (Diriba and Meng, 2021).

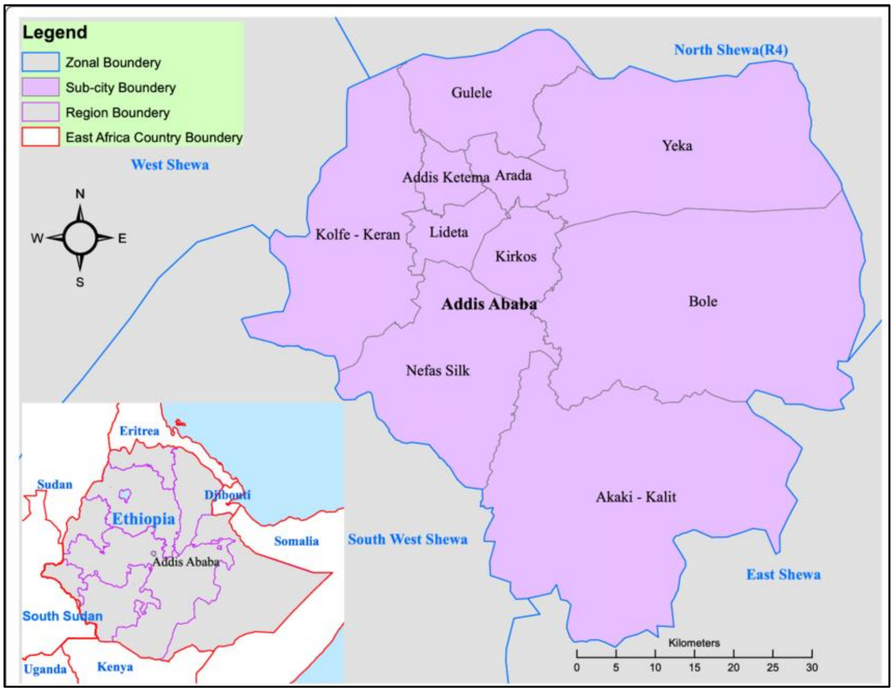


Figure 3-1 Addis Ababa city map and the Koshe dump site (2023

For the last 54 years, Addis Ababa has had only one open dumpsite where all collected waste is disposed of. The site is known as "Rappi" or "Koshe," which is in the southwest part of Addis Ababa city and is located 13km away from the city center. The dumpsite is found at the border of the Kolfe Keranio and Nefas Silk Lafto sub-cities, constituting 37 hectares of land. The present disposal method is crude open dumping, which is hauling the wastes by truck, spreading and leveling by bulldozer, and compacting by compactor.

The major problems associated with the disposal site are the site is getting full, surrounded by housing areas, primary schools, and different social institutions, and nuisance and health hazards for people living nearby the dumping site (Overview of Addis Ababa city Solid Waste Management System, 2010).

3.2.2 Data Collection Methods

In this study, an attempt has been made to provide a comprehensive insight into the trends of Municipal solid waste generation, collection, transportation, recycling, sorting, and challenges of solid waste disposal in the city of Addis Ababa based on the secondary data and existing literature reviews.

Analyzing the secondary data, literature review, and annual reports of Addis Ababa City solid waste management Agency supported by field visits and direct observation of solid waste management practices in Addis Ababa City and Koshe dump site were methodologically used for further analysis. To make a detailed analysis of municipal solid waste generation trends and collection rate, the Central Statistics Authority's annual population senses and data have been used.

For further analysis and study, related scientific articles published in international and reputable journals are mainly reviewed from African cities and cities of developing countries with similar population growth, economic growth, and consumption style. Moreover, documents from relevant government offices like the Addis Ababa Solid waste management agency, the Ethiopian statistical agency, different hospital data, and the Addis Ababa city mayor's Office were used to address the trends of improper solid waste management in the cities.

Secondary data analysis of the previous research findings and publications on municipal Solid waste management was used by comparing the practice and the experience of cities in developing countries, and the challenges facing municipal solid waste management were also critically highlighted. Furthermore, a Literature review of previous research findings and publication of African cities' solid waste management practices.

In this study, the trends of solid waste generated, collected, and disposed of at the dump site have been critically analyzed. Population growth trends in comparison with solid waste generation trends and collected solid waste have also been investigated for their impacts on the public health of Addis Ababa city and the community living around the Koshe open dump site.

3.3 Results and Discussion

3.3.1 Trends of Population Growth

Over the last 10 years (2011-2020), the population of Addis Ababa city has grown from 3,263,000 in 2011 to 4,794,000 in 2020, with an additional increment of more than 1.5 million people in the city, it is estimated to generate approximately more than 1,000,000 cubic meters of solid waste in the city annually. The rapid population growth in the city is due to fast urbanization and in-migration from all directions of the country in search of employment opportunities and services.

The following table presents the trend analysis of the population growth of Addis Ababa city during 2011-2020. The Central Statistics Authority of Ethiopia has estimated the total population of Addis Ababa city as of August 2019 to be 4,592,000, with an annual growth rate of 4.4 percent (CSA 2019). This constitutes approximately 20 percent of Ethiopia's urban population. The population growth in the city is far outpacing economic development, resulting in large slum and squatter settlements (CSA 2017).

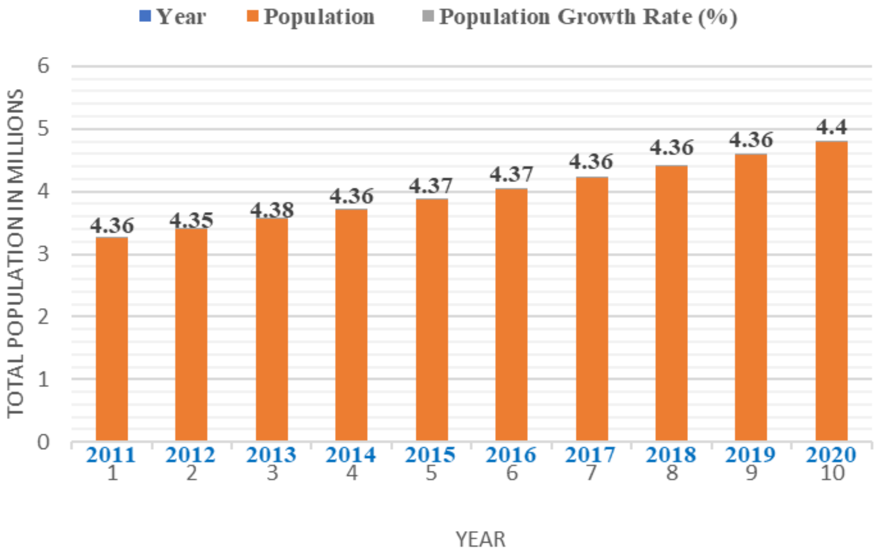


Figure 3-2 Trends of Addis Ababa city population Growth rate (2011-2020), UNDP (2022)

The population of Addis Ababa city showed an increasing trend from 3,263,000 in 2011 to 4,794,000 in 2020, with 4.36 and 4.40% growth rates, respectively (Figure 3.2). This figure indicates that the increasing population trend in the city is directly correlated with a growing trend for solid waste generation. As consumption increases due to increased population growth in the city, solid waste generation will also increase accordingly.

Therefore, Figure 3.2 indicates a link between population growth and increased solid waste generation in Addis Ababa City. Over the last 10 years, the population of Addis Ababa city has risen from 3,263,000 in 2011 to 4,794,000 in 2020, with an annual population growth rate of 4.38 to 4.40 from 2011 to 2020 respectively (Table 3.2). This implied that over the past ten years, the city has experienced a dramatic increase in solid waste production. The amount of waste produced over the last 10 years has dramatically increased.

This study identified that the enlarged expansion and increasing population in Addis Ababa, combined with a deficiency of resources to deliver basic facilities and urban services, have led to a series of difficulties, such as the increased generation of waste and improper solid waste management impacting the environment and the community health.

These results converge with those of Ouattara (2019), who, in his work, has shown that as the population increases, the waste generation stream becomes increasingly essential. However, this author adds that the current change in people's consumption habits, coupled with the demographic growth of cities, explains the increasing production of urban solid waste.

Furthermore, in 2017, a World Bank report on urbanization in Africa showed that Africa's high population growth and rapid urbanization (40%) create pressure on the environment and generate sanitation problems, including waste.

There is no actual data on the Addis Ababa city population until recently, and the Central statistics authority and city Administration estimates the population of Addis Ababa to be around 4,592,000 with an annual growth rate of 4.4 percent. However, the actual number of people living in Addis Ababa city has been estimated by different scholars and surpasses 8 million. Due to this mare facts Managing solid waste at all stages in Addis Ababa city has been very challenging.

This study further revealed that if municipal solid waste management in Addis Ababa city is not efficiently addressed, the current increasing trend of the population in the city has direct implications for solid waste generation, collection, sorting, transportation, and disposal to dump sites. These results reveal the urgent need to ensure efficient organization, skilled human resources, and government commitment to provide adequate waste management infrastructure, which is generally lacking in the Addis Ababa city government.

3.3.2 Trends of Per Capita Solid Waste Generation Rate.

According to Figure 3.3 below, the trends of the solid waste generation rate report of Addis Ababa city, which was conducted by different research studies, indicated that the solid waste generation rate in the city had shown an increasing trend in the last 8 years. The solid waste generation rate was 0.67 kg/cap/day and was found to be higher than both the previous year. In 2020 and 2021 solid waste generation rate was 0.48 and 0.45 kg/cap/day, respectively, with declining trends. This is because, during the lockdown, The waste generation rate in 2020 and 2021 significantly showed a declining trend in the city due to economic shock and lower consumption during the COVID-19 pandemic. Similar trend was also observed in TX, USA (Aurpa 2021).

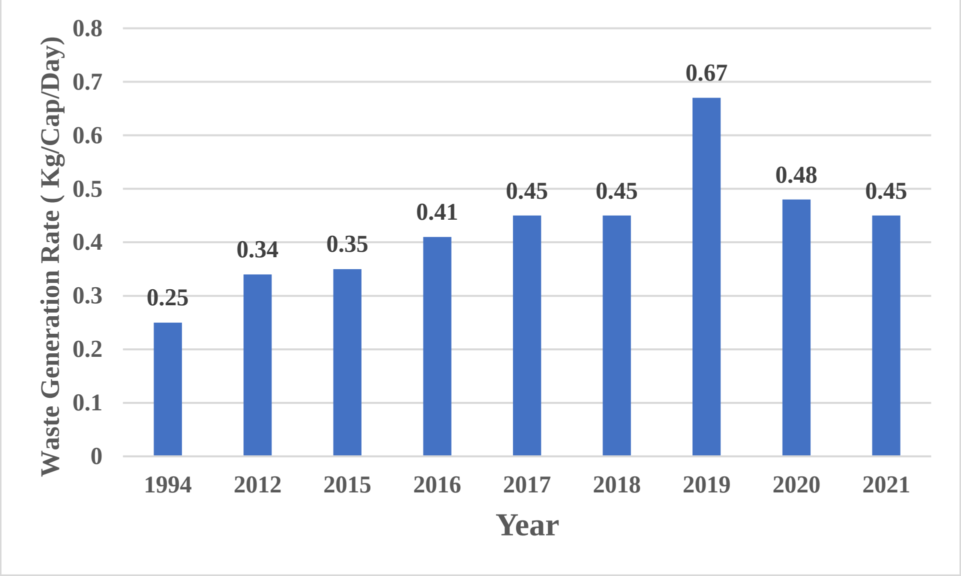


Figure 3-3 Trends of per capita Solid waste generation rate in Addis Ababa City (1994-2021)

Solid waste is usually quantified in terms of the generation rate, which is the daily amount of waste generated by a person or a facility. Per capita solid waste generation rate, which is expressed as Kg/capita/day, is the most common mechanism for quantification of municipal solid waste generated from households and is used to determine annual solid waste generation from different sources (Kawai and Tasaki, 2016).

For the city of Addis Ababa, there is no up-to-date and reliable data regarding the municipal solid waste generation rate estimate. However, different research findings and reports have shown that the trends of solid waste generated in Addis Ababa city have increased each year.

Bello et al. 2016 stated in Africa, there is an increase in per capita generation of both domestic and industrial waste due to an increase in consumption rate, especially eastern Africa is the most rapidly urbanizing region in Africa. As the population grows and urbanization increases in East Africa, as does the amount of waste. In 2015 the annual waste generation for urban Africa was 124 million tons. However, due to COVID-19, at the beginning of 2020, most activities were limited, and a shutdown was there (van et al. 2021; Aurpa et al. 2022).

On the other hand, according to an estimation from the Addis Ababa Solid Waste Management Agency Report (AASWMA, 2019), Addis Ababa generated a daily average of 3,200 tons of Municipal Solid Waste in 2019 or 0.67 kg/capita/day; this estimate seems plausible as a considerable amount of MSW is going uncollected and unreported. A 2020 study estimated that Addis Ababa’s average daily per capita solid waste generation from households alone was about 0.48 kg/capita/day. (Xie et al. 2021).

The declining trend of solid waste per/capita generation in 2020 was due to COVID-19 at the beginning of 2020, and hence most of the activities were limited because of the lockdown period and shutdown of economic activities around the globe. Due to the lack of reliable and systematic Municipal solid waste data collection and surveys in Addis Ababa, the complete picture of waste generation of the waste stream is largely unknown.

According to Kaza et al. (2018), comparing the solid waste generation rate of Addis Ababa, Nairobi, and Cape town cities with a similar population of 4.8, 4.4, and 4.4 million of the same-sized cities have resulted in 0.48kg/cap/day, 0.75kg/cap/day and 0.62kg//cap/day respectively indicating that the solid waste generation rate in Addis Ababa city was lower than cities with similar population size.

However, Per capita, solid waste generation rate of Addis Ababa city was higher than Sub-Saharan Africa's average of 0.46kg/cap/day and lower than the world average of 0.74kg/cap/day. (Kaza, et al., 2018). The generation of MSW in Addis Ababa city is generally associated with population growth, economic conditions, the standard of living, urbanization, and the illegal settlement of people from rural areas to the city.

3.3.2.1 Physical Composition of Municipal Solid Waste

Based on the physical composition of Solid waste samples collected from the two sub-cities, the type of solid waste generated from residential households was manually sorted to determine the material composition and to characterize the types of solid waste generated. The most common solid waste types generated from municipal areas were used for categorization and characterization. According to the data collected in Figure 3.4, studies on the physical composition of the MSW generated from residential households in the five cities of Ethiopia were assessed from annual reports of the city municipalities and similar studies conducted in the study areas.

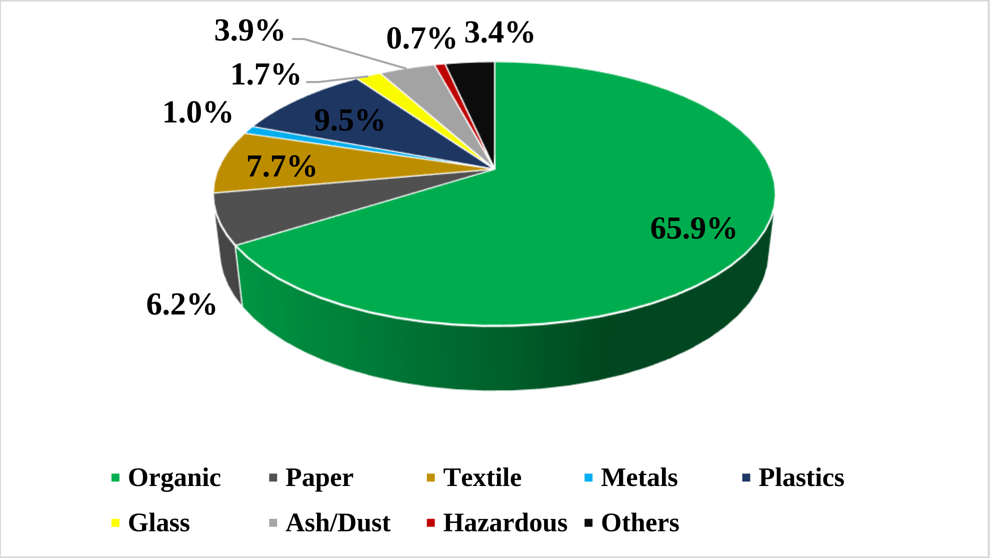


Figure 3-4 Percentage fraction type from the MSW collected from 5 cities in Ethiopia, October 2022.

According to the 2021 report of the cities, organic wastes are the most predominant contributors ranging from 64.5 – 74.2% with an average of 68.0%, followed by plastic wastes that contribute 8.4 – 10.5% of the total fraction with an average of 9.5%. The comparison of physical composition collected during this study showed that the previous data showed a higher percentage of Organic solid waste.

Similarly, according to the report organized by the Solid Waste Management Agency of Addis Ababa City (2021), the sources of municipal solid waste generated in the city was households' account 70%, street 10% commercial institutions, 9%, industries 6%, hotels 3%, hospitals 1% and other sources account 1%.

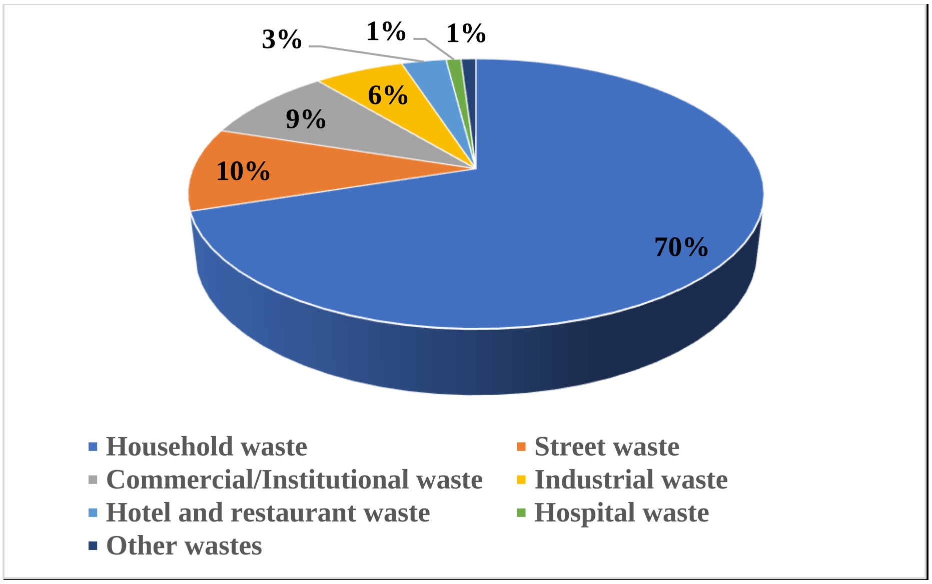


Figure 3-4 Sources of solid waste generated in Addis Ababa city (AASWME,2021)

On the other hand, the United Nations report has identified that 70% of the waste generated comes from households, 9% from commercial areas and 6% from street sweeping, 5% from industrial waste, and the remaining from hotels and hospitals (UN, 2010).

Based on the above data, this study has identified that the sources of solid waste in Addis Ababa city constitute the larger portion of the waste from the residence and household wastes from both the previous research and from the research conducted in this study.

Figure 3.5 further showed that 65.9% of the household waste in Addis Ababa city, if correctly managed and efficiently collected, was biodegradable organic with the untapped opportunity to generate methane gas, convert it into compost, and reduce the need for chemical fertilizers cost-effectively and reduces the amount of solid waste dumped into landfill and thereby reducing the impact of improper solid waste management.

3.3.3 Trends of Solid Waste Composition

According to the Annual reports from Addis Ababa city Cleansing Management Agency (2021), explained in Figure 3.6, the trends of Solid waste composition over the last 5 years have shown an increasing trend for both organic and plastic waste in the city. Organic waste has increased from 64% in 2017 to 74.29% in 2021. Similarly, plastic waste has increased from 5.2% in 2017 to 9.68% in 2021.

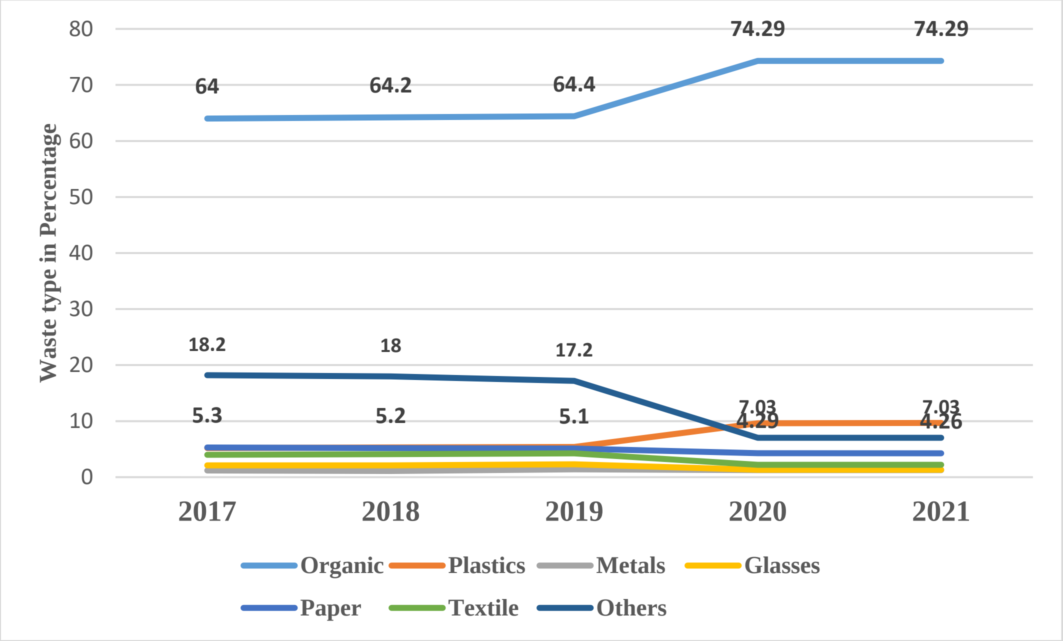


Figure 3-5 Trends of Solid waste composition

According to Figure 3.7, the trends of organic waste over the last 5 years have increased from 64% in 2017 to 69% in 2021. Similarly, the plastic waste composition from total solid waste was 5.2% in 2017 and 7% in 2021, implying an increasing trend in plastic waste. The composition of Municipal solid wastes is changing over time in that both organic and plastic waste have shown a rising trend from 2017 to 2021, respectively.

Unlike Organic waste and plastic waste, which have shown increasing trends, Glass, paper, textile, and other solid waste have shown decreasing trends during the five years, indicating that household composition in the city depends more on recyclable materials and biodegradable materials. The use of paper, glass, and textiles has shown very little compared to the city's recyclable wastes.

The increasing trends in both organic waste and plastic waste in Addis Ababa city might have a potential source for composting technology and recycling of plastic waste sustainably. Based on the trends of increasing trends of organic waste and plastic waste in a sustainable way, Addis Ababa city could have an opportunity in recycling and composting technology to tackle the challenges of improper solid waste management at the generation and collection state.

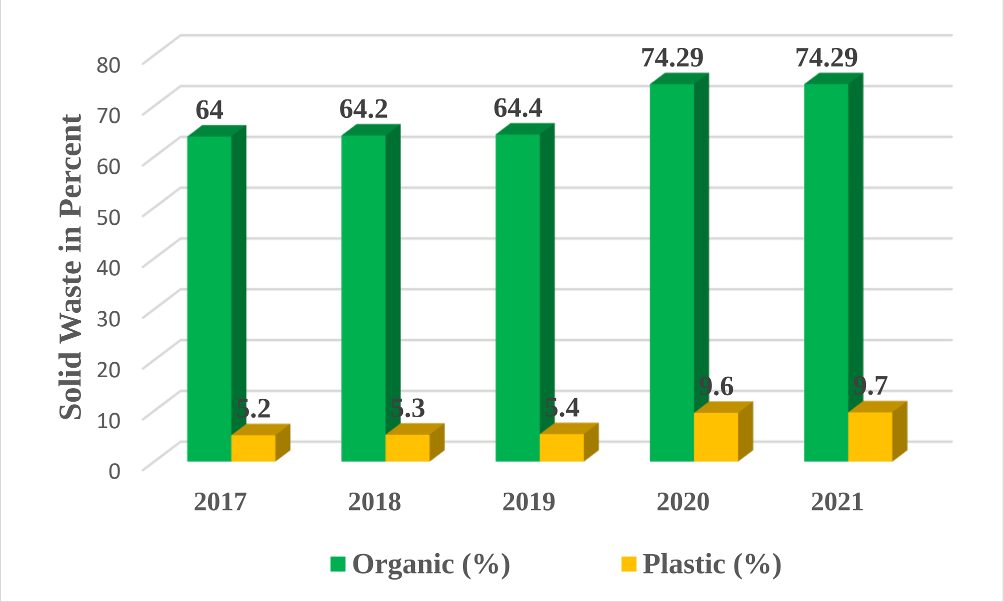


Figure 3-6 Trends of Organic waste and plastic waste from 2017-2021 (Annual reports from Addis Ababa city Cleansing Management Agency 2021)

Organic waste in the city has shown an increasing trend from 64% to 74.29 % from 2017 to 2021, respectively. Similarly, plastic waste shows an increasing trend from 5.2% to 9.61% from 2017 to 2021. On the other hand, solid waste composition for glasses, paper, and textile wastes is showing a declining trend during the year 2017 up to 2021.

Moreover, the above data revealed that in Addis Ababa, the trends of biodegradable solid waste are increasing from year to year, and it is the most significant amount of residential solid waste generated per household. In addition, plastics are generated significantly by mass in the composition of waste generated in Addis Ababa, following organic wastes, which account for 5.2% and 9.61% in 2011 and 2021, respectively.

In recent times, Africa has seen an increase in solid waste and a change in waste composition (world Bank 2018). As economic development and industrialization increase, organic waste decreases, particularly in developed countries. However, the waste generated by sub–Saharan African countries consists of a high percentage of organic waste due to the preparation of fresh food and the use of less packaging on goods that are sold in the markets; hence, the waste composition in these cities is characterized by food and green waste at 43%, plastics at 8.6%, paper and cardboard 10%, metal 5%, glass 3%, wood less than 1%, and other waste at 30% (UN,2010; Sandra and Weghmann 2019).

Further, this study revealed minimal research and finding on the composition of municipal solid waste in Addis Ababa city and its impact on the environment and public health of the community; the current trends of municipal solid waste composition imply management of solid waste. Solid waste can be easily converted into resources through composting and recycling. Yet this opportunity is not exploited, and waste management in Addis Ababa still challenges the environment and health.

3.3.3.1 Solid Waste Sorting

Sorting is a kind of activity separating different types of waste in their respective nature, and it makes waste management straightforward. In Addis Ababa city, solid waste segregation at the point of generation is not carried out, and 77% of the waste produced is dumped, with a low percentage being reused or recycled at the household level. On the contrary, some households separate at the household level into organic and inorganic only.

According to the Addis Ababa city Cleansing Management Agency report (2021), Out of the total population, 23 % of households in Addis Ababa city practice solid waste separation at the source. However, the remaining 77% have no practice of solid waste sorting practice.

Currently, 77% of the solid waste dumped at the Koshe open dump site without segregation directly impacts the environment and the community living around the dump site with long-term exposure to polluting the air quality of the surrounding environment. This indicates that since there are no effective solid waste sorting systems, such mixed wastes, including plastics wastes, end up in dumpsites where they are set on fire.

According to the data in 2021, plastic waste accounts for 7.9, organic waste accounts for 74.29, and 83.99 % of this waste, out of the total municipal solid waste, ends up with Koshe dumpsite affecting both the community health and the surrounding environment. On the contrary, Addis Ababa city has a very limited practice of preparing organic compost, which can be used as an alternative supply of chemical fertilizer for urban agriculture.

Hence, serious measures should be taken by the city administration in sorting solid waste at the origin, which has been used for composting purposes and recyclable materials. Solid waste sorting has a strategic advantage in that, on the one hand, an income-generating strategy and, on the other hand minimizing municipal solid waste management costs and waste minimizing the volume of solid waste dumped in the landfill, thereby protecting from polluting the environment.

A recent study has identified that Open burning methods result in the release of hazardous substances into the environment because of the plasticizers and flame retardants used in the plastics and contaminate air, soils, and food. (Cogut A, 2016). Only a small percentage of Addis Ababa families separate their solid waste on an ad hoc basis. Limited separation efforts by private and informal sectors occur in waste collection stages, such as waste sources, skip points, transfer stations, and the Reppie Landfill or other dump areas.

A similar study has revealed that sorting out at the generation sources is a fundamental method in separating solid waste, contributing to a decrease in waste volume, recovering valuable resources, lessening landfill size, and reducing costs on waste collection, transportation, and treatment (Curea 2017). Another study revealed that solid waste separation coverage in the city of Shanghai and Addis Ababa city was 90% and 28.6%, respectively. (Diriba D. and Xiang 2021).

This study identified that the inefficiency of solid waste sorting at the household level and at the source in Addis Ababa city is due to many reasons. First, the communities are not fully aware of the consequence of not sorting solid waste at the source, which affects public health and the environment. Second, the city municipality has no adequate professionals in terms of creating awareness of waste segregation in the community. Third, there is a lack of priority by the city municipality in allocating adequate finance and incentives for the public institutions engaged in transporting solid waste without sorting directly to the Koshe dump site, and fourth, weak technology usage in utilizing solid waste segregation leads to solid waste mismanagement.

3.3.3.2 Solid Waste Recycling

According to the annual report of Addis Ababa city Solid Waste Management Agency (2020), out of 17.41% recyclable solid waste, the recycled amount of municipal solid waste of Addis Ababa city was 4.5-5.0%, and there is much room for the city to cut waste disposal through waste separation at source and recycling in the city has not been regulated implying that the solid waste recycling practice and culture in Addis Ababa city remain very low.

A similar study has identified that in Addis Ababa city, very few informal recyclers are separating Municipal solid waste through door-to-door waste collection based on the recyclable materials' monetary value on the reuse market. A large portion of recyclable materials has not been separated and recycled. (Xie et al. 2021). In Addis Ababa city, approximately 5% of all waste generated is recycled **(**CCAC MSW Initiative, 2014). Since there is no formal recycling in the city, informal recycling plays a key role, especially in recycling iron, other metals, and bottles. There are also approximately 1,000 recyclers who pick through waste at the Reppie dump site to collect plastics, iron, and other materials.

In Addis Ababa city, the trends of plastic waste have increased from 5.2% in 2017 to 7% in 2021, which implies that plastic waste, if managed effectively at the generation and collection stage, could potentially be used as an input to implement plastic road projects and for other purpose of recyclable materials.

Comparing the recycling rate of Addis Ababa city with Selected African cities, it has been identified that the recycling rate in Addis Ababa city was very low compared to Maputo, Kampala, Dares Elam, Kigali, and Keniya. The plastic waste recycling rate of Addis Ababa, Maputo, Kampala, Dares Elam, Kigali, and Nairobi was 4.4%,16%,7.8%,16%,5%, and 16%, respectively. The recycling of plastic waste in Addis Ababa city is lower than the rate in other cities. (Figure 3.8).

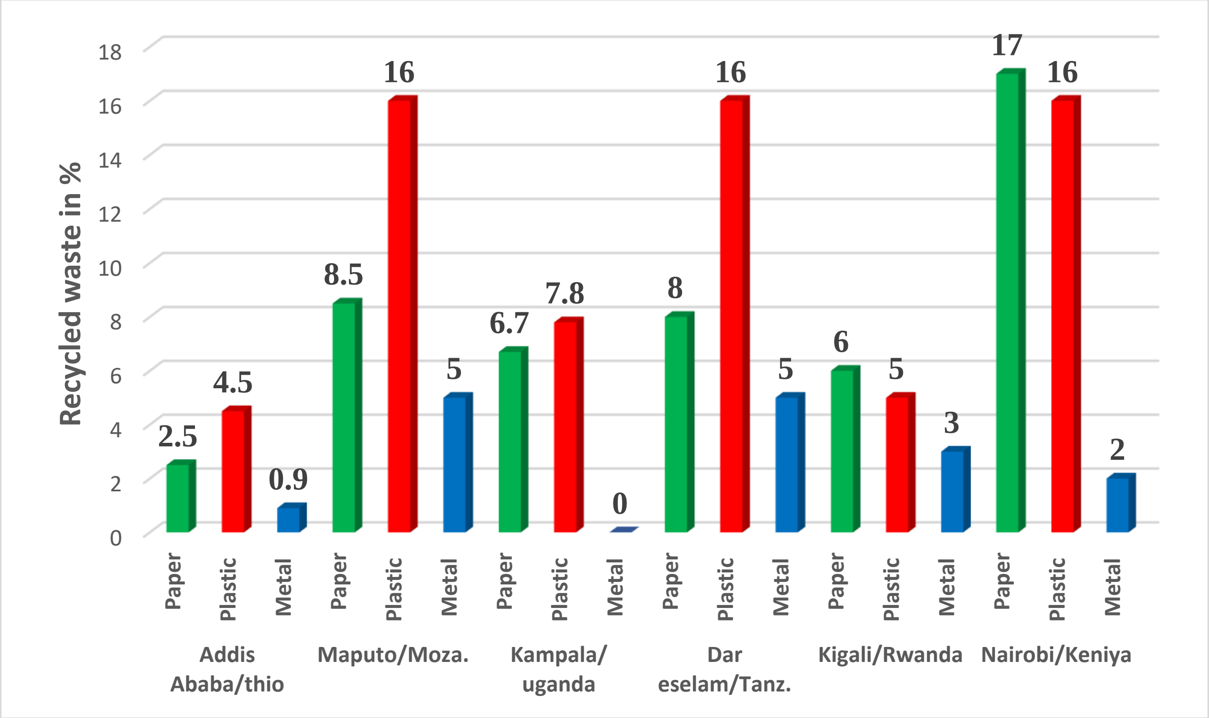


Figure 3.8 Comparison of Waste recycling in selected African cities

3.3.3.3 Composting

According to the annual report of the Addis Ababa City Solid Waste Management Agency, 74.29% of household waste was biodegradable organic (AASWMA,2020). The city has established the largest vegetable and fruit market around Nifasilk sub-city as a potential for composting material for the private sector to produce compost. This indicated that Addis Ababa city has a protentional of more than 74% of biodegradable waste, out of which the current estimated waste generated rate used for composting has been not more than 5% for an extended period of time,

In Addis Ababa city, very little attempt has been made to develop modern composting technology, and there is no composting center that can utilize the 74 % of the organic and biodegradable wastes generated from the city; all these wastes are disposed of at Koshe dumpsite expanding the volume of solid waste dumped in the landfill and polluting the environment. (Figure 3.9).

Similar studies revealed that very little had been done at the waste-generating sources to reduce the volumes of waste disposal through the processing of domestic waste into compost as there has been no well-organized and formal type of composting centers; sorting of compostables from the waste stream was practiced but only by a small minority of the households and other waste-generating sources by some NGOs especially on how to prepare compost and use it for vegetable gardening. Some were working on bio-intensive gardening for households and high schools. (Hayal et al. 2014)

If Addis Ababa city administration scales up such community-based interventions and practices at a household level, all biodegradable organic waste can be promising for compost production by minimizing municipal solid wastes diverted to the Koshe dump site.

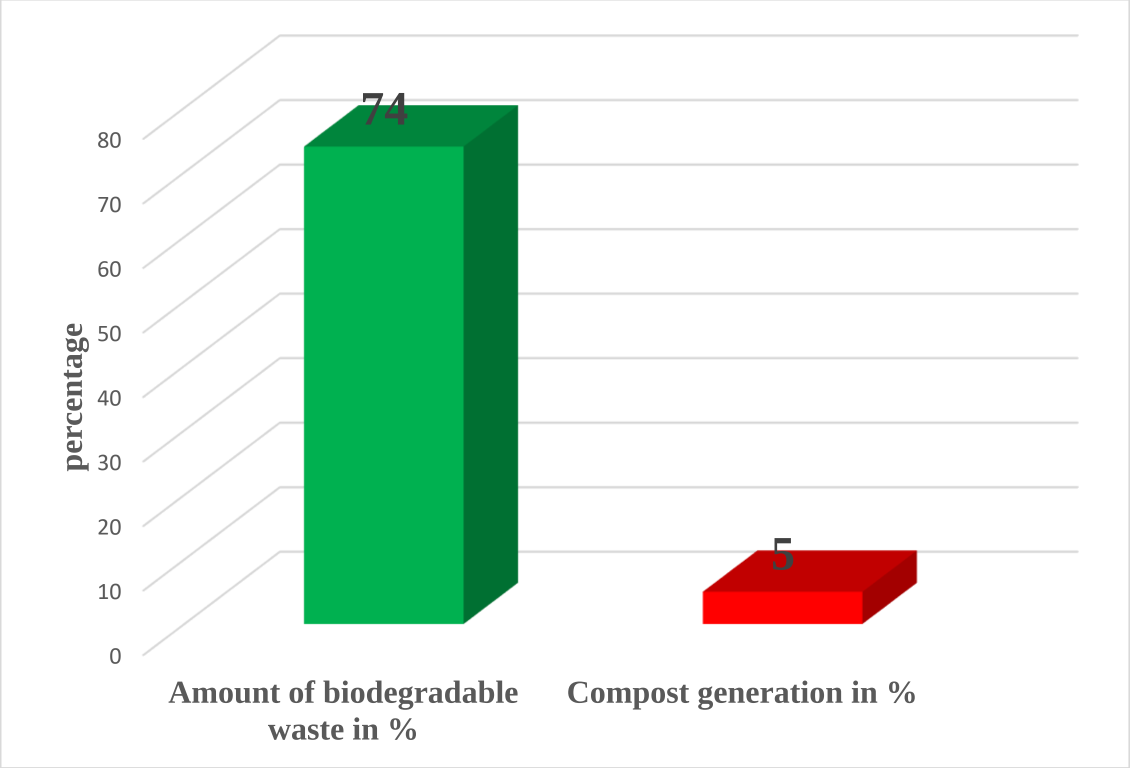


Figure 3.9 Compost generation rate in Addis Ababa city

This trend has implied that Addis Ababa city, even if it has enormous potential to generate biodegradable waste of 74% of the total solid waste, only 5% of the generated solid waste is converted into composting material. As reported by AASWMA, most of the generated biodegradable solid waste in Addis Ababa city goes to the Koshe open dump site and ultimately increases the amount of solid waste that goes to the dump site.

Ayilara et al. (2020) stated composting transforms degradable wastes into products that can be bio-fertilizers. It is environmentally friendly because composing protects underground water from being polluted compared to landfilling waste disposal methods. Similarly, the study conducted by Trivedi et al. (2015) in India encouraged organic composting technology must be encouraged for effective solid waste management by reducing disposed garbage quantity.

The Addis Ababa city administration should encourage small-scale composting at each sub-city by motivating communities and private sectors through various incentive mechanisms. Another study conducted in developing countries also shows that 50% of the solid waste generated in these countries is composed of organic waste that can be biodegradable, and it is suggested that a viable option for managing this waste is composting. One of the strategies to reduce municipal solid waste mismanagement in Addis Ababa city could be encouraging private and NGOs to engage in composting programs. Seng et al. (2018) indicated that converting organic waste into compost and resource recovery could share about 20% of Municipal Solid Waste.

3.3.3.4 Solid Waste Transportation

According to the Annual reports from Addis Ababa city Cleansing Management Agency (2021), the major source of the city’s solid waste is the households from which most of their waste is collected by primary collectors. In practice, most of the waste in Addis Ababa city is collected via the containers system. Still, the efficiency of this method is limited because of the city government's lack of capacity to deploy adequate vehicles and waste containers.

Similar studies have identified that most containers are not protected from rain and sun, which makes the rubbish rot and smell, creates unsightly urban spots, and leads to the deterioration of neighborhoods and a disturbance of human activities due to a shortage of containers, collected waste is improperly stored on open spaces and roadsides (Tassie et al. 2019).

The report of Addis Ababa city SWMA (2020) further presented that there are about 320 garbage transporting trucks,206 government and about 114 private garbage transporting trucks in Addis Ababa city. The existing reality in Addis Ababa is that waste transporting tracks are not available to the level demanded, and even some available trucks don't all operate at full capacity.

Currently, a single old track with a capacity of 3000kg transports about 8 cubic meters or 2160kg (72%), resulting in inefficient solid waste transportation practices, and most of the private companies have no sufficient human resources and vehicles to transport solid waste. (Figure 3.10)

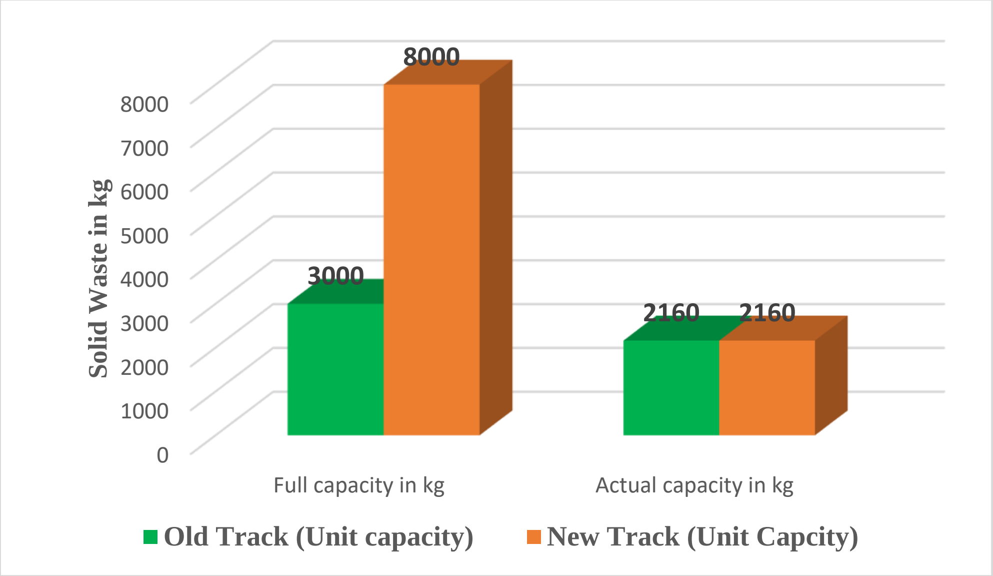


Figure 3.10 Track capacity of solid waste transportation in Addis Ababa city

This finding is in line with the theory of Schubeler (1996), which states the lack of skilled and adequate human resources. Transporting trucks and vehicles was the hindering factor for an effective waste management system. Another study has also shown that 75.4% of the community used a sack, and others used plastic bags. Only 24.6% of the residents were using standardized waste bins.

The collection time interval of the garbage by the municipality workers to the final landfill is long. As a result, the waste is more likely to contaminate during the stay due to an inefficient solid waste transportation system (Diriba and Meng, 2021). In addition to the limited vehicle supply by municipalities and private sectors, another obstacle to effective solid waste transportation in Addis Ababa is that existing vehicles are performing under high traffic jamming, inadequate maintenance budget, and inadequate alternative roads.

According to Tadesse Kuma (2004), infrastructure problems like traffic conditions and the problem of available roads were hindering factors from having quick, solid waste transport. Similar studies revealed that cities in low-income countries often lack sufficient transportation and equipment to collect waste, and hence, waste-collecting trucks are not available to the level demanded (Tassie et al. 2019)

According to Bogale and Tefera (2014), the truck work efficiency was estimated to be less than 40% of work truck days (there are 26 work truck days in a month excluding Sundays) capacity indicating a larger proportion of working days are lost due to maintenance problems, negligence of driver's, frequent accidents during traffic concentration.

Addis Ababa city municipal report identified that all the trucks carry only a single container with a maximum capacity of 8 cubic meters or 2160 kg at the time of disposal. Most of the trucks have no cover for waste containers, so they drop waste in the city on their way to the disposal site.

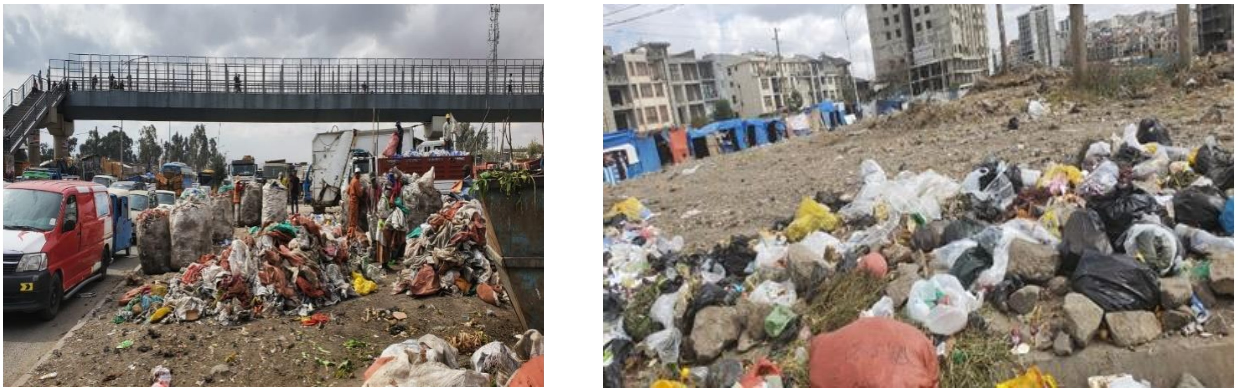
From the point of a review of this literature, Addis Ababa city and each sub-city are responsible for transporting to the final dump site "Koshe" (final dumping site) using trucks from garbage containers. But in practice, due to the inefficiency of human resources, finance, shortage of track, and government attention, solid waste in the city could not be transported and dumped at the Koshe dump site, increasing the rate of uncollected waste in the city. Moreover, the role of the private sector in the transportation of solid waste is highly limited.

This process of transportation of solid waste indicated that, even if the truck work efficiency of Addis Ababa city is to be estimated at more than 50 % of work truck-days, the rest of the solid waste has remained uncollected, improperly managed, and pollutes the surrounding environment being dumped for several days resulting in inefficient collecting capacity of solid waste.

According to site observation and field visits undergone in different sub-cities of Addis Ababa during the study period, the uncollected 20-30% of municipal solid wastes are disposed of indiscriminately before arriving Koshe dumping site in the form of open burning, thrown in an open space and on the side of the street, disposed in nearby rivers and thrown into the drainage system of the city.

The following picture of uncollected solid waste status in Addis Ababa city shows the inefficiency of solid waste transportation and the reality on the ground (Figure 3.11).

a) Koshe dump site side way b) Street dumping



c) Street dumping d) Illegal dumping site

Figure 3-11 Improper collection and transportation of solid waste in different locations of Addis Ababa City (2023)

3.3.4 Trends of Solid Waste Collection

The following table presents the trends of solid waste collected in Addis Ababa city over the last 10 years (2011-2020), and the detail presentation, evaluation, and analysis of the data were presented as follows.

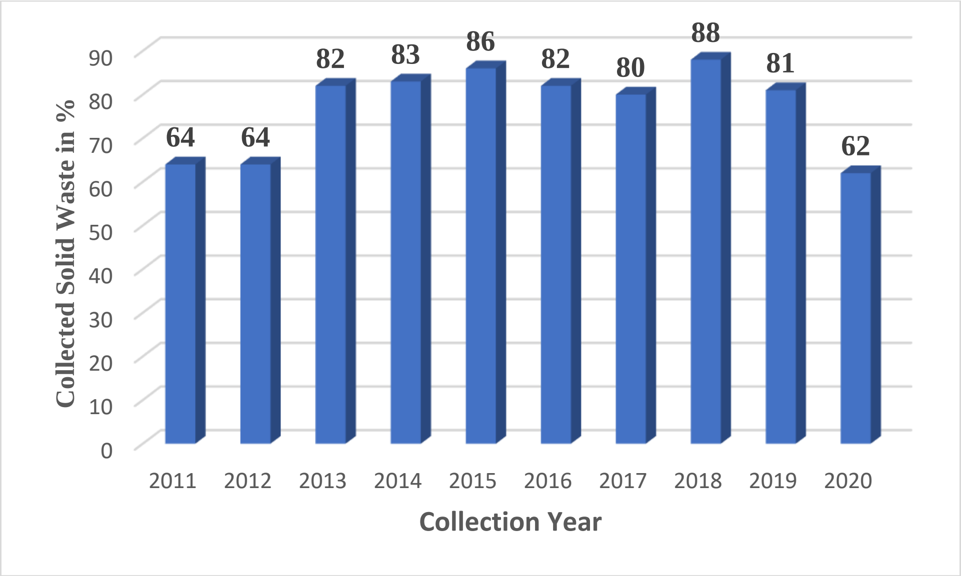


Figure 3-12 Trends of solid waste disposal in Addis Ababa City (M^3) Adapted from (Gelan, 2021) and AACCMA Report (2020)

According to the data presented in Figure 3.12 above, the trends of solid waste collection in Addis Ababa city have increased from 1,250,949 cubic meters in 2011 to 3,000,000 cubic meters in 2019, with an annual mean collection rate of 77%. However, the decreasing trend of solid waste collection in 2020, with a 62% collection rate, was observed due to the lockdown period of COVID-2019, during which the rate of household consumption and economic activities was declining.

The average annual collection of solid waste over the last ten years (2011-2020) was 1,976,033 cubic meters which was lower than the annual generation of solid waste of 2,511,076 cubic meters, indicating that there was an insufficient collection rate of solid waste in the city, with 23% left uncollected waste.

According to the Addis Ababa city Solid Waste Management Agency report, it should be noted that despite the rapidly increasing population, the total solid waste collected and transported has declined by more than 20% in the past two years (AASWMA Annual Report, 2019). This is a very worrying trend as it hints that households were using alternative means to dispose of solid waste, like open burning. With the rising population, the quantity of municipal solid waste generation in Addis Ababa city has consistently risen over the years, which was collected inefficiently, transported inadequately, and disposed of unscientifically.

The solid waste collection rate of Addis Ababa, Nairobi, and Cap town cities with similar populations of 4.8, 4.4, and 4.4 million of the same-sized cities have resulted in 70%, 50%, and 69%, respectively. The municipal solid waste collection rate in Addis Ababa is comparatively higher than in Nairobi and Cape Town. Moreover, the municipal solid waste collection rate of Addis Ababa city is greater than the Sub-Saharan African average of 44% and lower than the world average of 96%. (Kaza, et al., 2018).

An insufficient city solid waste collection system may have significant adverse environmental impacts, such as transmittable diseases, contamination of land and water, sanitation barriers, and harm to biodiversity. Its environmental damages include pollution of groundwater and shallow water by leachate and air pollution from the burning of waste that is not appropriately collected and disposed of. (Diriba and Meng, 2021)

Previous studies of the United Nations report have identified that in 2010, of the daily solid waste generated in Addis Ababa, 65% was collected, 5% recycled, and 5% composted. The remaining 25% is simply dumped on open sites, drainage channels, rivers, and valleys, as well as on the streets (UN, 2010). Similarly, the annual report of Addis Ababa city Solid Waste Management Agency has identified that the trends of solid waste collection rate have shown an increasing trend from 64% in 2011 to 81% in 2019.

The mean annual collection rate of 77% of solid waste generated wastes is transported directly to an uncontrolled landfill or Koshe (Reppi) open dump site, which now lies within the heart of the city, posing a serious environmental pollution and health risk to its surrounding neighborhoods.

The remaining 23% of municipal solid waste generated in the city is not being collected and rather burned, buried, or disposed of informally in a manner of polluting the environment.

On the other hand, the uncollected solid waste is dumped in non-allowable spaces, like channels, drains, roads, streets sides, rivers, sanitary drainage channels, and other exposed areas, and becoming a growing concern in Addis Ababa city (Tassie et al. 2019).

Recent studies have revealed that solid waste collection coverage in the cities of Shanghai, Harare, and Addis Ababa has been identified as 100%,100%, and 70%, respectively. (Kaza et al.2018; Diriba D.and Xiang 2021) Implying that Harare and Shengai cities have managed the solid waste collection rate in comparison with Addis Ababa city, where 30% of the uncollected waste was dumped indiscriminately in an unsafe place affecting the environment and public health. This implies that the inefficiency of the solid waste collection capacity in Addis Ababa city emanates from either due to lack of adequate financing or a lack of proper attention from the municipality in curbing the improper solid waste management practice.

Addis Ababa city has no appropriate solid waste management principle that scientifically quantifies and evaluates the trends of solid waste management at the generation, storage, collection, transportation, separation, and disposal stage. To protect the health and well-being of the population and the environment, solid waste management involves a wide range of considerations from the government, city municipality, and stakeholders who perform various functions to help maintain a clean, safe, and pleasant physical environment and human settlements. However, effective solid waste management is a growing challenge for all countries, especially developing countries like Ethiopia.

Such kinds of improper solid waste collection practices in Addis Ababa city are critical issues for the municipality, government, and policymakers, which can expose the city to uncontrolled and dual challenges. The first challenge was the uncollected 23% of municipal solid waste dumped on open sites, drainage channels, rivers, and valleys of Addis Ababa city, affecting the city's infrastructure. The second challenge was even if the collected 77% of the municipal solid waste, which was directly transferred to the Koshe open dumping site of the city, negatively impacted the environment and the community health living near the dump site.

In this regard, several research has shown that most cities of developing countries collect less than 50% of the total waste generated, leaving the uncollected waste to be flung into the street, usually bodies of water, vacant lots, or burned (Medina, 2007).

3.3.5 Solid Waste Disposal

The open dumpsite of Addis Ababa city is officially known as the “Reppie” landfill, commonly called by its local name Koshe in Amharic. Is established 60 years ago and occupies a 37-hectare surface area; Koshe dump site surroundings on all four sides are home to both plastic makeshift shelters and poorly constructed mud & wood houses that shelter hundreds of people.

Disposal is the ultimate stage in the solid waste management system for those wastes that have no further use to society. Waste disposal is one of the most important management practices that need to be carefully planned and managed. Most low-income countries like Ethiopia make use of open dumping as their form of disposal site.

In Addis Ababa city, all solid wastes collected by the municipality are brought to the largest single dumping site at Reppie or "Koshe" Open dumping area, which is in the southwest part of the city and has been in operation since the 1950s, receiving over 750 tonnes of waste per day. It has a surface area of 37 hectares and is located 13 km from the city center. The current disposal method is crude open dumping, hauling the wastes by truck, spreading, and leveling by bulldozing compacting by compactor or bulldozer.

Many of the world's cities are generating an ever-increasing amount of waste, and the effectiveness of their solid waste collection and disposal systems is declining. In urban centers throughout African regions, less than half of the solid waste produced is collected, and 95% of that amount is indiscriminately thrown away at various dumping sites on the periphery of urban centers, typically empty lots scattered throughout the city (Nigatu, Rajan, and Bizunesh 2011; Tewodros, Ruijs, and Hagos 2008).

Tanzania, for example, is faced with major problems of solid waste management, with an estimation of 30–50% of waste being left uncollected (Onibokun et al. 1999). In estimates for the capital city of Dar-es-Salaam, out of 3976 tons of solid waste generated each day, only 1440 tons are collected and sent to a landfill for disposal. In addition, approximately 70% of the daily waste generated is left near the houses, on the streets, in markets, or in drainage channels (Onibokun et al. 1999).

Addis Ababa city’s solid waste threatens the environment as only 65% produced per day is collected and disposed of at the Koshe dump site, 5% is recycled, and 5% is composted. The remaining 25% is uncollected and dumped in unauthorized areas. (Mohamed and Elias, 2017) In line with this, solid waste management is becoming a major public health and environmental concern in urban areas of Ethiopia; only 2% of the population received solid waste collection, transportation, and landfill disposal services (Kassa, 2010).

Municipal solid waste disposal in the Koshe dump site and continuous population growth can clearly be seen with the increase in solid waste generation of about 1000 tons daily. This generated waste must be collected, transported, and buried in the Koshe Reppi landfill opened in 1964. This landfill is in a 37-hectare area in the city center and has no air and water pollution control mechanism, with stockpiled waste reaching up to 30 m high.

The elimination of open dumping is the necessary steppingstone towards Environmentally sound waste disposal, which is explicitly addressed by target SDG 12, Target 4: “By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water, and soil to minimize their adverse impacts on human health and the environment.”

3.3.6 Challenges with the Koshe Open Dump Site

According to the direct field observation and critical evaluation made during the study period at the Koshe/ Reppie open dump site of Addis Ababa city, the following basic problems and challenges associated with the dump site have been identified for detailed analysis.

Out of the total solid waste generated in Addis Ababa city, more than 70% of the collected waste is dumped at the Koshe dump site, which is scientifically forbidden to dump waste as it is currently oversaturated dumpsite. Moreover, it was identified that the Koshe dump site was reaching saturation in 2010. According to Nguyen (Thanh et al. 2011), many cities in developing countries face serious environmental degradation and health risks due to the weakly developed municipal solid waste management system.

According to the review on the impacts of solid waste disposal sites in the Philippines, Galarpe inferred that potential contamination of disposal sites to the environment could manifest in river water, soil, air, plants, and scavenging animals adjacent to the dump site. Adjacent communities can similarly be affected, jeopardizing their own health, like the prevalence of gastrointestinal, skin, upper respiratory, and dengue diseases were likely common (Galarpe 2017).

In the study of Demayo (2012) on the Impact of Waste Dumps on Human Health, it was stressed that residents and traders in areas near a waste dump are prone to rash, lung infection, cholera, tetanus, dysentery, diarrhea, nauseating, childbirth defect, and premature birth more than those who live or trade in faraway areas. According to the detailed assessment made in the Koshe dump site, the identified major challenges were categorized as social, economic, and environmental, which need urgent action and alternative solutions by all concerned bodies.

3.3.6.1 Social Challenges of the Dump Site

a) Nuisance, bad odor, and health hazards for people living near the dump site.
b) Unprotected and secured area for children, women, animals, and scavengers
c) The dump site is already saturated and at full capacity since 2010.
d) Surrounded by housing areas, schools, and institutions.
e) More than 300-400 waste pickers per day work continuously for their livelihoods.
f) More than 200,000 communities are currently living near all corners of the Koshe dump site.
g) A large-scale waste landslide resulted in over a hundred deaths in 2017.
h) Methane gas (CH4) explosions contribute to global warming.
i) Becoming an uncontrolled and unsecured dumpsite for the community and for Addis Ababa city, leading to political and social unrest.

3.3.6.2 Economic Challenge of the Dump Site

a. No dedicated finance for the rehabilitation of the dumpsite from the city.
b. Very limited machinery, compactors, graders, and bulldozers that regularly work at the disposal site.
c. No treatment protection facilities at the bottom of the land
d. No large-scale composting facility available as a disposal option
e. No odor or vector control mechanism.
f. No fencing or demarcation of the dump site
g. No large-scale composting facility is available as a disposal option.
h. No leachate containment or leachate collection facility
i. All waste dumped in the Koshe site is without separation, even organic waste.

3.3.6.3 Environmental Challenges of the Dump Site

a. Waste products, when burnt like plastic and rubber, pollute the atmosphere with noxious fumes.
b. No rainwater drains off; as a result, migration occurs through the run-off of precipitation.
c. Blows litter and spreading wastes outside the site and in the surrounding.
d. Organic waste emits an obnoxious odor on its decomposition and pollutes the environment by producing methane (CH4)
e. High air pollution above the limit of WHO and EEPA standard
f. High leachate concentration pollutes the underground and surface water.
g. The dump site is adjacent to the Little Akaki River polluting the nearby farmland.
h. There is uncontrolled burning of solid waste, creating smoke and air pollution.

Open dumpsites in developing urban cities involve in- discriminate disposal of waste. They are uncontrolled and therefore pose major health threats that affect urban cities' landscapes. The UNEPA (2006) stated that waste that are not managed properly, especially solid waste from households and the community, are a serious health hazard and lead to the spread of infectious diseases.

From the above basic challenges of the half-century-old Koshe open dump site, Addis Ababa city is facing an urgent need and alternative solutions to handle its growing Municipal solid waste generation supported with scientifically identified recommendations. To this end, further investigation and research studies should be mandatory to protect the environment and the public health of the community residing near the dump site.

Figure 3-13 Communities living around Koshe open dump site 2023.

Figure 3.13 implied that Such kind of improper waste disposal in the Koshe dump site is the disposal of waste in a way that has negative consequences for the community nearby the site and the environment. The air pollution due to improper solid waste management and the Koshe dump site has continued to plague the city of Addis Ababa at an increasing speed. Hence, one of the core challenges identified was the current continued pollution of the surrounding air near the Koshe dumpsite and Akaki river. Similar studies were conducted in Indian cities in that air pollution increases the health risks of the people living around the dump site and reduces the aesthetic value of the environment (Chadar et al. 2017)

In Nairobi, for example, municipal waste is taken to the Dandora dumping site, a former quarry. Residents living close to the dumpsite are therefore exposed to environmental and disease risks.

The disposal sites are, in most cases, located in environmentally sensitive, low-laying areas such as wetlands, forest edges, or adjacent to bodies of water. They often do not have liners, fences, soil covers, and compactors, as in most developing countries (Troschinetz and Mihelcic, 2009).

Addis Ababa city Koshe dumping site has no leachate collection system, and the leachate of the dumpsite can easily percolate the nearby river of Little Akaki, where the surrounding communities use the polluted river for animal drink and irrigation as means of income generation by selling fruits and vegetables for the city.

Van Niekerk and Weghmann (2021) stated in Africa, open dumping is by far the most common one, which open dumping in this context refers to the unplanned dumping of waste without the involvement of environmental protection mechanisms with adverse impact on both the community and the environment. In line with this, van Niekerk and Weghmann (2021) stated many cities in Africa have only one official landfill site for the whole city, which in many cases is overflowing and a serious health and safety concern.

The implication of such improper solid waste management in Addis Ababa city and Koshe open dump site will ultimately lead to economic, social, and environmental crises whereby waste disposal methods have proven to be socially catastrophic and destructive to human health and the environment.

3.4 Conclusion

Addis Ababa city has no appropriate solid waste management principle that scientifically quantifies and evaluates the trends of solid waste management at the generation, storage, collection, transportation, separation, and disposal stage. Moreover, effective solid waste management is a growing challenge that needs careful attention from all countries, especially cities of developing countries like Addis Ababa.

The main problem of municipal solid waste management in Addis Ababa city is, however, not only brought about by the amount of waste accumulated in the cities but also by the governments and waste management authorities' incapability to cope with the problem's scope. Parallel to the rising population, the quantity of municipal solid waste generation in Addis Ababa city has consistently risen over the years, which is collected inefficiently, transported inadequately, and disposed of unscientifically.

The amount of solid waste generated in Addis Ababa city is rising over time due to economic growth, changes in consumer behavior, and people's lifestyles. But it is hard to manage and handle the increase in solid waste with the existing waste management infrastructure in the city. Thus, the municipal solid waste management system in the city was challenging and has become a serious problem.

To protect the health and well-being of the population and the environment, solid waste management involves a wide range of considerations from the government, city municipality, and stakeholders who perform various functions to help maintain a clean, safe, and pleasant physical environment and human settlements.

The study suggests minimizing waste from its source by reducing generation, applying composting, reusing, and recycling waste in sustainable and integrated systems in Addis Ababa through locally applicable solid waste management. The study finally proposes valuable suggestions that may be beneficial for improving the current approach to support Integrated and sustainable MSW in Addis Ababa city.

Furthermore, Addis Ababa city authorities must explore the 3Rs (Reduce, Reuse, and Recycle) and circular economy methods, such as waste separation at source, biogas generation, Composting, and E-waste recycling. Creating effective SWM in the city involves many stakeholders and requires strong political will, leadership, and commitment from senior city officials. Moreover, public awareness and participation are essential to waste reduction, source separation, and recycling activities. Effective SWM also requires robust institutional arrangements with a strong capacity for implementation and enforcement.

CHAPTER FOUR

Trends of the Ambient air Quality status of Addis Ababa City and Koshe Open Dump Site

Abstract

This study assessed the air quality trends of Addis Ababa city and Koshe open dump site for eight months by measuring the pollutants level with an assessment of its seasonal implication. The air pollution data was collected using Aeroqual 200/500 series to record primary data from selected twelve sample collection areas of Addis Ababa city and Koshe open dump site.

During the study period, PM2.5, PM10, CO_2, CO, $SO_{2,}$ and CH_4 gases were measured based on The World Health Organization (WHO) and the Ethiopian Environmental Protection Authority (EPA) standards and guidelines. The collected primary data were compiled properly and subjected to statistical analysis. The Microsoft office excel software was used to present and interpret the collected data in tabular, chart, and graphical form using trend analysis of eight-months pollutant data. The data collection timeframe was separated into three main seasons, namely the dry season or winter (November, December, and January), the wet season or summer (June, July, August, and October), and the Spring season (March, April, and May).

The eight-month average fine Particulate Matter (PM 2.5) emissions statistics result of Addis Ababa city result has shown 56.6µg/$m^{3,}$ which is more than three times the standard set by the WHO limit of 15µg/m^3 but below the standard set by EEPA of 65µg/m^3. On the other hand, the eight-month average fine Particulate Matter (PM2.5) emissions statistics result of the Koshe dump site result has shown 204µg/$m^{3,}$ which is more than thirteen times the standard set by the WHO limit of 15µg/m^3 and more than three times the standard set by EPA of 65µg/m^3.

The trends of PM2.5 concentrations at the Koshe open dump site were significantly higher during the winter season than during the summer season. A higher concentration of PM2.5 harms the communities living around Koshe open dump site.

The Eight-month average Particulate Matter (PM10) emissions statistics result of Addis Ababa city average result has showed 129µg/m^{3,} which is more than two times the standard set by the WHO limit of 45µg/m^3 but below the standard set by EEPA of 150µg/m^3. On the other hand, the Eight-month average Particulate Matter (PM10) emissions statistical result of the Koshe dump site has shown 378µg/m^{3,} which is more than eight times the standard set by the WHO limit of 45µg/m^3 and more than two times the standard set by EPA of 150µg/m^3

The trends of PM10 concentration results of the Koshe open dump site during the wet or summer season (August 2022) were 156µg/m^3. The trends of PM10 concentration results of the Koshe open dump site during the dry season (December) were 393 µg/m^{3,} which is more than two times greater than the emission level recorded during the wet or summer season.

In both the Addis Ababa city average and Koshe dump site, the highest concentration of CO was registered during the winter/dry season of the month (21 December 2022) with 3072µg/m^3 and 9425µg/m^{3,} respectively. In contrast, the lowest emission of CO for Addis Ababa city average and Koshe dump site was registered during the summer/wet season (August 2022) with 414µg/m^3 and 1045µg/m^{3,} respectively. Similarly, the CO concentration of Addis Ababa city average and Koshe dump site during winter/dry season (November 2022, December 2022, January 2023) was 3072µg/m^3, 2209µg/m^{3,} and 2597µg/m^{3,} respectively.

The highest concentration of CO during the dry season was because of the unavoidable Ethiopian culture of open burning of solid waste during the dry season in general and specifically on 21 November 2022 as an accepted norm and culture of the urban community impacting air quality and public health each year.

NO$_2$ concentration at the Koshe dump site during summer (August 2022 and October 2022) was recorded at 121µg/m^3 and 128µg/m^{3,} respectively. In contrast, the concentration of NO$_2$ at the Koshe dump site during the winter or dry season of the Months (November 2022, December 2022, and January 2023) has been registered at 136µg/m^3,142µg/m^3, 139µg/m^{3,} and 131µg/m^3 respectively exceeding above the limit of WHO standard of 25µg/m^3 and below the limit of EPA standard of 200µg/m^3.

SO$_2$ concentration at the Koshe dump site during the wet season or summer (August 2022 and October 2022) was 310µg/m^3 and 350µg/m^{3,} respectively, which exceeded the standard set by the World Health Organization (WHO) of 40µg/m^3 and the Ethiopian Environmental Protection Authority (EEPA) guidelines of 125µg/m^3.

The increasing trend of ambient air pollution in Addis Ababa city has created an adverse health impact on the community living around Koshe open dump site. The study can be useful for the government, municipalities, researchers, and policymakers as a limited number of studies on air pollution to Addis Ababa supplement government policymakers' decisions. The study further indicated limited air quality monitoring technologies and weak institutional setups to regulate air pollution in Addis Ababa city.

4.1 Introduction

Air pollution is, in the words of the World Health Organization, "the world's largest single environmental health risk" (WHO, 2014a). It is also one of the world's largest health risks tout courts. It is a major risk factor in several diseases leading to disabilities and deaths, including cancers, lower respiratory infections, and cardiovascular and cerebrovascular diseases.

About 80% of people in urban areas are exposed to air pollution exceeding the air quality standard set by World Health Organization (WHO), and even 98% of cities in low-middle-income countries and 56% in high-income countries do not meet the WHO guidelines (WHO, 2016). More than 4.2 million estimated people die worldwide yearly due to exposure to ambient (outdoor) air pollution by cardiac arrest, brain stroke, cancer, and other chronic respiratory diseases (WHO, 2016).

Air pollution has become a severe concern for its potential health hazard; however, often less attention is given in most developing countries, including Ethiopia. Over four million deaths are attributed to outdoor air pollution yearly, as reported by the World Health Organization (WHO); most of these deaths are primarily cardiovascular and respiratory diseases (WHO, 2019). Air pollution is the biggest threat to public health, with the highest exposure in low- and middle-income countries (WHO, 2019). In these countries, the air quality levels are not compliant with the new WHO guideline values (WHO, 2021).

For instance, ambient air pollution in three small cities in India (Patiala, Nainital, and Bulandshahr) shows that Bulandshahr exhibited the highest level of PM pollution, followed by Patiala and Nainital. For Patiala, the average level of PM concentration during the 14-month observation period was approximately 105µg/m^3 and 182 µg/m^3 for PM2.5 and PM10, respectively. The levels for Bulandshahr over the same period were approximately 122µg/m^3 of PM2.5 and 225µg/m3 of PM10. These levels were more than twice the average daily safe limit prescribed by the NAAQS. For Nainital, the average levels of PM concentrations were less than 30 µg/m^3 for PM2.5 and less than 70µg/m3 for PM10, both well within the average daily safe limit allowed under the NAAQS (Agrawal et al.,2021)

Some of the systematic reviews that contributed to the development of the new Air Quality Guideline (AQG) reported that a 10 µg/m3 rise in the daily mean concentration of PM_{10} was associated with 0.6% and 0.9% increases in daily cardiovascular and respiratory disease mortality, respectively. In addition, 10 µg/m^3 increases in NO2 and O_3 were associated with an elevated risk of 0.72% and 0.43% in daily all-cause mortality, respectively (Orellano et al. 2020). Another meta-analysis found a positive association between SO2 and all-cause mortality with an estimated additional risk of 0.59% for a 10 µg/m3 increment in 24-h concentration (Orellano et al. 2020).

In a recent assessment, ambient air pollution ranked seventh among modifiable disease risk factors, above other factors such as high cholesterol, household air pollution, and alcohol use. (Murray et al., 2019); in contrast to the other risk factors, air pollution is not easily adaptable at individual levels.

Recent studies have reported that more than three-quarters of the people in India are exposed to pollution levels higher than the limits recommended by the National Ambient Air Quality Standards in India (NAAQS) and significantly higher than those recommended by the World Health Organization. Despite the poor air quality, monitoring air pollution levels is limited even in large urban areas in India and virtually absent in small towns and rural areas. The lack of data results in a minimal understanding of spatial patterns of air pollutants at a local and regional level. (Agrawal et al., 2021)

Except in south Africa, Air quality monitoring in other regions of the African continent is not well established, resulting in a lack of data for such studies. In the City of Cape Town, epidemiological time-series studies have shown short-term associations between air pollution and cardio-respiratory disease mortality (Wichmann and Voyi, 2012); however, none assessed the independent effects of multiple pollutants. Recent research findings by Global Burden of Disease (2019) identified that the total annual number of deaths caused by outdoor air pollution in Ethiopia was measured across all age groups, and both sexes were found to be around 9657 people. Out of this data, more than 80% of deaths are in the country's urban area.

A review from China found an increase of 0.75% and 1.12% for a corresponding rise of 10µg/m3 in NO2 and SO2 for Cardiovascular Disease deaths, respectively (Zhao et al. 2017). However, few studies have investigated the short-term association between hospital admissions and ambient air pollution in sub-Saharan Africa. There is an insufficient number of studies on ambient air pollution

(AAP) from sub-Sahara Africa (SSA), and most air pollution studies are on indoor air pollution due to the burning of fuel for household use.

4.2 Methodology and Instrumentation

4.2.1 Study area

This study was located at Addis Ababa, the capital city of Ethiopia, which is located between 9.03° N, latitude and 38.74° E, longitude which covers an area of 540 square kilometers (54,000 hectares) in a plateau ranging from 2200-2800 meters of altitude above sea level. The Koshe dumpsite spans an area of 37 hectares, located 13 km Southwest of the city center in the middle of the Kolfe Keranio sub-city and Nefas Silk Lafto Subcity, which is currently surrounded by residential houses and institutions, with the only dumpsite serving the Addis Ababa City since 1964.

Addis Ababa city has 11 sub-cities, and an air pollution data collection study was conducted in all sub-cities of Addis Ababa except in the Gulele sub-city (Figure 4.1). This study was located at 12 selected areas of Addis Ababa city, including the Koshe solid waste disposal site, measured for Eight months.

The pollutant measured was collected from 12 selected locations and study areas in Addis Ababa city, namely Koshe Dump Site, Lebu Square, Megenagna Square, Stadium, Goro Square, Akaki Kality Square, Kotebe Square, Torhayloch Square, Bole Airport Square, Menilik Hospital Square, Ayat (Derartu) Square and the Mayor Office Center (Figure 4.2).

The study focuses on the trends of air pollution in the entire Addis Ababa city in comparison with the air pollution status of the Koshe open dump site. The pollutant measured was PM2.5. PM10, CO, NO_2, SO_2, and the Methane emission at Koshe dumpsite.

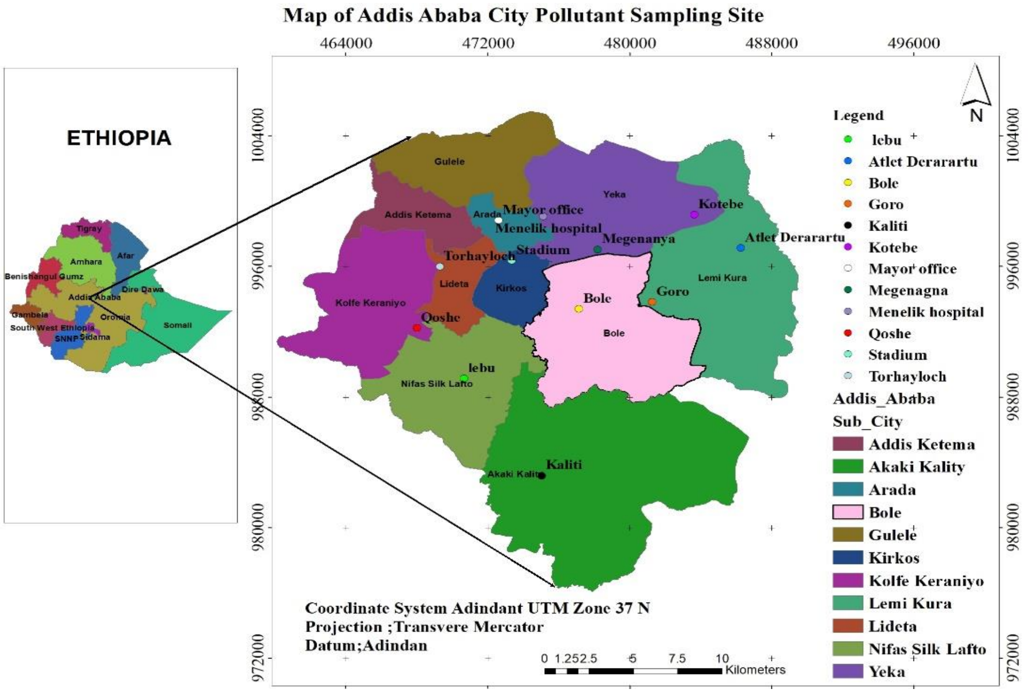
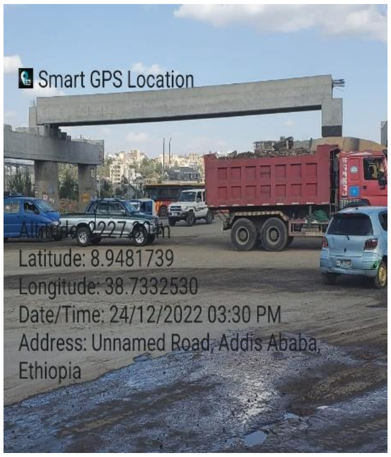
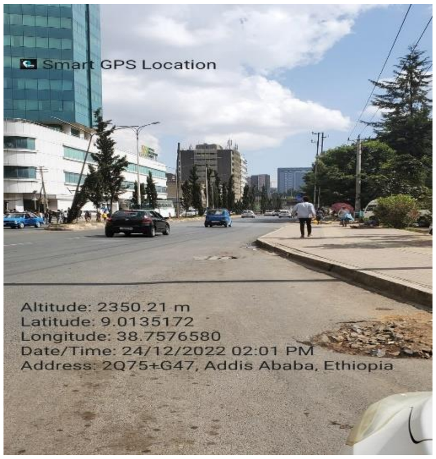


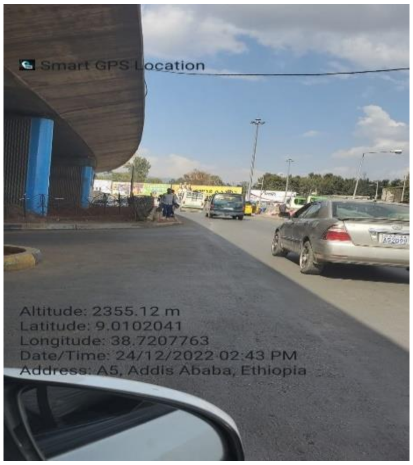
Figure 4-1 Air pollutant location of Addis Ababa city and Koshe Dump Site (2023)



a) Labu square



b) Stadium Square

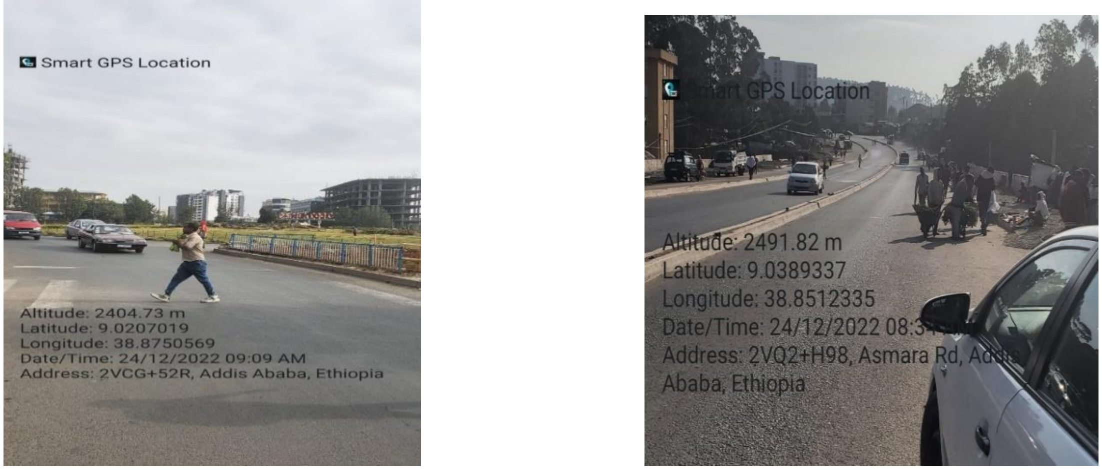


c) Tor Hayloch Square

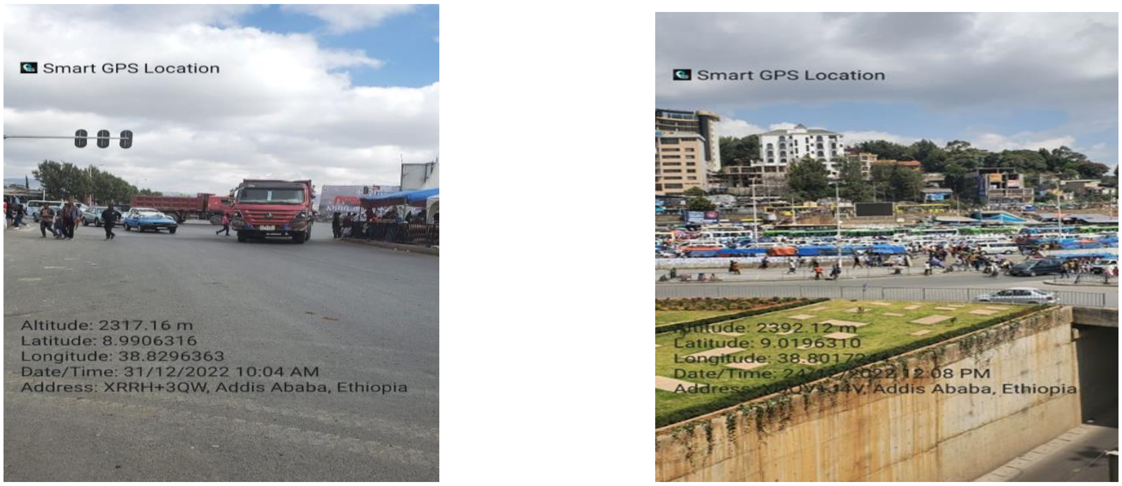
d) Menelik Hospital

e) Bole airport square

f) Mayor Office Center



g) Atlet Derartu Square h) Kotebe Square



i) Goro Square j) Megenaya Square

k) Akaki Kality Square l) Koshe Open Dump site

Figure 4-2 Addis Ababa City Ambient Air Pollutants collection sites (2023)

Table 4-1 GIS Location of the pollutant in Addis Ababa city (2023)

No	**Location name**	**Sub-city**	**Latitude**	**Longitude**	**Altitude asl in meter**
1	Lebu Square	Nifas Silk Lafto	8°56'53.4"N	38°43'59.7"E	2227
2	Torhayloch Square	Lideta	9°00'36.7"N	38°43'14.8"E	2355
3	Stadium Square	Kirkos	9°00'48.7"N	38°45'27.6"E	2350
4	Mayor office	Arada	9°02'09.0"N	38°45'02.8"E	2470
5	Menelik hospital	Arada	9°02’16.5” N	38°46’25.4”E	2454
6	Megenanya Square	Bole	9°01'10.7"N	38°48'06.2"E	2392
7	Bole Airport	Bole	8°59'12.2"N	38°47'31.5"E	2331
8	Atlet Derarartu Square	Bole/Lemi Kura	9°01'14.5"N	38°52'30.2"E	2405
9	Kotebe Square	Yeka	9°02'20.2"N	38°51'04.4"E	2492
10	Goro Square	Bole	8°59'26.3"N	38°49'46.7"E	2317
11	Kaliti Square	Akaki Kality	8°53'40.0"N	38°46'22.7"E	2160
12	Koshe Square	Kolfe Keranyo	8°58'36.2"N	38°42'31.9"E	2287

Table 4-2 Weather condition and metrological data of Addis Ababa City from July 2022-May 2023

Month	Weather condition	Ave. Temp in (°C)	Rainfall in mm Average	Wind speed miles/ hour	Wind direction
August 2022	Rainy/Wet	18.6	269	4.5	SW (21%), S(23%) and W(32%) total 76%
October 2022	Partly rainy	16.2	40	6	NE (23%) SE (18%) and E(44%) total 85%
Nov. 2022	Sunny /Dry	15.8	9	8	E(55%) SE (15%) and NE(20%) total 90%
Dec. 2022	Sunny /Dry	16	13	5	E(64%) and NE (20%) total 84%

Month	Weather condition	Ave. Temp in (°C)	Rainfall in mm Average	Wind speed miles/ hour	Wind direction
January 2023	Sunny /Dry	16.2	20	7.7	E(74%) and SE (13%) total 87%
March 2023	Partly rainy	17.4	80	7	NE(9%) E(35%) SE(13%) S(20%) Total 77%
April	Partly rainy	18.2	95	6	E(43%) NE(16%) SE(12%) total 71%
May	Partly rainy	18.1	91	3	E (23%) SE(10%) S(19%) SW(12%)

According to the Ethiopian Metrological Service data, the climate of Addis Ababa city is subtropical, influenced by altitude, with a rainy season from June to September and the wettest month being August. The driest period goes from November to January. The rain showers gradually increase from February to May, but there are still many hours of sunshine. The driest weather is in November, when an average of 9 mm of rainfall occurs. The wettest weather is in August when an average of 269 mm of precipitation occurs (Table 4.2).

The winter season is classified as the sunny and dry season during December, January, and February. The summer season is classified as the wet season (monsoon season) and the heaviest rainy season in the months of June, July, August, and September. The Autumn season has experienced occasional showers in the months of March, April, and partially May.

4.2.2 Instrumentation Plan

To monitor the air pollutants in all selected locations of the Addis Ababa city and Koshe open dump site, Aeroqual 200/500 series instruments were used to record the data from Aeroqual readings across all the selected twelve locations. The Series 200/500 air quality sensor enables accurate real-time surveying of common outdoor air pollutants, all in an ultraportable handheld monitor. During the study period, PM2.5, PM10, CH4, CO2, CO, and SO2 sensor heads were used for measuring the concentrations of each specific gas, and all sensor heads were interchangeably used on the same base unit, and data were collected for eight months to evaluate the trends of emission.

The Aeroqual Series 200/500 Monitor displays the minimum, maximum, and 10-minute average gas concentrations of the selected location over the measurement period. The concentration unit selection was displayed in either ppm or converted into microgram per cubic meter (µg/m^3) based on WHO and the Ethiopian Environmental Protection Authority (EPA) standards and guidelines. The collected data were compiled and tabulated in proper form. They were subjected to statistical analysis to present and interpret the collected data in chart and graphical form using trend analysis.

During the data collection period, the measured location's Latitude, longitude, and altitude were recorded by smart GPS Location software. The sample pollutant measured was taken for 8 months (August 2022, October 2022, November 2022, December 2022, January 2023, March 2023, April 2023, and May 2023). Pollutant sample data was collected in the morning at 7:AM-11 AM and in the afternoon at 1:PM-5 PM, and average data was collected each month (Figure 4.3).

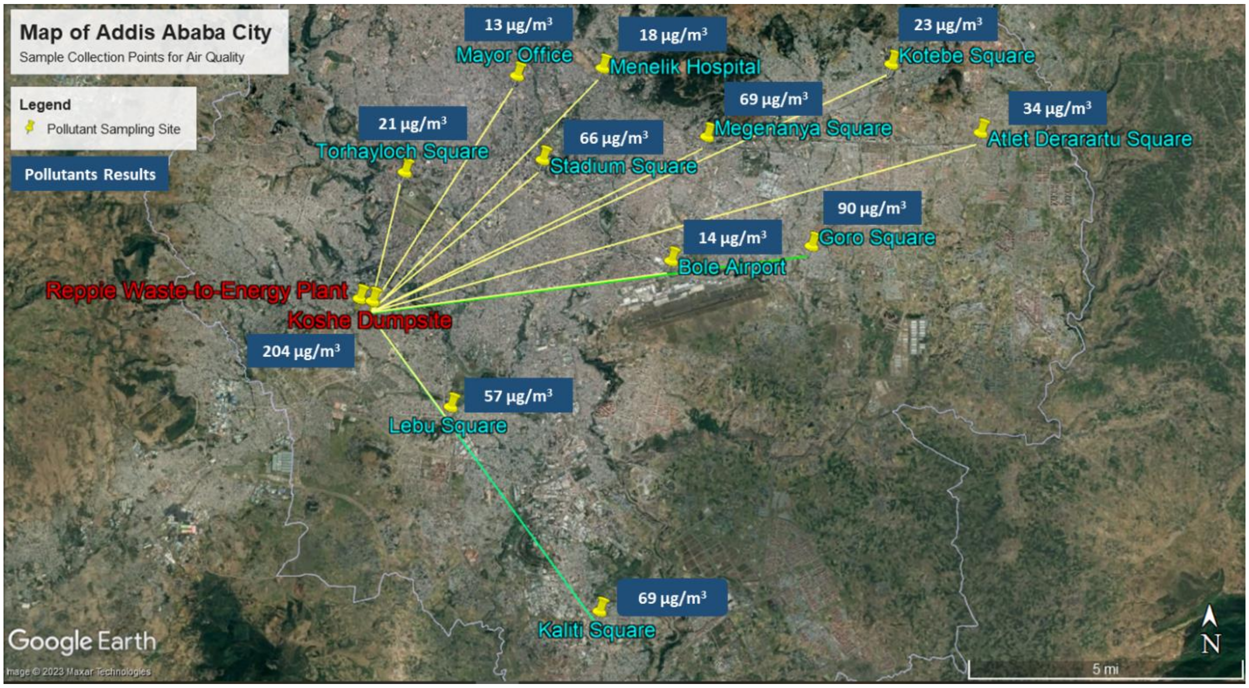


Figure 4.3 Location Site of Pollutants and its distance from Koshe dump site of Addis Ababa City

4.3 Results and Discussion

4.3.1 Ambient Air Quality in Addis Ababa City and Koshe Dump Site

Primary data of ambient air quality data was collected from 12 locations in Addis Ababa city to identify, evaluate, and determine the emission level of the identified major pollutants. Based on the standards and guidance set by the World Health Organization (WHO) and the Ethiopian Environmental Protection Authority, major pollutants were identified to measure the air quality of Addis Ababa city and particularly the Koshe open dump site.

The pollutants analyzed in this study were Particulate Matter ($PM_{2.5}$), Particulate Matter (PM_{10}), Carbon monoxide (CO), Nitrogen dioxide (NO_2), Sulfur dioxide (SO_2), and Methane (CH4). The pollutants measured result in eleven (11) locations of Addis Ababa city were analyzed to compare with those measured at the Koshe Open dump site. In Addis Ababa city, the period of heavy rain and summer (Wet season) is from June to September and accounts for 80% of the annual rainfall, while slight rain occurs between March and May. The dry period (winter) is between October and January, with an average annual rainfall of 1200 mm.

The average air Pollutants measured in Addis Ababa City and Koshe Open dump site for eight months were separated into three major seasons, namely August 2022 and October 2022 (representing the wet and summer seasons), whereas; November 2022, December 2022, January 2023, (define the dry or winter season) and March, April and May 2023 (Represents partially rainy and partially sunny) Moreover, the trend analysis of the air quality of Addis Ababa city average and seasonal implication with the previous literature review were critically analyzed based on the pollutants measured result during the study period.

4.3.1.1 Particulate Matter (PM2.5)

Figure 4.4 presented the trends of Eight-month PM2.5 concentration of Addis Ababa city average and the Koshe dump site, which has recorded a remarkable increase during the study period exceeding the standard set by both the World Health Organization (WHO) and the Ethiopian Environmental Protection Authority (EEPA) guidelines.

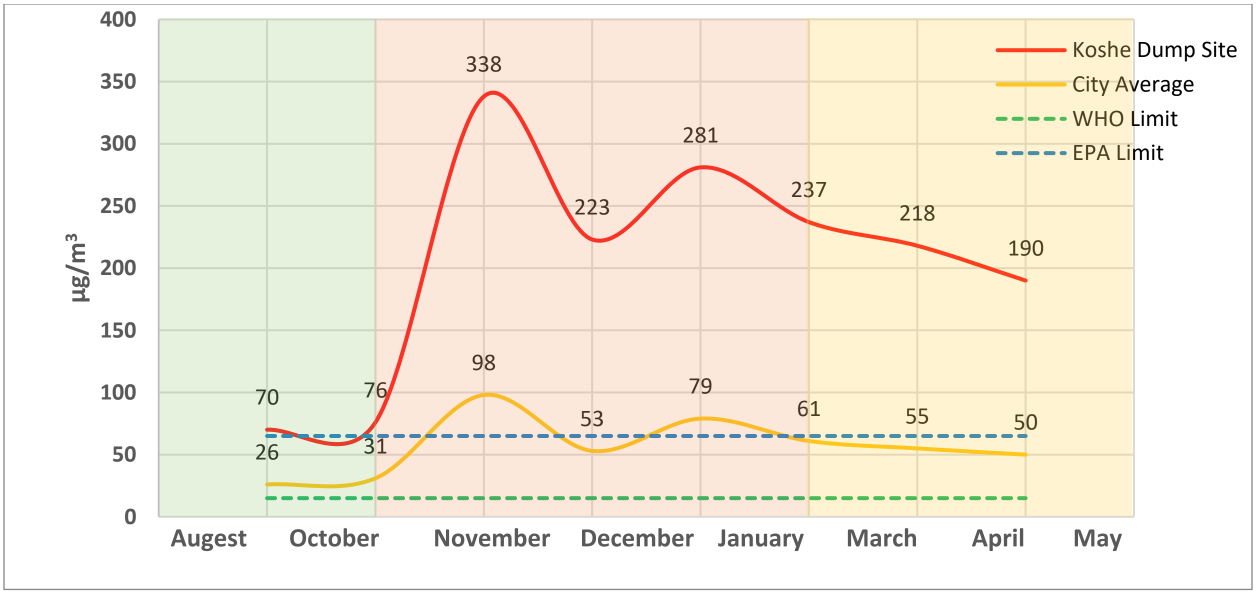


Figure 4-4 PM 2.5 Concentration in Addis Ababa city and Koshe open dumping site (2023)

Particulate Matter (PM2.5) emissions for the Addis Ababa city average showed that 26µg/m^3, 31µg/m^3, 98µg/m^3, 53µg/m^3, 79µg/m^3, 61µg/m^3, 55µg/m^3 and 50µg/m^3 during August 2022, October 2022, November 2022, December 2022, January 2023, March 2023, April 2023 and May 2023 respectively (Figure 4.7).

According to the data collected from a 57-year-old municipal solid waste (MSW) of Koshe Open dump site of the Addis Ababa city fine Particulate Matter (PM2.5) emissions statistical result showed that 70µg/m^3, 76µg/m^3, 338µg/m^3, 223µg/m^3 281µg/m^3, 237µg/m^3 218µg/m^3 and 190µg/m^3 during August 2022, October 2022, November 2022, December 2022, January 2023, March 2023 April 2023 and May 2023 respectively.

The eight-month average fine Particulate Matter (PM 2.5) emissions statistics result of Addis Ababa city result has shown 56.6µg/m^{3,} which is more than three times the standard set by WHO limit of 15µg/m^{3} but below the standard set by EEPA of 65µg/m^{3}. On the other hand, the eight-month average fine Particulate Matter (PM2.5) emissions statistics result of the Koshe dump site result has shown 204µg/m^{3,} which is more than thirteen times the standard set by the WHO limit of 15µg/m3 and more than three times the standard set by EPA of 65µg/m3. (Figure 4.5)

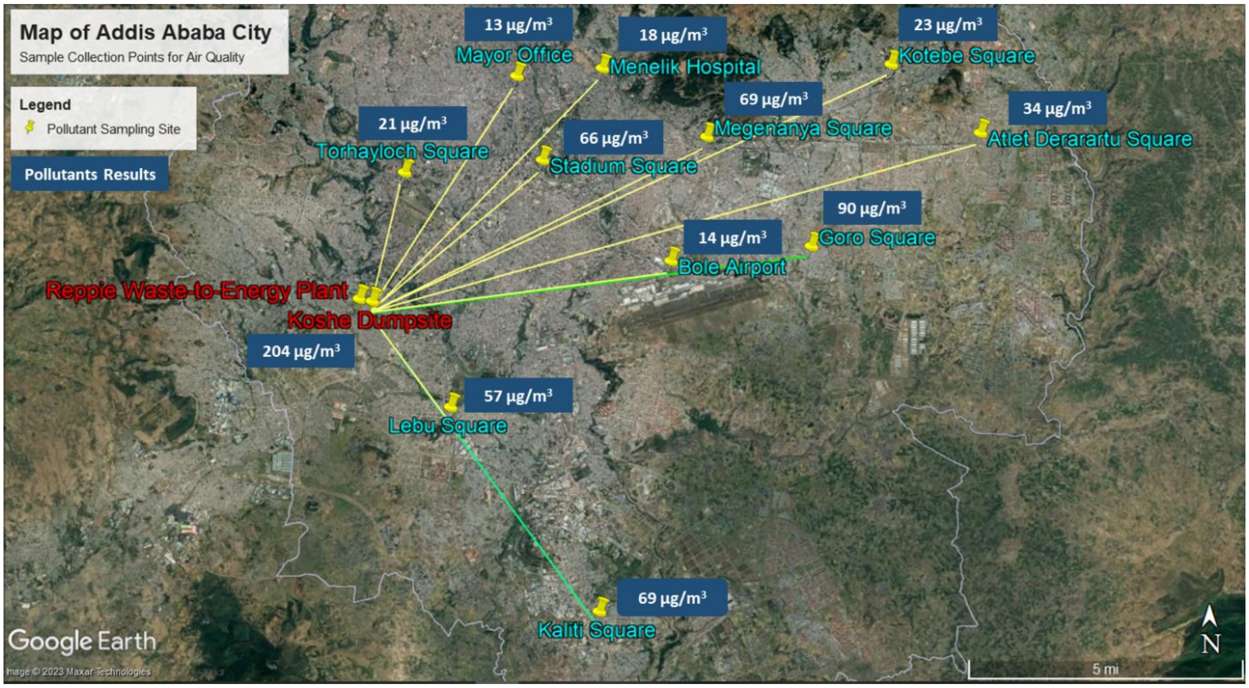


Figure 4.5 Location Site of the average result of PM2.5 Concentration in Addis Ababa City

Particulate Matter sources at the Koshe dump site were mainly from fine clouds of dust blown in the dump site, open waste burning, uncontrolled solid waste dumping site, and burning from Rephi Waste to energy plant. Whereas the sources of Particulate Matter in the city average, were mainly from vehicular traffic, open waste burning in the city, road constructions, use of solid fuels, industrial and manufacturing processes, construction area, and dust from local soils.

According to the previous study conducted by Bulto and Berkessa (2021), the average yearly PM2.5 concentrations in Addis Ababa, Beijing, and New Delhi were 23.6 µg/m3, 51.5 µg/m3, and 107.1µg/m3 respectively. This study indicated that the results of PM2.5 concentration in Addis Ababa city (Bulto and Berkessa 2021) recorded a low value of PM2.5 emission results compared to this study, indicating that particulate matter emissions have shown an increasing trend from year to year.

The PM2.5 concentration recorded on 21 November 2022 was found to be the highest pollutant data compared to the remaining Eight -month's PM2.5 concentration statistical result for both the Addis Ababa city average and the Koshe dump site. PM2.5 concentration result of the Koshe open dump site and the Addis Ababa city statistical result on 21 November 2022 has shown 338µg/m^3 and 98µg/$m^{3,}$ respectively. PM2.5 concentration result of the Koshe open dump site and the Addis Ababa city is greater than the result showed in August, October, December, January, and March (Figure 4.4).

This is due to the unexpected elevation of PM emissions on 21 November 2022; practicing open burning of solid waste in Addis Ababa city as an accepted norm and culture of the Ethiopian community, which unknowingly impacted air quality during “21 November” Memorial Day each year. On this specific day, most of the household members of the city are responsible for collecting and performing open burning of all types of solid wastes in the open air, including used tire and plastic wastes, which ultimately pollute the surrounding environment contributing to the higher PM emission level (Figure 4.4). This open burning of solid waste is a unique ceremony known as ‘‘Hidar Sitaten’’meaning a local Ethiopian Amharic language which means ‘‘Smoking November” annually practiced and commemorated for the memory of Spanish flu cases in Ethiopia on 21 November as a smoking holiday each year (Figure 4.4).

Open burning Practice in different parts of Addis Ababa City are shown in Figure 4.6. Open burning activities on ‘’Hidar Sitaten’ day are widely observed at the front of every resident's housing and premises, resulting in air pollution in the entire Addis Ababa city (Bulto 2020). Bulto (2020) further showed in his finding that the emission of PM2.5 from the open burning of solid waste was the main source of air pollution in Addis Ababa city on Hidar Sitaten day (21 November 21). According to his study, the highest PM2.5 concentration recorded in Addis Ababa city on Hidar Sitaten day (21 November) in 2019 was 215µg/m3, while the highest PM2.5 concentration during this study was 338µg/m^3 and the highest PM2.5 emission result than the previous study results.

Another study has identified that the increased concentration of fine dust in ambient air due to the open burning of solid waste is strongly associated with morbidity and mortality worldwide (Kim et al. 2016). A 2014 report in Dhaka City, Bangladesh, showed that major sources of air pollution include open landfills, incineration of plastic waste, industrial processes, surface dust, and vehicle emissions contribute about 85% of local air pollution (William, 2020).

Similarly, the major reasons for the higher PM2.5 concentration in the Koshe dump site were the disposed amount of waste in the site undergone without segregation, sorting of waste, and no compost facilities for the organic waste, which contributed to the highest emission level, including methane gas. In addition, the major sources of PM2.5 in the Koshe dump site were the incineration of plastic waste, Rephi waste to energy plant processes, and longtime dump site dust.

According to the recent studies by Garima et al. (2022), the concentration of PM2.5 in Togo, Lomé was (23.2µg/m^3), which is lower than Accra, Ghana (49.5µg/m^3), Abidjan, Côte d’Ivoire (23.8-113.4µg/m^3), and Kasuwa, Nigeria (65 µg m−3), indicating that while air quality is at unhealthy levels in Togo, it may not be as severe as several other African cities including the current study in Addis Ababa city.

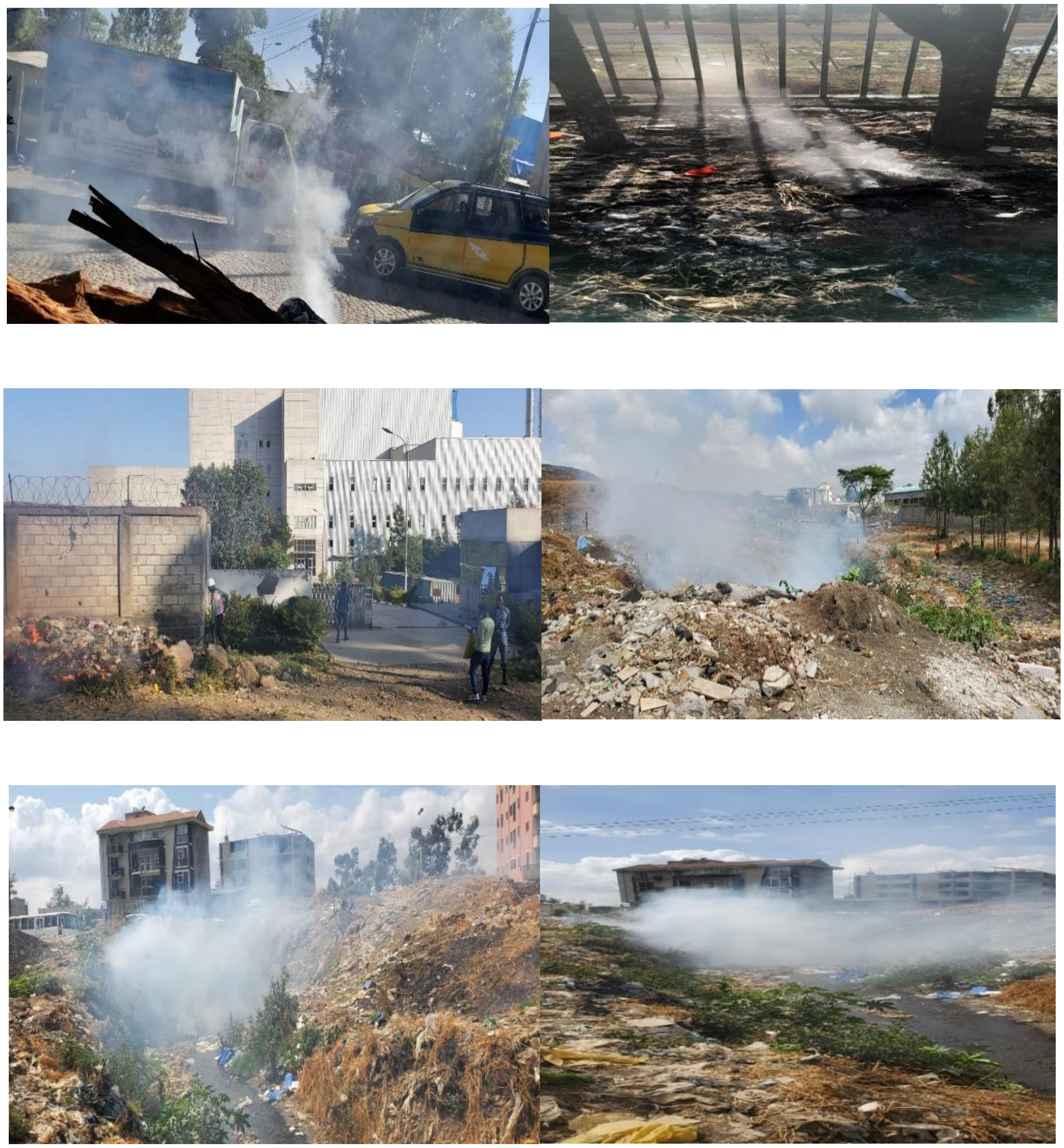


Figure 4-6 Open burning Practice in different parts of Addis Ababa City on 21 November (2023)

4.3.1.2 Particulate Matter (PM10)

According to the data presented in Figure 4.7 below, the trends of the eight-month PM10 concentration of Addis Ababa city average and the Koshe dump site have shown a significant rise during the study period exceeding the standard set by both World Health Organization (WHO) and the Ethiopian Environmental Protection Authority (EEPA) guidelines.

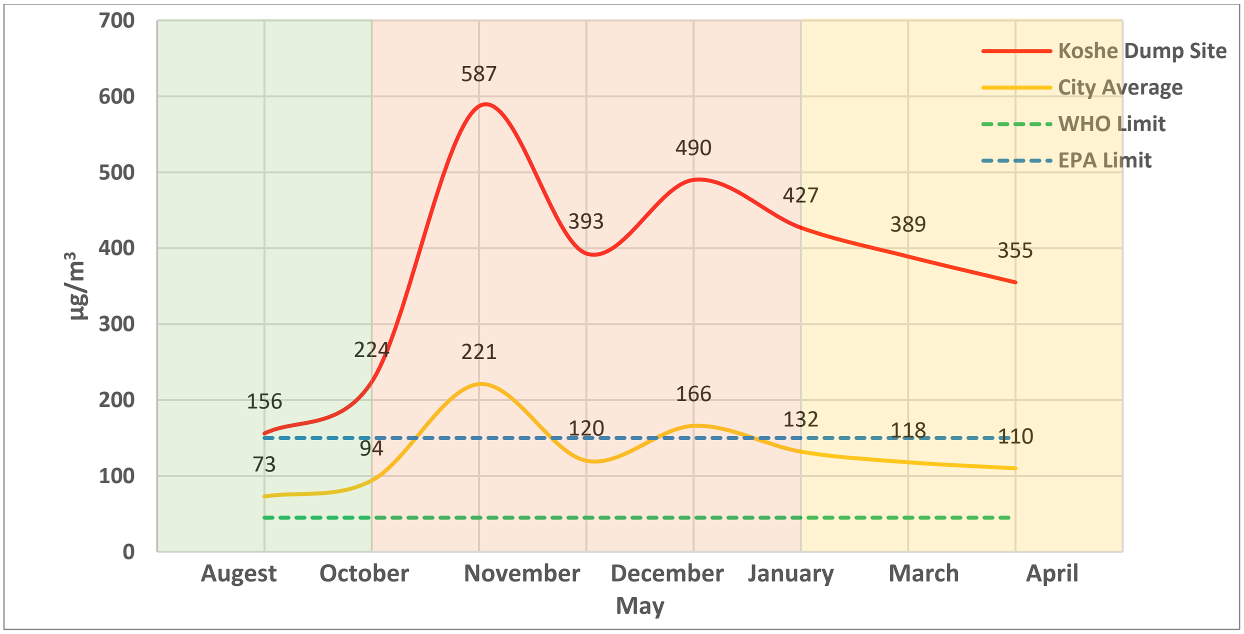


Figure 4-7 Trends of PM10 concentration in Addis Ababa City and Koshe dump site (2023)

Particulate Matter (PM10) emissions for the Addis Ababa city average recorded 73µg/m^3, 94µg/m^3, 221µg/m^3, 120µg/m^3, 166µg/m^3, 132µg/m^3, 118µg/m^3 and 110µg/m^3 during the month August 2022, October 2022, November 2022, December 2022, January 2023, March 2023 April 2023 and May 2023 respectively. Similarly, according to the data collected from Koshe Open dump site of the Addis Ababa city coarser Particulate Matter (PM10) emissions statistical result showed that 156µg/m^3,224µg/m^3,587µg/m^3,393µg/m^3 490µg/m^3,427µg/m^3 389µg/m^3 and 355µg/m^3 during the month August 2022, October 2022, November 2022, December 2022, January 2023, March 2023 April 2023, and May 2023 respectively (Figure 4.10).

The Eight-month average Particulate Matter (PM10) emissions statistics result of Addis Ababa city average result has showed 129µg/m^{3,} which is more than two times the standard set by the

WHO limit of 45µg/m^3 but below the standard set by EEPA of 150µg/m^3. On the other hand, the Eight-month average Particulate Matter (PM10) emissions statistical result of the Koshe dump site has shown 377µg/m^3, which is more than eight times the standard set by the WHO limit of 45µg/m^3 and more than two times the standard set by EPA of 150µg/m^3 (Figure 4.8).

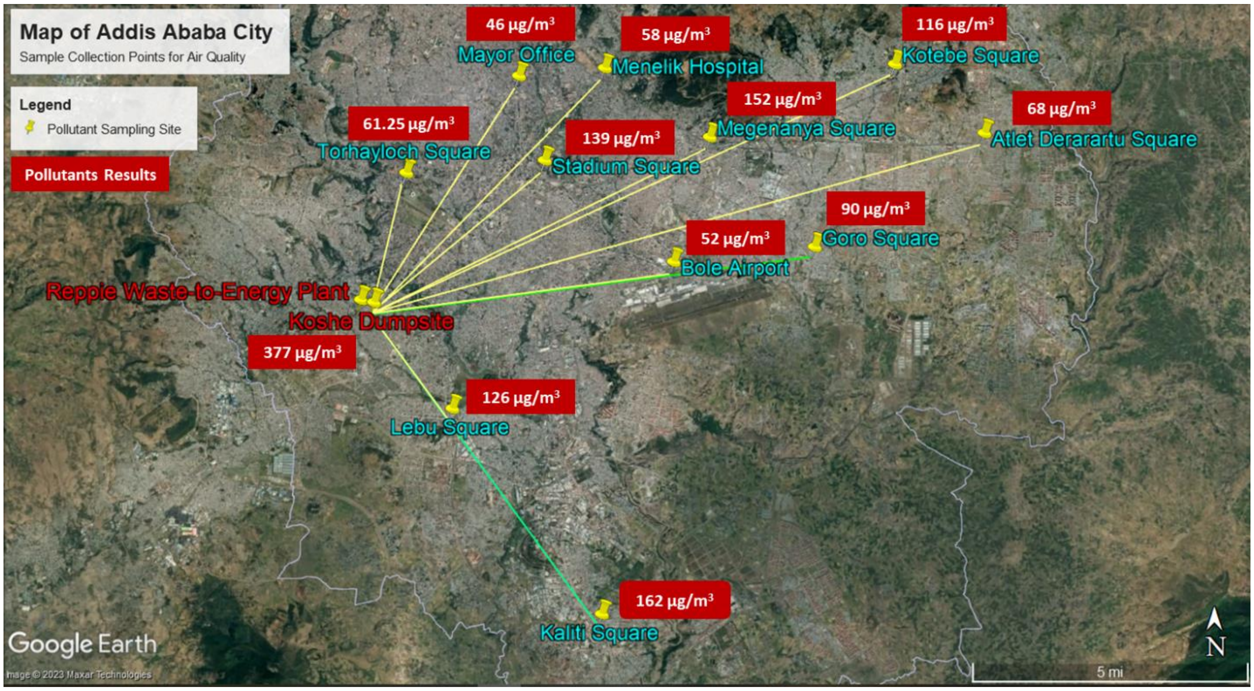


Figure 4.8 Location Site of the average result of PM10 Concentration in Addis Ababa City

Like the PM2.5 concentration result of the Koshe dump site and the Addis Ababa city average, the PM10 concentration of the Koshe dump site and the Addis Ababa city's average result on 21 November 2022 was registered very high with a remarkable difference as compared to the result recorded in the rest of the months under study.

Accordingly, the PM10 concentration result of the Koshe dump site and Addis Ababa city average on 21 November 2022 was 587µg/m^3 and 221µg/m^{3,} respectively, which is by far greater than the result recorded in the rest of the seven months. (Figure 4.7). The main reason for this unexpected elevation of PM emission on 21 November was due to the practice of open burning of solid waste activities in the entire city of Addis Ababa, including the Koshe open dump site on that specific day of the month. Recent research findings on PM10 concentration during open burning versus the normal time have shown a significant difference in emission levels.

PM10 concentrations in Malaysia during the normal time were found to be 45.0µg/m3 and 47.0µg/m3 in semi-urban (Muar) and urban cites (Cheras), respectively (Che Samsuddin et al., 2018). The result was lower than PM10 concentrations resulted in Addis Ababa city. Whereas during the smoke-haze phenomenon, PM10 concentrations in Muar and Cheras cities of Malaysia were 358 µg/m3 and 415 µg/m3, respectively, for the two cities, indicating a very unhealthy air quality. Local and transboundary smoke-haze has afflicted Malaysia for many years (Che Samsuddin et al., 2018).

The trends of PM10 concentration in Addis Ababa city and Koshe open dump site have shown an increasing trend during the study period. Lower PM10 concentration was registered in Addis Ababa city average and Koshe dump site during August 2022, which has shown a growing trend in November 2022. Then the concentration of PM10 in both Addis Ababa city and Koshe open dump site have shown a declining trend during April and May 2023.

Chalvatzaki et al. (2010), in a study of particulate matter concentrations at landfill sites in Crete, Greece, concluded that the average concentrations of PM10 inside the landfill facilities ranged between 113 and 4,597 µg/m3, which is similar to the over 500-3,344 µg/m3 found in the landfill sites and within 250 meters from their vicinity.

4.3.1.3 Carbon Monoxide (CO)

According to Figure 4.9, the trends of the six-month CO concentration of Addis Ababa city average is below the standard set by the World Health Organization (WHO) and the Ethiopian Environmental Protection Authority (EEPA) guidelines. In comparison, the trends of the six-month CO concentration of the Koshe dump site have been recorded as exceeding the standard set by the World Health Organization (WHO) and below the Ethiopian Environmental Protection Authority (EEPA) guidelines, respectively.

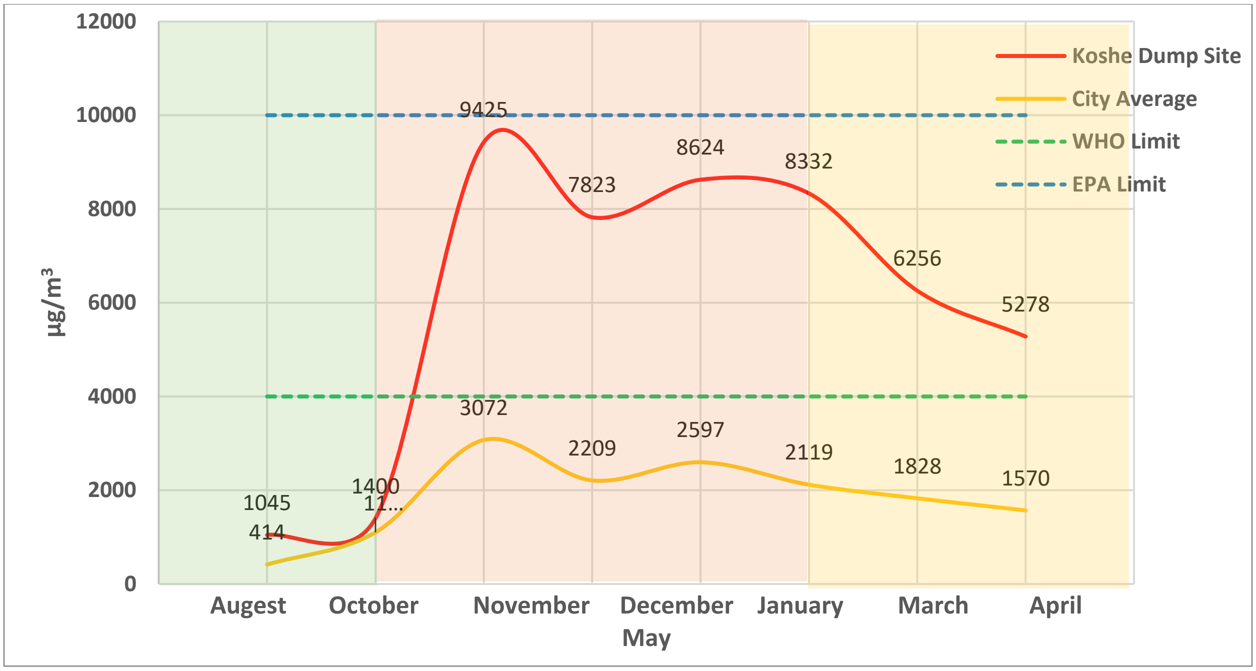


Figure 4-9 Trends of CO concentration in Addis Ababa city average and Koshe Dumpsite (2023)

The concentration of CO at Addis Ababa city average during August 2022, October 2022, November 2022, December 2022, January 2023, March 2023, April 2023, and May 2023 were 414µg/m^3, 1101µg/m^3, 3072µg/m^3,2209µg/m^3,2597µg/m^3 and 2119µg/m^3, 1828µg/m^3, and 1570µg/m^3 respectively which was below the standard set by World Health Organization (WHO) of 4000µg/m^3 and the Ethiopian Environmental Protection Authority (EEPA) guidelines of 10,000µg/m^3 (Figure 4.9).

The concentration of CO at Koshe dump site during August 2022, October 2022, November 2022, December 2022, January 2023, March 2023, April 2023, and May 2023 were 1045µg/m^3, 1400µg/m^3, 9425µg/m^3, 7823µg/m^3, 8624µg/m^3, 8332µg/m^3 2119µg/m^3 and 2119µg/m^3 respectively which is below the standard set by the Ethiopian Environmental Protection Authority (EEPA) guidelines of 10,000µg/m^3.

Similarly, the CO concentration of Koshe dump sites in August 2022, October 2022, April 2023, and May 2023 were below the standard set by the World Health Organization (WHO) of 4000µg/m^3. However, CO concentration at the Koshe dump site in November 2022, December 2022, and January 2023 exceeded the standard set by the WHO limit of 4000µg/m^3. This is because during winter and dry seasons (November 2022, December 2022, and January 2023), sources of

CO concentration at the Koshe dump site were mainly from open waste burning and burning form Rephi Waste to the energy plant.

According to the study conducted in Nigeria by Popoola et al. (2022), the concentration of CO emitted from the open burning of solid waste in Ilorin, Nigeria, showed that the hourly average concentration was 25,267µg/m3, the daily average concentrations were 4,609µg/m3, and the Results for annual concentrations were 4470 µg/m3 which exceeded the limit set by WHO (Popoola et al., 2022).

The results from other studies on the seasonal variations of CO concentration were shown in the ambient environment of Gazipur City of Bangladesh. The highest CO (2370 µg/m^3) concentration was measured in the winter season, 2017, and the lowest concentration (730 µg/m^3) during the monsoon season, 2018. Similarly, the seasonal cycle of CO had a high peak in the winter and a base in the summer season (Mukta et al. 2020). Seasonal variations with maximum concentrations of CO in winter and minimum concentrations in summer were observed in Kuwait and Japan. (Mukta et al., 2020).

Moreover, both Addis Ababa city and Koshe open dump site, experienced uncontrolled incineration of solid waste on 21 November, which has contributed to increased emission of carbon monoxide (CO) smokes, affecting the environment negatively in both Koshe open dump site and most location of the Addis Ababa city. The increased emission of CO in Addis Ababa city and the Koshe open dumpsite may be toxic due to the nature of the elements in the waste dumps resulting in respiratory disease.

A study conducted in Owerri dumpsite, Nigeria, by Adogu et al. (2015) reported that burning of solid waste near residential areas is frequently practiced, which has increased in recent years and emitting CO gas which has caused many health problems by polluting the air. (Adogu et al. 2015). CO inhalation is the most common cause of poisoning in the industrialized world. It can cause multi-organ dysfunction and frequently necessitate admission to intensive care units. (Green and Abbey,2022).

4.3.1.4 Nitrogen Dioxide (NO_2)

According to Figure 4.10 presented below, the trends of the Eight-month Nitrogen dioxide concentration of Addis Ababa city average exceed the standard set by the World Health Organization (WHO) but below the Ethiopian Environmental Protection Authority (EEPA) guidelines. Similarly, the trends of the Eight-month Nitrogen dioxide concentration of the Koshe dump site exceeded the standard set by the World Health Organization (WHO) of 25µg/m^3 and below the Ethiopian Environmental Protection Authority (EEPA) guidelines of 200µg/m^3.

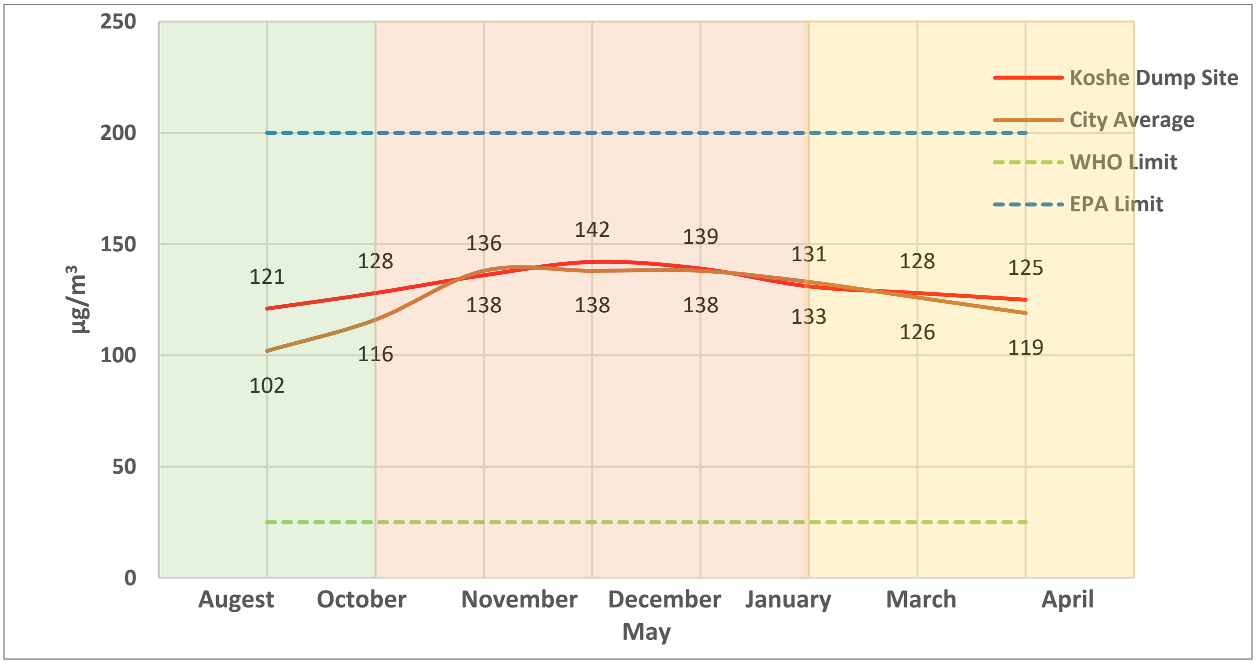


Figure 4-10 Trends of Nitrogen Dioxide concentration in Addis Ababa city average and Koshe dump site.

The concentration of NO_2 at Addis Ababa city average during August 2022, October 2022, November 2022, December 2022, January 2023, March 2023, April 2023, and May 2023 were 102µg/m^3, 116µg/m^3, 138µg/m^3,138µg/m^3, 138µg/m^3,133µg/m^3 126µg/m^3 and 119µg/m^3 respectively exceeding above the limit of WHO standard and below the limit of EPA standard (Figure 4.10).

The average concentration of NO_2 at Koshe open dump was 121µg/m^3,128µg/m^3,136µg/m^3 142µg/m^3 and 139µg/m^3 131µg/m^3, 128µg/m^3 and 125µg/m^3 during August 2022, October 2022, November 2022, December 2022, January 2023, March 2023, April 2023 and May 2023 respectively exceeding above the limit of WHO standard and below the limit of EPA standard (Figure 4.10).

Recent studies have shown that the seasonal variations of NO_2 concentration were shown in the ambient environment of Gazipur City, Bangladesh, from October 2017 to September 2018. The highest concentration of NO_2, 110.49µg/$m^{3,}$ was measured in the dry winter season (December-February),2017, and the lowest concentration of NO_2, 21.40µg/$m^{3,}$ was measured during the monsoon season (June-September), 2018. (Mukta et al., 2020). The study result of Gazipur city of Bangladesh showed that it was much lower than the concentration of NO2 compared to the Koshe open Dump site of Addis Ababa City.

A significant concentration of NO_2 was found around the Koshe dump site of Addis Ababa city during the study period showing increasing trends during the dry season (November 2022, December 2022, and January 2023). The sources of NO_2 emissions In Addis Ababa city and Koshe dump site were primarily from open burning of solid waste, fossil fuel burned in motor vehicles and engines, Incineration of Solid waste by Rephi Waste to Energy power plants, industries, and emissions from old vehicles and other equipment.

According to the study conducted in Nigeria by Popoola et al. (2022), the concentration of NO_2 emitted from the open burning of solid waste in Ilorin, Nigeria, showed that the hourly average concentration was 4,700µg/m3, the daily average concentrations were 730µg/m3, and the results for annual concentrations were 130µg/m3. The percentage recommended limit by World Bank has exceeded 15 folds. Popoola et al (2022).

4.3.1.5 Sulfur Dioxide (SO_2)

According to Figure 4.1 presented below, the trends of the six-month SO_2 concentration of Addis Ababa city average and the Koshe dump site have been recorded a remarkable increase during the study period exceeding the standard set by both World Health Organization (WHO) of 40µg/m^3 and the Ethiopian Environmental Protection Authority (EEPA) guidelines of 125µg/m^3.

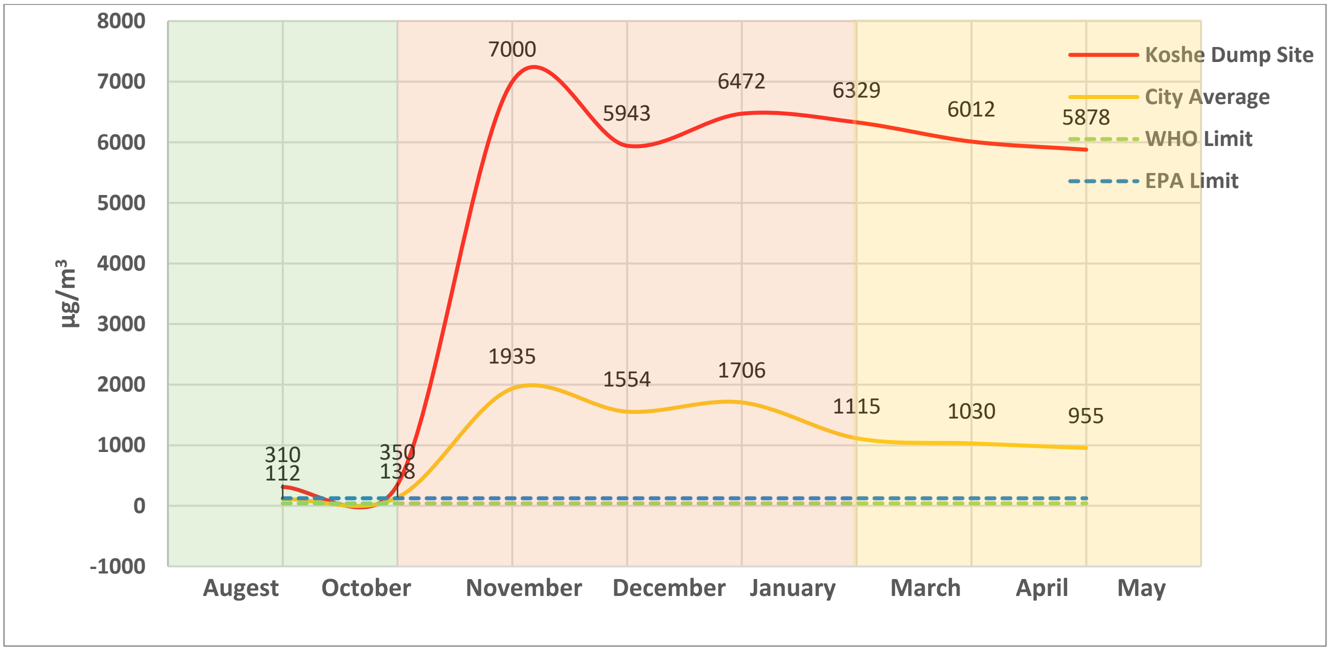


Figure 4-11 Trends of Sulfur dioxide concentration in Addis Ababa city and Koshe dump site (2023).

The average concentration of SO_2 at the Koshe Open dump site during August 2022, October 2022, November 2022, December 2022, January 2023, March 2023, April 2023, and May 2023 were 310µg/m^3, 350µg/m^3, 7000µg/m^3, 5943µg/m^3 6472µg/m^3 and 6329µg/m^3 and 6012µg/m^3 and 5878µg/m^3 respectively exceeding the limit set by both WHO and EPA standard with highest extremes**.**

Similarly, the average concentration of SO_2 in Addis Ababa city average during August 2022, October 2022, November 2022, December 2022, January 2023, March 2023, April 2023, and May 2023 were 112µg/m^3, 138µg/m^3, 1935µg/m^3,1554µg/m^3 1706µg/m^3, 1115µg/m^3, and 1030µg/m^3 and 955µg/m^3 respectively exceeding the limit set by of both WHO and EPA standard.

From the above data, the highest average concentration of SO_2 registered was 7000µg/m^3 in 21 November 2022, and the lowest average concentration of SO_2 recorded was 310µg/m^3 in August

2022, respectively. This is because, during the dry season concentration of ambient air pollution like SO_2 was dramatically increased due to the uncontrolled incineration of solid waste during the dry season (November, December, and January), which has caused increased emission of sulfur dioxide at Koshe dump site during incineration of the municipal waste which affects the environment negatively.

According to the study conducted in Nigeria by Popoola et al. (2022), the concentration of SO_2 emitted from the open burning of solid waste in Ilorin, Nigeria, showed that the hourly average concentration was 954 µg/m3 for the daily average concentrations was 144 µg/m3 and the results for annual concentrations were 24µg/m3. Higher concentration of SO_2 emissions in Addis Ababa city and Koshe dump site was due to the open burning of solid waste from fossil fuel burned in motor vehicles and engines, Incineration of Solid waste by Rephi Waste to Energy power plants and old vehicles.

4.3.2 Seasonal Implication of Ambient Air Quality in Addis Ababa and Koshe Dump Site

4.3.2.1 Seasonal Implication of PM2.5

Figure 4.12 presented PM2.5 concentration for the Addis Ababa city average and Koshe open dump site, indicating an increasing trade during the study period of eight months and, most importantly, there is a remarkable difference in the result of concentration of PM2.5 during the winter (dry season) as compared to the summer (wet) season.

According to the weather classification of Addis Ababa city, the wet or summer seasons of the months are June, July, August, September, and partly October. The dry or winter season of the months are November, December, January, and February. Whereas March, April, and May months are found to be rainy and cloudy in relation to the other dry season of the months.

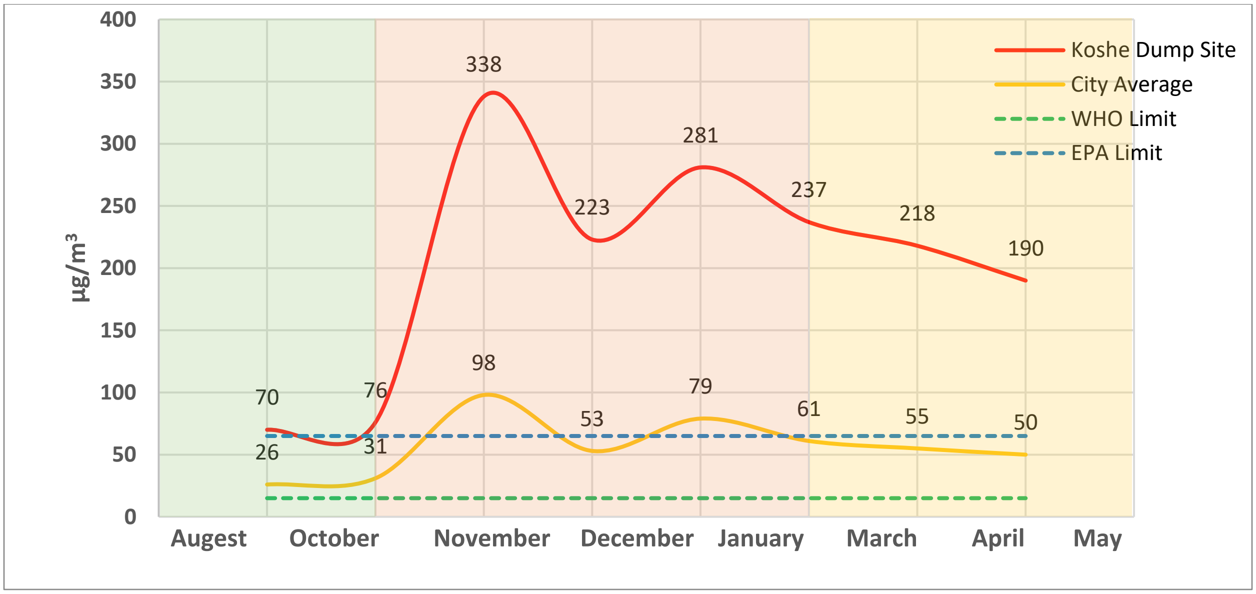


Figure 4-*12* Seasonal Implication of PM2.5 concentration in Addis Ababa city and Koshe dump site (2023)

The result of PM2.5 concentration in the Addis Ababa city Average and Koshe Open dump site during the summer season (August and October) has shown a declining trend at the beginning, and the concentration has increased extremely during the winter/dry season of the month (November, December, and January). Consequently, the concentration of PM2.5 has shown a declining trend during the spring season (March, April, and May) of the study period, slightly higher than the PM2.5 concentration recorded during the summer season (Figure 4.12).

PM2.5 concentration in Addis Ababa city average during the Summer/wet season (August 2022 and October 2022) were 26µg/m^3 and 31µg/m^{3,} respectively, with very much lower results. Whereas PM2.5 concentration in Addis Ababa city average during the Winter/dry season of the month (November 2022, December 2022, and January 2023) were 98µg/m^3, 53µg/m^{3,} and 79µg/m^{3,} respectively, with very much higher results. On the other hand, PM2.5 concentration in Addis Ababa city average during March 2023, April 2023, and May 2023 were 61µg/m^3, 55µg/m^{3,} and 50µg/m^{3,} respectively, showing a declining trend. This is because, during the wet and summer seasons, the concentration of PM2.5 becomes much lower than during the dry or winter season of the month.

PM2.5 concentration in Addis Ababa city average during March 2023, April 2023, and May 2023 were 61µg/m^{3,} 55µg/m^{3,} and 50µg/m^{3,} respectively, showing a declining trend. This is because, during the wet and summer seasons, the concentration of PM2.5 becomes much lower than during the dry or winter season of the month. Like the weather condition during the wet season, the concentration of PM2.5 during March, April, and May 2023 has shown a declining trend but not as lower as in August and October 2022

Similarly, the PM2.5 concentration of Faisalabad city in Punjab province, Pakistan, was recorded to be decreased significantly in the month of August 2013, which was found to be lower than the permissible limits of WHO (Niaz et al. 2016).

The trends of PM2.5 concentration in the Koshe dump site during the eight months of the study period showed an increasing trend with higher results than the average PM2.5 concentration in Addis Ababa city. This is because, during the wet season, the wind speed was slower than the dry season diluting PM2.5 concentrations to course one. According to the weather condition and metrological data of Addis Ababa city, the wind speed of the city in August 2022 was 4.5 miles per hour which were lowest than in November 2022 with a speed of 8 miles per hour, indicating that wind speed is relatively lower in the summer as compared to the dry season of the month.

Research study has revealed that the lower average PM2.5 concentrations during the summer could be due to prevailing southerly or southeasterly winds drawing clean marine air masses from the South China Sea or the Northwest Pacific Ocean, diluting PM2.5 concentrations (Wang et al., 2005; Yuan et al., 2006).

PM2.5 concentrations in the Koshe dump site during the summer/wet season (August 2022 and October 2022) were 70µg/m^{3} and 76µg/m^{3,} respectively, with lower results. On the other hand, PM2.5 concentration in the Koshe dump site during winter/dry season (November 2022, December 2022, and January 2023) were 338µg/m^{3,} 223µg/m^{3,} and 281µg/m^{3,} respectively, with higher results. On the other hand, PM2.5 concentrations in the Koshe dump site during March 2023, April 2023, and May 2023 were 237µg/m^{3,} 218µg/m^{3,} and 190µg/m^{3,} respectively, showing a declining trend. Even though the PM2.5 concentration in the Koshe dump site during March, April, and May

2023 showed a declining trend, it was still exceeding the standard set by the WHO limit of 15µg/m^3 and the standard set by EEPA of 65µg/m^3 (Figure 4.4).

In Dhaka, the average concentration of PM2.5 from 2016 to 2020 was 86.1 µg/m^3 (William, 2020) and seasonally 37.7µg/m^3 in September 2019, 64.6µg/m^3 in October 2019 and 181.8µg/m^3 in January 2020 with an annual average concentration of 83.3µg/m^3 (IQAir, 2020c). This study result is higher than the PM2.5 concentration result of the current study in Addis Ababa City.

A recent study showed that during winter or dry season (November to January), PM 2.5 mean concentrations in three cities of Darus Salam, Narayonganj, and Gazipur were found to be 175.8 µg/m3, 203.2 µg/m3, and 167.5 µg/m^3 respectively. Whereas during rainy or wet season (June to September), PM2.5 mean concentrations in the cities of Darus Salam, Narayonganj, and Gazipur were found to be 32.8 µg/m^3, 26.3 µg/m3and 27.4 µg/m^3 respectively. (DOE, 2019a).

The findings from this study have shown that PM2.5 concentration in Addis Ababa city average and Koshe dump site was recorded the highest concentration level during the smoky month of 21 November 2022 with PM2.5 concentration of 98µg/m^3 and 338µg/m^{3,} respectively. During this month, Addis Ababa city was covered by smoke with open burning of all types of solid waste like plastic waste, used tires, and household waste, starting from early in the morning throughout the daytime polluting the air of the entire city.

Moreover, in Addis Ababa city, the dry season of the months is highly preferable for the traffic movement of all types of vehicles than the wet or summer season. The trends of waste incineration and open burning of solid waste are much more practiced in the dry season than in the wet season of the month. Particularly, the Koshe open dumpsite was known for its potential to generate the highest particulate matter (PM) emission during the dry season than in the wet season, which can pose respiratory health problems specifically for the communities residing in the adjacent dumpsite. The frequent open burning, movement of heavy-duty vehicles, unloading, and compaction of waste at the MSW dumpsite emits Particulate matter.

Masum and Pal (2020) studied that In Chittagong city of Bangladesh, the mean concentration of PM2.5 were 124.52 and 41.16 µg/m3 during the dry and wet seasons, respectively. The PM2.5

concentration recorded in In Chittagong City of Bangladesh is lower than in the Koshe open dump site. Still, the trends during the wet and dry seasons were found to be similar, showing the highest emission of PM2.5 during the dry season.

Recent studies have also shown that communities living adjacent to the vicinity of landfill sites in Hong Kong areas located less than 500m from the landfill site, namely Southeast New Territories (SENT), recorded PM2.5 concentrations in summer and winter differently. In summer, PM2.5 concentrations were generally low from August to September and achieved maximum in early October. In SENT, PM2.5 concentrations during summer were at a minimum from July to August, followed by a peak observed in October. Under real-time PM2.5 monitoring, PM2.5 concentrations were significantly higher in winter than in summer (Lui et al. 2019).

Similarly, PM2.5 concentrations at Koshe open dump site were significantly higher in winter than in summer. PM2.5 concentrations at Koshe open dump site during summer (August 2022) resulted in 70µg/m^{3,} whereas PM2.5 concentrations at Koshe open dump site during winter and dry season (November 2022, December 2022 and January 2023) resulted in 338µg/m^{3}, 223µg/m^{3,} and 281µg/m^{3} respectively (Figure 4.4).

The association between the abundance of PM2.5 and exposure to it has both short– and long-term health effects (Tainio et al., 2021). However, there is a severe lack of studies associating PM2.5 with health hazards in Ethiopia, though a couple of recent works estimated the disease burden for the current and long–lasting air pollution in Addis Ababa city.

Higher concentration of PM2.5 has a negative impact on the communities living around Koshe open dump site. Most of the time, communities living around Koshe open dump site undergo social activities like shopping, children school, and playing during the dry season, which is easily exposed to fine Particulate Matter higher than during the summer. Particulate matter concentration around open dumpsites is a major environmental problem, especially for the air we inhale. The PM2.5 concentration has lifetimes of days and weeks and has capacity of traveling distance of up to 1000 kilometers polluting the environment faster than PM10 concentration level (Kim et al. 2015).

According to the Space Environment Research Laboratory, Center for Atmospheric Research conducted in Nigeria (Abulude and Abulude, 2021), the concentrations of Particulate Matter PM2.5 concentrations during the dry season were 61µg/m3 in Delta State, 63.63µg/m3 in Osun State,79.1µg/m3 in Kebbi State, 86.26µg/m3 in Lagos State and 66.6µg/m3 in Abuja State. High values of PM2.5 concentrations were found to be reported in Lagos state. The overall air pollution situation in the cities was serious in the months of December, January, and February 2021, according to an exploratory study of the air quality of the states over a period of 2-7 months (Abulude and Abulude, 2021).

Even though this study was like the above findings, PM2.5 concentration in Addis Ababa city was found to be higher than the other cities with higher increasing trends of the emission level. Bulto (2020) further showed in his finding that the emission of PM2.5 during the winter and summer seasons in the entire city of Addis Ababa. According to his finding, in Addis Ababa, the highest PM2.5 concentration recorded in November 2019 was 215µg/m3, whereas the concentration of PM2.5 recorded in June 2018 was 42.3µg/m3. This finding also indicated that the mean concentration of PM 2.5 during winter was higher than during summer.

Perungudi dumpsite is one of the oldest major dumpsites in Chennai, India, with a dumping rate of about 2200–2400 tons per day. According to a study conducted in the Perungudi dumpsite, the temporal characteristics of toxic fine particulate matter (PM2.5) emissions from a 30-year-old municipal solid waste (MSW) dumpsite were above the permissible limit set by WHO. (Peter et al., 2018).

Accordingly, the mean statistics result of PM 2.5 concentration in Perungudi dumpsite in Chennai, India, showed 52.75µg/m3, 72.34µg/m3, and 45,82µg/m3 during Monsoon, Winter, and summer seasons, respectively. The finding was more than five times the standard set by the WHO limit.

The increasing trend of PM2.5 concentration in Koshe open dump site has a negative impact on the communities living around the dump site, and this implies that airborne fine Particulate Matter emitted from the open Municipal Solid Waste (MSW) dumpsite cause environmental and public health risks. It has been found that with increasing PM2.5 concentration, communities living near open dump site would grow susceptible to certain diseases, including acute respiratory symptoms, asthma, lung cancer, and mortality (Deng et al., 2013).

A great number of epidemiology studies have revealed a significant association between fine PM2.5 and human health, particularly cardiovascular and respiratory diseases (Ai et al., 2018; Lin et al., 2017). However, the magnitudes of such associations largely vary by season and location (Beelen et al., 2015). The increasing trends of PM2.5 concentration in Addis Ababa city and Koshe open dumping site has both locational and seasonal implications in that the higher concentration of PM2.5 during the dry season coupled with dumpsite areas has direct seasonal and locational implications which negatively affects the public health of the communities living near the Koshe dump site.

As more and more municipal solid waste is dumped into the Koshe open dumpsite without any sorting and segregation, the concentration of PM2.5 has dramatically increased (Figure 4.13). It has polluted the air from time to time, impacting the community living around the dump site.

Past epidemiological studies have suggested an apparent correlation between particulate matter (PM) exposure at different concentration levels and its serious health effects (Dockery, 2009). A study conducted by Guttikunda and Goel (2013) reported that long-term exposure to elevated concentrations of PM2.5 leads to a higher occurrence of mortality and morbidity due to the exacerbation of cardiovascular and respiratory diseases. Picture 4.10 explain that the Koshe open dump site situation contributes the lion's share in adversely polluting the environment.

Figure 4-13 Current situation of Koshe open dump site in Addis Ababa City (2023)

4.3.2.1.1 Metrological Implication on PM2.5 Concentrations

As far as the metrological factor is considered, this stud has identified that concentrations of PM2.5 in Addis Ababa city average and Koshe dump site have significant correlation with air temperature, precipitation, wind speed, and wind direction depending on the dry and wet season of the month under study.

During the summer season, when the weather condition is rainy, with a peak in August, the average temperature for Addis Ababa city was 19°C which was lower than the temperature recorded in the dry season. PM2.5 concentration of Addis Ababa city average and Koshe dump site during the summer season (August 2022) were recorded at 26μg/m^3 and 70μg/m^{3,} respectively, which with low concentration as compared to PM2.5 concentration during the dry season. This data indicated that with the lower temperature in summer, concentrations of PM2.5 in the city significantly decreased.

On the contrary, during the dry season (November 2022), the average temperature of Addis Ababa city was 25.2 °C which was higher than the temperature recorded in the summer season (August 2022). PM2.5 concentration of Addis Ababa city average and Koshe dump site during the dry season (November 2022) was found to be 98μg/m^3 338μg/m^{3,} respectively, with a very high result than PM2.5 concentration in August 2022. This indicated that with relatively higher temperatures during the dry season, a higher amount of PM2.5 concentration was recorded. Moreover, PM and Wind speed have been observed as having a negative correlation in the summer and fall but positive in winter from December up to February (Zhang et al. 2015).

According to the research findings conducted in the winter/dry season in Poland, especially in Polish towns, smog episodes, i.e., extremely high mass concentrations of particulate matter PM2.5 is, observed in high-altitude weather, with higher temperatures and low wind (Cichowicz et al. 2020).

During the wet season (August 2022), the precipitation of Addis Ababa city was 269 mm, the highest amount of rainfall in the city. In comparison, the PM2.5 concentration of Addis Ababa city average and Koshe dump site during the wet season (August 2022) was recorded very low as compared to the PM2.5 concentration during the dry season. This indicated that as precipitation increases, PM concentration in the city decreases. This is because the higher amount of rainfall has negatively affected the concentration of PM2.5 in the city.

During the dry season (November 2022), the precipitation of Addis Ababa city was 9mm which was lower than the precipitation recorded in the wet season (August 2022). In contrast, the average PM2.5 concentration of Addis Ababa city and Koshe dump site during the dry season (November 2022) was higher than the PM 2.5 concentration in the wet season (August 2022). The above data has implied that precipitation negatively correlates with fine particulate matter and greatly impacts concentrations of PM2.5. As rainfall amount increases, the concentration of fine particulate matter decreases.

Many researchers have reported that the concentration of air pollutants varies depending on meteorological factors and the source of pollutants (Chen et al. 2018). Particulate matter (PM2.5 and PM10) concentrations from Athens and Birmingham have been found to be significantly correlated with other pollutants and meteorological parameters, namely, nitrous oxides (NOx), carbon monoxide (CO) (Vardoulakis et al. 2008). Negative correlations have been observed between PM concentration and wind speed (WS), and precipitation. As wind speed and Precipitation increase, the concentration of PM10 ultimately decreases.

According to Table 4.2, meteorological service data of the city, the windiest month of the year in Addis Ababa is November, with an average hourly wind speed of 7.7 miles per hour. The calmest month of the year in Addis Ababa is August, with an average hourly wind speed of 4.5 miles per hour. The predominant average hourly wind direction in Addis Ababa varies throughout the year. The wind is most often from the west for 2.2 months, in June, July, and August, with a peak percentage of 58% in July. The wind is most often from the east for 9.8 months, from September to May, with a peak percentage of 93% in January. Higher wind speeds generally translate to a greater dispersion of air pollutants, resulting in lower air pollution concentrations in areas with stronger winds.

The wind direction in Addis Ababa city has a significant impact on PM2.5 concentration depending on the dry and wet seasons. The Koshe Open dump site is located in the Southwest part of the city, and the wind blows from the Southwest and south part of the Koshe dump site to the Northeast and Eastern parts of the city, where most of the PM2.5 data were collected. During the summer season (August 2022), the wind direction record of the city showed that Southwest (21%), South (23%), and West (32%), and a total of 76% of wind blows to the Northeast and eastern part of the city.

According to this study, during the dry season (November, December, and January) wind direction record of Addis Ababa city showed that East and Northeast 90%, East (64%) and Northeast 84% and East and Southeast 87% wind blows in November, December, and January respectively to the South west and western part of Koshe dump site contributing to the concentration of PM.

Wind speed plays a leading role in cleansing the atmosphere of fine particulate matter as compared to coarse particulate matter. Windspeed affects the turbulence near the ground. The greater the wind speed, the greater the dispersion of particulates, and the greater the particulate's dilution effects and transport, hence the lower the mass concentration (Mkoma and Mjemah, 2011).

Different research findings revealed that wind direction exhibited a moderately negative correlation with PM 2.5. Apart from wind speed, wind direction plays an influencing role by transporting particulate matter from different neighboring regions to the sampling location, contributing significantly to the variation in concentration of the particulate matter (Guerra 2006).

Similarly, the Koshe open dump site, located in the southwest part of Addis Ababa city, was the source point of PM2.5 concentration with the potential of traveling to different locations of Addis Ababa city. Koshe dump site is around 13 km far from the center of the city, and the southwestern wind direction has the potential to transport PM2.5 through the entire 54km radius of the Addis Ababa city and the newly established Sheger city of Oromia regional government.

Particularly, the Sebeta sub-city and Burayu Sub city are parts of Sheger city of Oromia regional state, which is located at the neighbors of the Koshe open dump site with an average distance of 10 kilometers away from the dump site, which can easily be influenced by PM2.5 concentration blown by the wind from the southwest part of the dumpsite. According to the basic evaluation of PM properties conducted by Kim et al. (2015), the travel distance of PM2.5 was estimated to be up to 1000km suspended on air with lifetimes of days up to several weeks.

4.3.2.2 Seasonal Implication of PM10

PM10 concentration for the Addis Ababa city average and Koshe open dump site has shown an increasing trade during the study period of eight months, and most importantly, there is a remarkable difference in the result of the concentration of PM10 during the Winter (dry season) as compared to the summer (wet season) as presented on Figure 4.14.

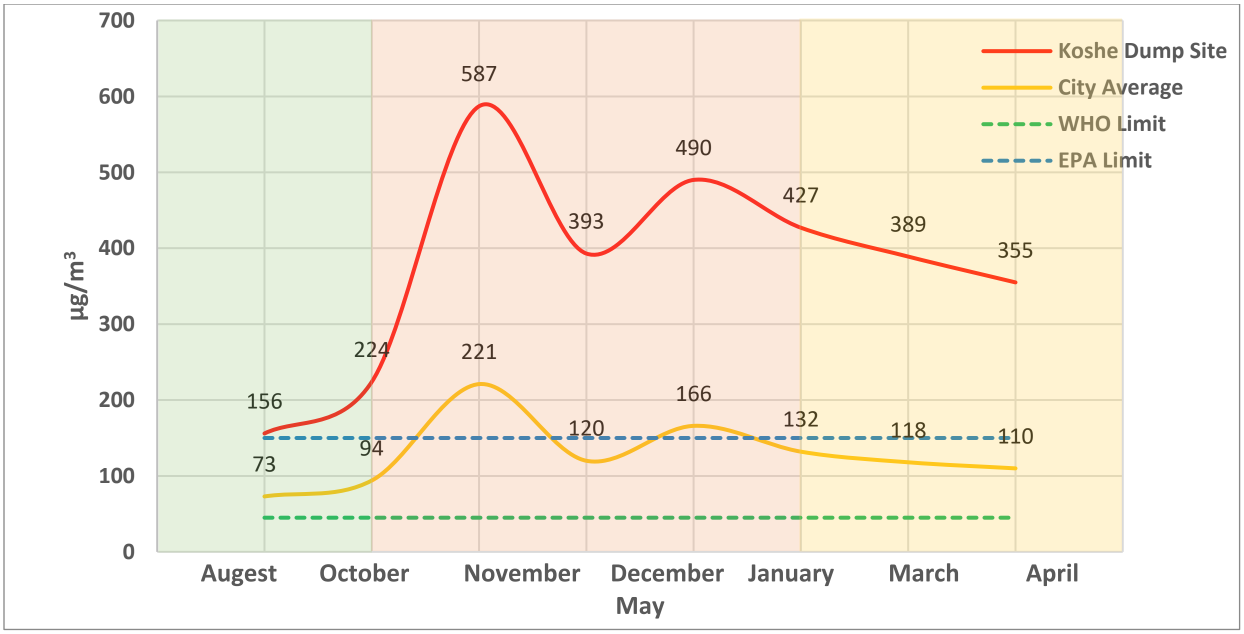


Figure 4-14 Seasonal implication of PM10 concentration in Addis Ababa city and Koshe dump site (2023)

PM10 concentration in Addis Ababa city average during the eight months of the study period (Figure 4.14) has resulted in an increasing trend, and according to the findings of this study, the PM10 concentration result of the Addis Ababa city average and Koshe open dump site during wet or summer season was by far lower than PM10 concentration during the winter or dry season of the months.

PM10 concentration in Addis Ababa city average during summer/wet season (August 2022 and October 2022) were 73µg/m^3 and 94µg/m^{3,} respectively, with very lower results. Whereas PM10 concentration in Addis Ababa city average during winter/dry season (November 2022, December 2022, and January 2023) were 221µg/m^3 and 120µg/m^3 166µg/m^{3,} respectively, with higher results.

PM10 concentration in Addis Ababa city average during March 2023, April, and May 2023 was 132µg/m^3, 118µg/m^{3,} and 110µg/m^{3,} which showed a declining trend. This is because, during the cloudy and rainy season of the month, the concentration of PM10 becomes lower than during the dry or winter season of the month (Figure 4.14).

Similarly, the trends of PM10 concentration in the Koshe dump site during the eight months of the study period resulted in an increasing trend but very far higher than the PM10 concentration from the city average. Accordingly, the PM10 concentration at the Koshe dump site during the Summer/wet season (August 2022 and October 2022) was 156μg/m^3 and 224μg/m^{3,} respectively, with lower results. Far away from the above results, PM10 concentration of Koshe dump site during winter/dry season (November 2022, December 2022, and January 2023) were 587μg/m^3, 393μg/m^{3,} and 490μg/m^{3,} respectively, with very much higher results than the wet season.

PM10 concentration in the Koshe dump site during March 2023, April, and May 2023 were to be 427μg/m^{3,} 389μg/m^{3,} and 355μg/m^3 showing a declining trend and still exceeding the standard set by the WHO limit of 45μg/m^3 and the standard set by EEPA of 150μg/m$^{3.}$

Faustini et al. reported a case study about the correlation between PM10 concentration and associated respiratory diseases. An increase of PM10 of more than seven times the standard set by WHO indicated that there is a direct relation with the aggravation of respiratory disease (RD) in the communities residing at the Koshe open dump site. An Italian study reported a 10 μg/m3 increase in the daily mean of PM10 was associated with a 0.59% and 0.67% rise in respiratory disease (RD) and Chronic Obstructive Pulmonary Disease (COPD) hospital admissions, respectively (Faustini et al. 2013).

PM10 concentration in Addis Ababa city average and Koshe dump site on the day of 21 November 2022 were 221µg/m^3 and 587µg/m^{3,} respectively, resulting in the highest concentration level of Pm10 during the study period. This was due to the smoky month of the year celebrated by the community as a culture and norm, which affected the city's environment negatively. During that specific day of 21 November, Addis Ababa city was covered by the smoke practicing open burning of all types of solid waste like plastic waste, used tires, and household waste, starting from early in the morning throughout the daytime, polluting the entire city's air.

Moreover, the trends of waste incineration and open burning of solid waste are much more practiced in the dry season than in the wet season of the month. Notably, the Koshe open dumpsite was known for its potential to generate the highest particulate matter (PM) emission through open burning of solid waste, incineration, and longtime dust formation in the dump site during the dry season than in the wet season affecting the public health negatively.

The PM10 concentration results of the Koshe open dump site during the dry season of the month (November, December, and January) were more than two times greater than the emission level recorded during the wet or summer season. This indicated that Koshe open dumpsite is known for its potential emission of PM10, which can pose respiratory health problems for communities residing in the adjacent dump site.

Recent studies have shown that PM10 means concentrations during the winter season (November to January) in the cities of Darus Salam, Narayonganj, and Gazipur were found to be 280.3µg/m3, 358,0µg/m^3, and 257.3 µg/m^3 respectively. Whereas during the rainy or wet season (May to October), PM10 means concentrations in the cities of Darus Salam, Narayonganj, and Gazipur were found to be 64.5 µg/m^3, 86.0 µg/m^3, and 50.6 µg/m^3, respectively. (DOE, 2019a).

From the above data result, it can be concluded that, like Addis Ababa city, PM10 concentrations in cities of Darus Salam, Narayonganj, and Gazipur during the winter season were recorded higher concentration than in the wet or rainy season in all cities under study.

Similar studies have also identified that the ambient air particulate matter (PM10) was evaluated in Dalian-China and Faisalabad, Pakistan, in 2016. The PM10 concentration in Dalian-China and Faisalabad, Pakistan, was 109µg/m^3 and 164.3µg/m^3, respectively, with an average of 148.3µg/m^3. The PM10 concentration in Dalian-China and Faisalabad, Pakistan, in the winter season, is higher than in the summer season (Niaz et al. 2016).

According to the Space Environment Research Laboratory, Center for Atmospheric Research conducted in Nigeria (Abulude and Abulude, 2021), the concentrations of Particulate Matter of PM10 concentrations during the dry season were 68.29µg/m^3 in Delta State, 20.54µg/m^3 in Osun State,185.4µg/m^3 in Kebbi State,101.23µg/m^3 in Lagos State and 74.71µg/m^3 in Abuja State. High values of PM10 concentrations were found to be reported in Kebbi State. The overall air pollution situation in the locations was serious in December, January, and February 2021, according to an exploratory study of the air quality of the states over 2–7 months (Abulude and Abulude, 2021). This study identified that the PM10 concentration result of the authors finding was much lower than the PM10 concentration result recorded in Addis Ababa city, indicating that air pollution trends have increased occasionally, worsening the community health.

4.3.2.2.1 Metrological Implication on PM10 Concentrations

Data collected from the metrology service has indicated that concentrations of PM10 in Addis Ababa city average and Koshe dump site have significant correlation with air temperature, precipitation, wind speed, and wind direction depending on the dry and wet season of the month.

In August, the weather condition was rainy at the peak of the summer season, and the average temperature for Addis Ababa city and the Koshe dump site was 19°C, lower than the average temperature registered during the dry season. PM10 concentration of Addis Ababa city average and Koshe dump site during the summer (August 2022) were 73µg/m^3 and 156µg/m^3, respectively, lower than in the dry season. These data indicated that as air temperature declined during the summer, the concentrations of PM10 in the city and Koshe dump site showed a decreasing trend to the dry season of the months.

During the dry season of the month (November 2022) average temperature of Addis Ababa city was 25.2 °C which was higher than the average temperature recorded during the summer season (August 2022). The average PM10 concentration of Addis Ababa city and Koshe dumpsite during the dry season (November 2022) was 221µg/m^3 and 587µg/m^3, respectively, higher than the PM10 concentration recorded in August 2022. This data indicated that the average PM10 concentration of Addis Ababa city and the Koshe dump site area was positively correlated with the average temperature recorded in the city. As the city's temperature increased, the dramatic concentration of PM10 showed an increasing trend.

According to the research findings conducted in the winter/dry season in Poland, especially in Polish towns, smog episodes, i.e., extremely high mass concentrations of particulate matter PM10 is, observed in high-altitude weather, with higher temperatures and low wind **(**Cichowicz et al. 2020).

During the wet season (August 2022), the precipitation of Addis Ababa city and Koshe dump site was 269 mm which recorded the highest rainfall in the city. In contrast, the average PM10 concentration of Addis Ababa city and Koshe dump site during the wet season (August 2022) was recorded at 73 µg/m^3 and 156µg/m^{3,} relatively lower than the PM10 concentration recorded during the dry season. This data indicated that as precipitation showed an increasing trend, PM10 concentration in the city declined, implying that rainfall during the summer season has an impact on the emission of PM. This is because, as rainfall amount increases, it mainly gets rid of coarse particles (PM10)

On the other hand, during the dry season of the month (November 2022), the precipitation in Addis Ababa city was recorded at 9mm, which was lower than the precipitation recorded during the wet season of the month (August 2022). At the same time, the PM10 concentration of Addis Ababa city average and Koshe dump site during the dry season of the month (November 2022) were 221µg/m^3 and 587µg/m^{3,} respectively, much higher than PM10 concentration during the wet season of the month (August 2022).

According to Owoade et al. (2012), conducted on the correlation between particulate matter concentrations and meteorological parameters at a site in Ile-Ife, Nigeria, results showed that PM10 concentrations have observed with seasonal variation, which was characterized by high concentrations in the dry season and low in the rainy season. PM10 exhibited negative correlations for rainfall, whereas it positively correlated with wind speed and wind direction depending on dry and wet seasons.

This study identified that precipitation has a negative correlation with the concentration of PM10, and November was the driest month in the city with a tiny amount of rainfall, with the highest concentration of PM10 in both Addis Ababa city and Koshe dump site. As rainfall amount decreases in the city, PM10 concentration dramatically increases.

Many researchers have reported that the concentration of air pollutants varies depending on meteorological factors and the source of pollutants (Chen et al. 2018). PM10 concentrations from Athens and Birmingham have been found to be significantly correlated with other pollutants and meteorological parameters, namely, nitrous oxides (NOx), and carbon monoxide (CO) (Vardoulakis et al. 2008). Negative correlations have been observed between PM10 concentration, wind speed (WS), and precipitation. As wind speed and Precipitation increase, the concentration of PM10 ultimately decreases.

The wind direction in Addis Ababa city significantly impacts PM10 concentration depending on dry and wet seasons. The Koshe Open dump site is located in the Southwest part of the city, and the wind blows from the Southwest and south part of the Koshe dump site to the Northeast and Eastern parts of the city, where most of the PM10 data were collected. During the summer season (August 2022), the wind direction record of the city showed that Southwest (21%), South (23%), and West (32%), and a total of 76% of wind blows to the Northeast and eastern part of the city.

During the dry season of the month (November, December, and January) the wind direction record of Addis Ababa city showed that East and Northeast 90%, East (64%) and Northeast 84%, and East and Southeast 87% wind blows in November, December, and January respectively to the Southwest and western part of Koshe dump site contributing to the concentration of PM10.

Different research findings revealed that wind direction exhibited a moderately negative correlation with PM10, and apart from wind speed, wind direction plays an influencing role by transporting particulate matter from different neighboring regions to the sampling location, contributing significantly to the variation in concentration of the particulate matter (Guerra 2006).

Similarly, the Koshe open dump site, located in the southwest part of Addis Ababa city, was the source point of PM10 concentration with the potential to travel to different locations of Addis Ababa city. Koshe dump site is around 13 km far from the center of the city, and the southwestern wind direction has the potential to transport PM10 but to a lower extent than PM2.5 as PM10 is courser particles to travel longer distances. According to the basic evaluation of PM properties conducted by Kim et al. (2015), the travel distance of PM10 was estimated to travel up to 10km, suspended on air with lifetimes of minutes to hours. This indicates that the impact of wind direction on PM10 was insignificant in affecting other parts of the city as PM10 is a coarser particle that makes traveling longer distances difficult.

4.3.2.3 Seasonal Implication of Carbon Monoxide

CO concentration for the Addis Ababa city average and Koshe open dump site have shown an increasing trend during the study period of eight months, and most importantly, there is a remarkable difference in the result of the concentration of CO during the Winter (dry season) as compared to the summer/wet season (Figure 4.15).

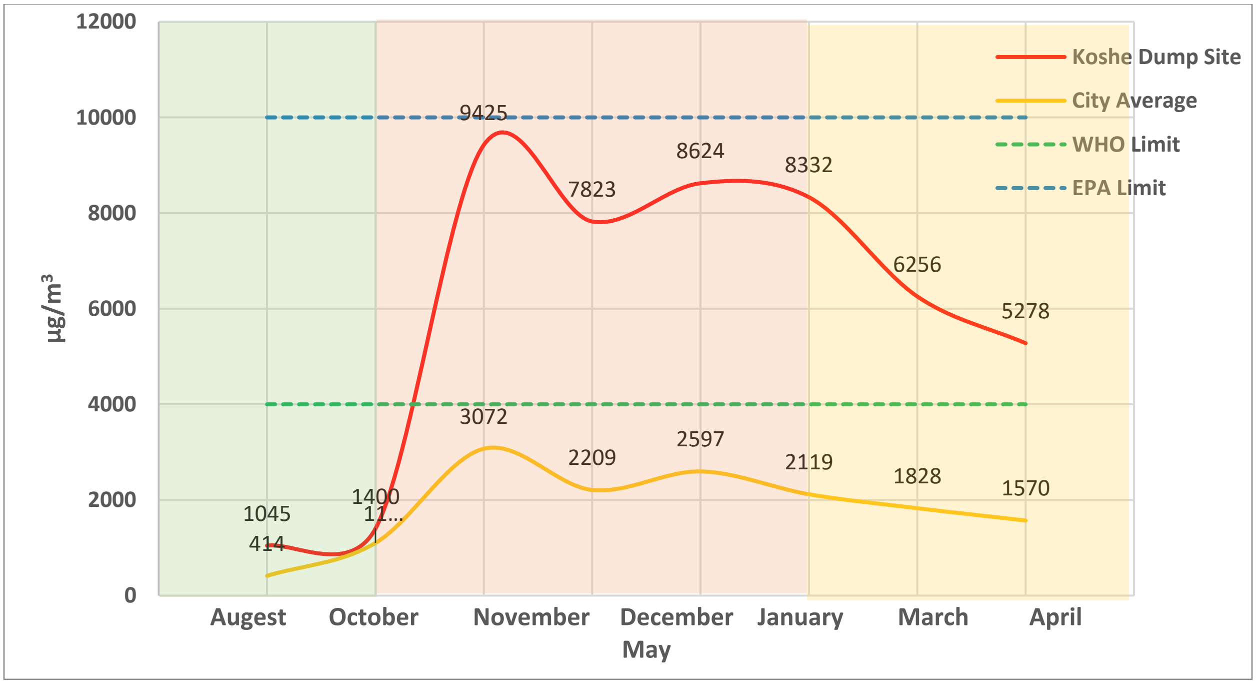


Figure 4-15 Seasonal implication of Carbon monoxide concentration in Addis Ababa city and Koshe dump site (2023)

The CO concentration in the Koshe dump site and Addis Ababa city average have direct seasonal implications in that the highest CO concentration was recorded during the dry season than the wet season of the months.

In both the Addis Ababa city average and Koshe dump site, the highest concentration of CO was registered during the winter/dry season of the month (21 December 2022) with 3072µg/m^3 and 9425µg/m^{3,} respectively. In comparison, the lowest emission of CO for Addis Ababa city average and Koshe dump site was registered during the summer/wet season (August 2022) with 414µg/m^3 and 1045µg/m^{3,} respectively. Similarly, the CO concentration of Addis Ababa city average and

Koshe dump site during winter/dry season (November 2022, December 2022, January 2023) was 3072µg/m^{3}, 2209µg/m^{3,} and 2597µg/m^{3,} respectively. (Figure 4.15)

The highest concentration of CO during the dry season was because of the unavoidable Ethiopian culture of open burning of solid waste during the dry season in general and specifically on 21 November 2022 as an accepted norm and culture of the urban community impacting air quality and public health each year.

The concentration of CO at the Koshe dump site in March 2023, April 2023, and May 2023 was 8332µg/m^{3}, 6256µg/m^{3,} and 5278µg/m^{3,} respectively, with a declining trend but still exceeding the limit set by the WHO and below the standard set by EPA.

Moreover, the emission from incomplete combustion of carbonaceous compounds and old vehicles contributed to the higher emission of CO during the dry season. Figure 4.16 describes the open burning of solid waste in Addis Ababa city and Koshe open dump site.

Figure 4-16 Open burning of solid waste in Addis Ababa city and Koshe open dump site (2023)

4.3.2.4 Seasonal Implication of Nitrogen dioxide (NO_2)

According to the data presented in Figure 4.17 below, Nitrogen Dioxide (NO_2) concentration for the Addis Ababa city average and Koshe open dump site during eight months of the study period exceeded the standard set by the World Health Organization (WHO) of 25µg/m^3 but below the Ethiopian Environmental Protection Authority (EEPA) guidelines of 200µg/m^3 respectively.

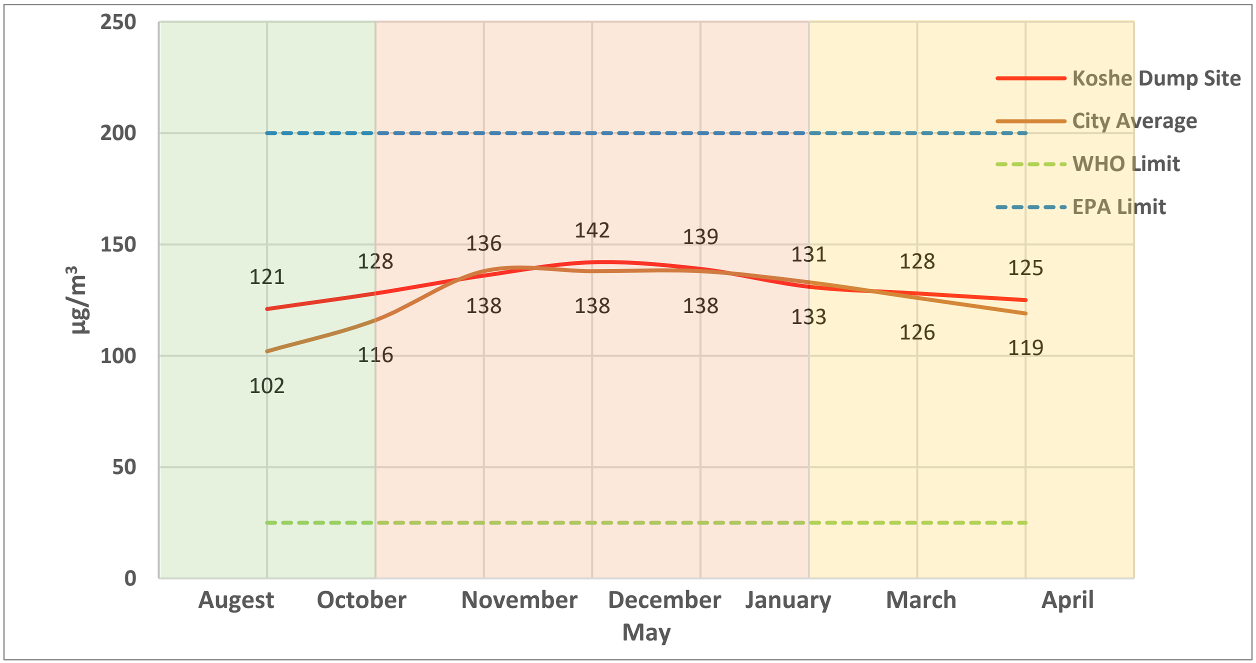


Figure 4-17 Seasonal implication of Nitrogen Dioxide in Addis Ababa city and Koshe dump site (2023)

Unlike CO concentration, the NO_2 concentration of Addis Ababa city average and Koshe dump site during the summer or the wet season exceeded the standard set by the World Health Organization (WHO) of 25µg/m^3 but below the Ethiopian Environmental Protection Authority (EEPA) guidelines of 200µg/m^3 respectively. Similarly, the NO_2 concentration of Addis Ababa city average and Koshe dump site during the summer, or the wet season has exceeded the standard set by the World Health Organization (WHO) of 25µg/m^3 but below the Ethiopian Environmental Protection Authority (EEPA) guidelines of 200µg/m^3 respectively.

Accordingly, the concentration of NO_2 at Addis Ababa city average during the summer/wet season (August 2022, October 2022) was 102µg/m^3 and 116µg/m^{3,} respectively. In contrast, the concentration of NO_2 at Addis Ababa city average during winter or dry season of the Months (November 2022, December 2022, and January 2023) were with flat records of 138µg/m^3,138µg/m^3, 138µg/m^{3,} and 133µg/m^3 respectively exceeding above the limit of WHO standard and below the limit of EPA standard (Figure 4.17). Whereas the concentration of NO_2 at Addis Ababa city average in March 2023, April 2023, and May 2023 were 133µg/m^3,126 µg/m^3 and 119µg/m^{3,} respectively, with declining trend. This result was due to the cloudy and partially rainy season of the month in the city.

The concentration of NO_2 at the Koshe dump site during summer (August 2022 and October 2022) was recorded at 121µg/m^3 and 128µg/m^{3,} respectively. In comparison, the concentration of NO_2 at the Koshe dump site during the winter or dry season of the Months (November 2022, December 2022, and January 2023) was 136µg/m^3,142µg/m^3, and 139µg/m^{3,} respectively exceeding the limit of WHO standard and below the limit of EPA standard. Similarly, the concentration of NO_2 at the Koshe dump site in March 2023, April 2023, and May 2023 were 131µg/m^3,128µg/m^{3,} and 125µg/m^{3,} respectively, with declining trends.

This study has identified that in Addis Ababa city, higher traffic pollution has contributed to a higher concentration of $NO_{2,}$ whereas a higher concentration of NO_2 in the Koshe dump site is mostly due to the burning of solid waste and incineration of Rephi waste to energy plants. Some reports indicated that Nitrogen Dioxide (NO_2) is one of the highly reactive gases primarily emitted from cars, trucks and buses, power plants, and off-road equipment exhaust. (Tarekegn and Gulilat,2018). Higher concentration of NO_2 emissions in Addis Ababa city and Koshe dump site was due to the open burning of solid waste from fossil fuel burned in motor vehicles and engines, Incineration of Solid waste by Rephi Waste to Energy power plants and old cars.

4.3.2.5 Seasonal Implication of Sulfur Dioxide (SO_2)

SO_2 concentration of Addis Ababa city average during the wet season or summer (August 2022 and October 2022) was 112µg/m^3 and 138µg/m^{3,} respectively, exceeding the standard set by the World Health Organization (WHO) of 40µg/m^3 and above the Ethiopian Environmental Protection Authority (EEPA) guidelines of 125µg/m^3 for October 2022. SO_2 concentration of Addis Ababa city average during winter or dry season (November 2022, December 2022, January 2023) was 1935µg/m^3, 1554µg/m^{3,} and 1706µg/m^{3,} respectively which exceeded the standard set by World Health Organization (WHO) of 40µg/m^3 and the Ethiopian Environmental Protection Authority (EEPA) guidelines of 125µg/m^3 (Figure 4.18).

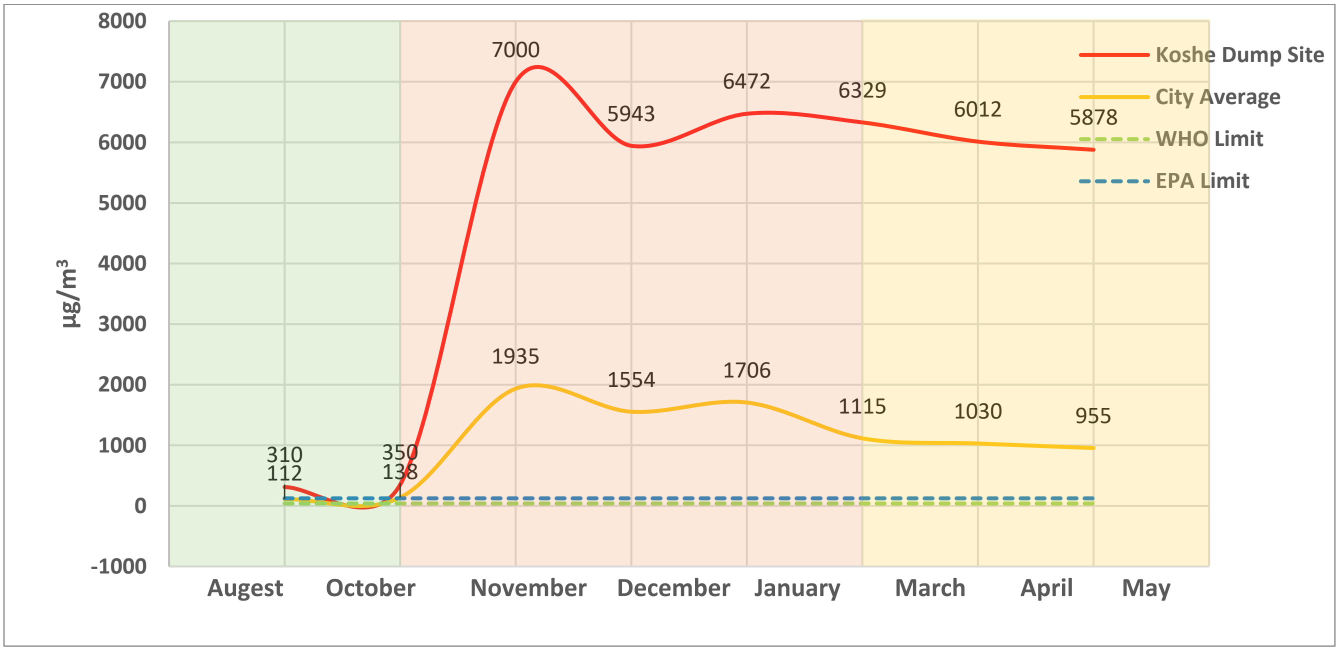


Figure 4-18 Seasonal implication of Sulfur dioxide (SO_2) concentration in Addis Ababa city and Koshe dump site (2023)

SO_2 concentration of Addis Ababa city average for March, April, and May 2023 were 1115µg/m^3, 1030µg/m^{3,} and 930µg/m^{3,} respectively, which by far exceeded the standard set by the World Health Organization (WHO) of 40µg/m^3 and the Ethiopian Environmental Protection Authority (EEPA) guidelines of 125µg/m^3 but with a declining trend (Figure 4.21).

SO_2 concentration of the Koshe dump site during the wet season or summer (August 2022 and October 2022) was 310µg/m^3 and 350µg/m^{3,} respectively, which exceeded the standard set by the World Health Organization (WHO) of 40µg/m^3 and the Ethiopian Environmental Protection Authority (EEPA) guidelines of 125µg/m^3. Similarly, the SO_2 concentration of the Koshe dump site during winter or dry season of months (November 2022, December 2022, and January 2023) was 7000µg/m^{3,} 5943µg/m^{3,} and 6472µg/m^{3,} respectively, which by far exceeded the standard set by World Health Organization (WHO) of 40µg/m^3 and the Ethiopian Environmental Protection Authority (EEPA) guidelines of 125µg/m^3 (Figure 4.21).

Emission of Sulfur dioxide (SO_2) at the Koshe dump site, as compared to the Addis Ababa city average during summer and winter seasons of the months, was recorded the highest concentration. This is because a higher concentration of SO_2 emissions in Addis Ababa city and Koshe dump site was due to the open burning of solid waste, from fossil fuel burned in motor vehicles and engines, Incineration of Solid waste by Rephi Waste to Energy power plants and old vehicles which involves sulfur, copper, zinc, and iron and SO_2 gas emitted to the atmosphere. Recent studies have identified that burning solid waste in the city results in SO_2 emissions into the atmosphere (Elmina, 2016). However, the distribution of human-made pollutants, particularly $SO_{2,}$ is generally uneven (Fitriana, 2019).

4.3.2.6 Methane (CH_4) Concentrations

The trends of Methane concentration in the Koshe dump site have direct seasonal implications in which the lowest concentration of 1240µg/m^3 was recorded in August 2022. The highest result was recorded in January 2023 with 56000µg/m3, indicating an increasing trend. More concentration of methane gas was registered during the dry season of January 2023 compared to the summer season of October 2022. (Figure 4.19).

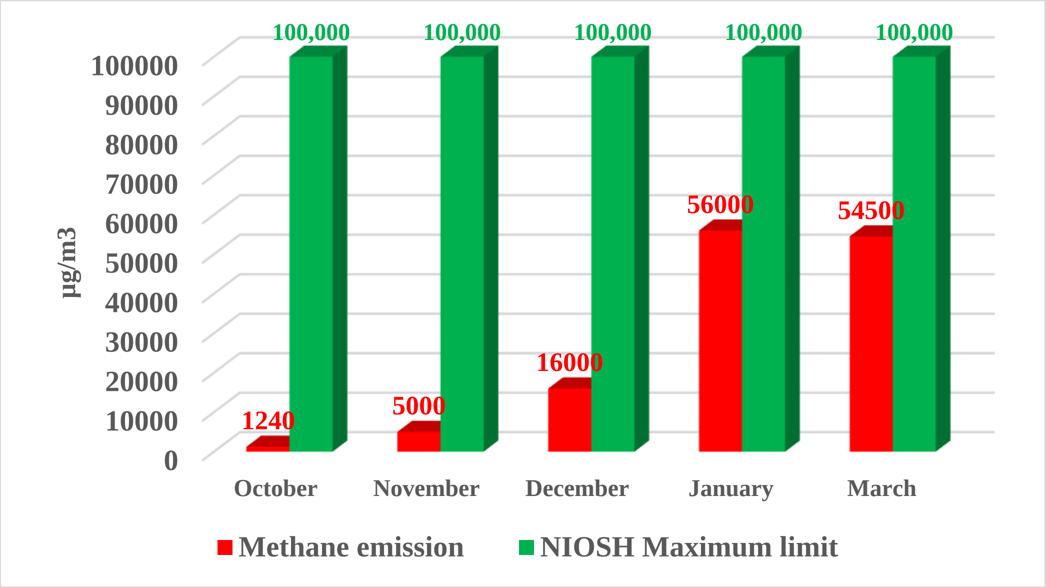


Figure 4-19 The trends of Methane emission result at Koshe dump site (2023)

Different literature and global environmental publications revealed that methane emission from solid waste management was highly linked with landfilling of municipal solid waste. Methane emitted from landfills was estimated to account for 3% to 19% of anthropogenic emission sources globally (Singh et al. 2016).

The trends of methane concentration showed an increasing trend during the month of October 2022, November 2022 and December 2022, January 2023, and March 2023 with 1240µg/m^3, 5000µg/m^3,16000µg/m^3, 56000µg/m^3 and 54500µg/m^3 respectively which was below the National Institute for Occupational Safety and Health's (NIOSH) maximum recommended safe methane concentration for workers during an 8-hour period of 100ppm or100,000µg/m^3.

The levels of methane within the identified solid waste dump sites of Niger Delta areas carried during the dry season of December 2013 ranged between 2310ppm and 2771ppm, which shows that the molecules present in the atmosphere were more than two times the regulatory limit of 1000ppm. (Rim-Rukeh,2014) resulting in a higher level of methane concentration as compared to this study. The Occupational Safety and Health Administration (OSHA) has no permissible exposure limit for methane, but the National Institute for Occupational Safety and Health's (NIOSH) maximum recommended safe methane concentration for workers during an 8-hour period is 1000 ppm (0.1 percent).

The increasing trends will have negative health impacts on the communities living nearby Koshe open dump site, implying that the policies and proclamations of the country didn't pay attention to the emission reduction of methane gas. Recent research studies on methane emission have shown that a huge amount of methane has been emitted from Addis Ababa over the last five years. The methane generation in the solid waste disposal site was highly dependent on the amount of solid waste disposed of at the site. (Ali and Tarekegn 2018). Exposure to CH_4 from landfill sites may result in wheezing, shortness of breath, asphyxia, loss of consciousness, burning in the mouth, or coughing (Kumar & Gupta, 2021).

Similar studies have shown that the annual emission of CH_4 showed a very sharp increment year to year, correlating with the sharp increase of solid waste disposal in the study area. The activities that were applied to manage and reduce the emission of CH_4 in the study area were very poor (Ali and Tarekegn 2018)

4.4 Conclusion

This paper describes the trend analysis of air quality in Addis Ababa City and Koshe open dump site, where the city's major municipal solid waste dump sites contribute to atmospheric pollution in Addis Ababa City. For this research study, different air pollutant parameters were determined using a 200/500 Aeroqual series of handheld air quality monitoring equipment for eight months. Finally, the detailed ambient air quality status of Addis Ababa city average and the Koshe Open dump site were critically analyzed and evaluated based on the field instrumentation and air pollutants data gathering methodologies. The main results and conclusions are summarized as follows:

4.4.1 Particulate Matters (PM 2.5)

The eight-month average fine Particulate Matter (PM 2.5) emissions statistics result of Addis Ababa city result has shown 56.6µg/m^{3,} which is more than three times the standard set by the WHO limit of 15µg/m^{3} but below the standard set by EEPA of 65µg/m^{3}. In contrast, the result of the Koshe dump site showed 204µg/m^{3,} which is more than thirteen times the standard set by the WHO limit of 15µg/m^{3} and more than three times the standard set by the EPA of 65µg/m^{3}.

PM2.5 concentration in Addis Ababa city average was higher during November 2022, December 2022, and January 2023, resulting in 98µg/m^{3},53µg/m^{3,} and 79µg/m^{3} respectively. This is because, during the dry seasons, the concentration of PM2.5 is relatively higher than in the wet season due to the weather conditions. Moreover, the trends of PM2.5 concentrations at the Koshe open dump site were significantly higher during the winter season than in the summer season. And the higher concentration of PM2.5 has a negative impact on the communities living around Koshe open dump site.

PM2.5 concentration of Addis Ababa city average and Koshe dump site during March 2023, April 2023, and May 2023 showed a declining trend. This is because, during the wet and summer seasons, the concentration of PM2.5 becomes much lower than during the dry or winter season of the month. Like the weather condition during the wet season, the concentration of PM2.5 during March, April, and May 2023 has shown a declining trend but not as low as in August and October 2022.

PM10 concentration of Addis Ababa city average and Koshe dump site during March 2023, April 2023, and May 2023 showed a declining trend. This is because, during the wet and summer seasons, the concentration of PM10 becomes much lower than during the dry or winter season of the month. Like the weather condition during the wet season, the concentration of PM2.5 during March, April, and May 2023 has shown a declining trend but not as lower as in August and October 2022.

4.4.2 Particulate Matters (PM10)

The eight-month average Particulate Matter (PM10) emissions statistics result of Addis Ababa city average result has showed 129µg/m^{3,} which is more than two times the standard set by WHO limit of 45µg/m^{3} but below the standard set by EEPA of 150µg/m^{3}. In comparison, the result of the Koshe dump site has shown 377µg/m^{3,} which is more than eight times the standard set by the WHO limit of 45µg/m^{3} and more than two times the standard set by EEPA of 150µg/m^{3}.

The PM10 emission level of Koshe open dump site and the Addis Ababa city during the wet or summer seasons were lower than PM10 concentration during the winter or dry seasons. The trends of PM10 concentration results of the Koshe open dump site during the wet or summer season (August 2022 were 156µg/m^{3}. The trends of PM10 concentration results of the Koshe open dump site during the dry season of December were 393 µg/m^{3,} which is more than two times greater than the emission level recorded during the wet or summer season.

4.4.3 Carbon Monoxide (CO)

The CO concentration of Addis Ababa city average and Koshe dump site during summer or the wet season (August 2022 and October 2022) was registered (414µg/m^{3} and 1045µg/m^{3}) and (1101µg/m^{3} and 1400µg/m^{3}) respectively below the standard set by World Health Organization (WHO) of 4000µg/m^{3} and the Ethiopian Environmental Protection Authority (EEPA) guidelines of 10,000µg/m^{3}.

The CO concentration of Addis Ababa city average during November 2022, December 2022, January 2023, and March 2023 of the dry season was 3072µg/m^{3}, 2209µg/m^{3}, 2597µg/m^{3,} and 2119µg/m^{3,} respectively which were below the standard set by World Health Organization (WHO) of 4000µg/m^{3} and the EEPA guidelines of 10,000µg/m^{3}.

The CO Concentration of the Koshe dump site during November 2022, December 2022, January 2023, and March 2023 of the dry season were 9425µg/m^{3},7823µg/m^{3},8624µg/m^{3,} and 8332µg/m^{3,} respectively which exceeded the standard set by World Health Organization (WHO) of 4000µg/m^{3} and below the EEPA guidelines of 10,000µg/m^{3}.

4.4.4 Nitrogen Dioxide (NO_2)

The concentration of NO_2 at Addis Ababa city average during summer (August 2022, October 2022) was recorded at 102µg/m^3 and 116µg/m^{3,} respectively. In contrast, the concentration of NO_2 at Addis Ababa city average during winter or dry season of the Months (November 2022, December 2022, January 2023, and March 2023) has been registered to be 138µg/m^3,138µg/m^3, 138µg/m^3 and 133µg/m^3 respectively exceeding above the limit of WHO standard of 25µg/m^3 and below the limit of EPA standard of 200µg/m^3.

The concentration of NO_2 at the Koshe dump site during summer (August 2022 and October 2022) was recorded at 121µg/m^3 and 128µg/m^{3,} respectively. At the same time, the concentration of NO_2 at the Koshe dump site during winter or dry season of the Months (November 2022, December 2022, January 2023, and March 2023) has been registered to be 136µg/m^3,142µg/m^3, 139µg/m^3 and 131µg/m^3 respectively exceeding above the limit of WHO standard of 25µg/m^3 and below the limit of EPA standard of 200µg/m^3. Higher concentration of NO_2 emissions in Addis Ababa city and Koshe dump site was due to the open burning of solid waste from fossil fuel burned in motor vehicles and engines, Incineration of Solid waste by Rephi Waste to Energy power plant and old vehicles.

4.4.5 Sulphur Dioxide (SO_2)

SO_2 concentration of Addis Ababa city average during the wet season or summer (August 2022) was 112µg/m^{3,} which exceeded the standard set by the World Health Organization (WHO) of 40µg/m^3 and below the Ethiopian Environmental Protection Authority (EEPA) guidelines of 125µg/m^3.

SO_2 concentration of Addis Ababa city average during winter or dry season of the months (November 2022, December 2022, January 2023, and March 2023) was 1935µg/m^3 1554µg/m^3 1706µg/m^3 and 1115µg/m^3 respectively which exceeded the standard set by World Health Organization (WHO) of 40µg/m^3 and the Ethiopian Environmental Protection Authority (EEPA) guidelines of 125µg/m^3.

SO_2 concentration at the Koshe dump site during the wet season or summer (August 2022 and October 2022) was 310µg/m^3 and 350µg/m^{3,} respectively, which exceeded the standard set by the

World Health Organization (WHO) of 40µg/m^3 and the Ethiopian Environmental Protection Authority (EEPA) guidelines of 125µg/m^3.

SO_2 concentration of Koshe dump site during winter or dry season of the months (November 2022, December 2022, January 2023, and March 2023) was 7000µg/m^3 5943µg/m^3 6472µg/m^3 and 6329µg/m^{3,} respectively which exceeded the standard set by World Health Organization (WHO) of 40µg/m^3 and the Ethiopian Environmental Protection Authority (EEPA) guidelines of 125µg/m^3. The higher concentration of SO2 emissions in Addis Ababa city and Koshe dump site was due to the open burning of solid waste from fossil fuel in motor vehicles and engines, Incineration of Solid waste by Rephi Waste to Energy power plants and old cars.

4.4.6 Methane (CH_4)

The trends of Methane concentration in the Koshe dump site have direct seasonal implications in which the lowest concentration recorded were 1240µg/m^3 in August 2022. The highest result was recorded in January 2023 with 56000µg/m3, indicating an increasing trend. More concentration of methane gas was registered during the dry season of the month as compared to the summer season.

Even though the result of Methane emissions in the Koshe dump site was below NIOSH's maximum recommended safe methane concentration for workers during an 8-hour period which is 100ppm or 100,000 µg/m^3, trends of methane concentration showed increasing trends during October 2022, November 2022 and December 2022, January 2023 and march 2023 with 1240µg/m^3, 5000µg/m^3,16000µg/m^3, 56000 and 54500µg/m^3 respectively.

The present study can be helpful for the government, municipalities, researchers, and policymakers as a limited number of studies specific to air pollution in Addis Ababa city supplements government policymakers' decisions.

The study further indicated limited air quality monitoring technologies, no relevant expertise, and a weak institutional setup to regulate air pollution in Addis Ababa city. On top of the above facts, there is not enough air pollution-related literature regarding the current Addis Ababa city situation.

CHAPTER FIVE

Determination of Water Pollution Status in Koshe Open Dump Site of Addis Ababa City

Abstract

This paper investigated the water pollution status at the Koshe dump site and the downstream Akaki River by taking wastewater and leachate samples. It was analyzed for relevant physicochemical parameters and critical heavy metals according to internationally accepted procedures and standard methods. The various physicochemical parameters examined in wastewater and leachate include pH, TDS, BOD, COD, and the vital heavy metals analyzed include Chromium (Cr), Lead (Pb), Copper (Cu), Zink (Zn), Nickel (Ni) and Mercury (Hg).

The laboratory result indicated that for BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), and TDS (Total Dissolved Solids) downstream of Akaki River during the rainy season (August 2022) showed that 97mg/L, 416MG/L, and 800mg/L respectively exceeding the permissible limits of EEPA and WHO standards except for BOD below the WHO standards.

Whereas the laboratory result for BOD, COD, and TDS downstream of Akaki River during the dry season (February 2023) showed that 139mg/L, 806mg/L, and 742mg/L respectively, which exceeded the permissible limits of EEPA and WHO standards, except for BOD below the WHO standards. The wastewater laboratory analysis for downstream Akaki River results showed that both BOD and COD results were very high during the dry season. Still, TDS concentration was higher in the wet season than in the dry season of the month.

The study further identified that the laboratory result of heavy metal concentrations for Nickel, Mercury, Lead, and Chromium downstream of Akaki River during the rainy season (August 2022) were 0.01mg/L, 0.1mg/L, 0.031mg/L and 0.4mg/L respectively exceeding the permissible limits of WHO standards. Moreover, the laboratory result for wastewater during the dry season (February 2023) indicated that heavy metal concentrations of Nickel, Mercury, Lead, and Chromium after the Leachate was Mixed with Akaki water river resulted in 0.2mg/L, 0.008mg/L, 0.17mg/L and 0.2mg/L respectively which is more than WHO permissible limit.

Furthermore, this study has identified that currently, no pollution control method is being practiced at the Koshe open dump site and the downstream rivers. Therefore, the author strongly recommends the present Koshe dump dumpsite be left and treated accordingly to minimize the impact of persistent heavy metals in the area that negatively impact the community health.

Keywords: Heavy metals, physicochemical parameters, water pollution, dry season, wet season,

5.1 Introduction

As in most developing countries, polluted stream water has been used in crop production within and around Addis Ababa (the capital of Ethiopia) since the 1940s to produce various crops for both market and home consumption. It is the primary source of income for many producers and small traders doing business in the vegetable market. Moreover, residents of the city benefit because they obtain fresh leafy vegetables at lower prices. (Alebel B. Weldesilassie et al.2010). However, there were undesirable health effects on the farmers and consumers.

Farmers are exposed to skin infections and consume part of their produce, especially if vegetables in local demand are grown. The situation regarding wastewater use in agriculture in Addis Ababa is, in principle, like that in other cities in sub-Saharan African countries where wastewater is used for irrigation. (Alebel B. Weldesilassie et al.2010) Water pollution by heavy metals due to quick expansion in industrialization and improper solid waste management has brought risks that cause various impacts on the natural environment, such as humans, animals, soils, and plants.

One of the significant pollution problems caused by the MSW landfill is landfill leachate, which is generated because of precipitation, surface run-off, and infiltration of groundwater percolating through a landfill, biochemical processes, and the inherent water content of wastes themselves.

Leachate is the liquid residue resulting from the landfill's various chemical, physical, and biological processes. Landfill leachate is generated by excess rainwater percolating through the waste layers in a landfill. A combination of physical, chemical, and microbial processes in the waste transfer pollutants from the waste material to the percolating water (Christensen and Kjeldsen, 1989).

After a landfill site is closed, a landfill will continue to produce contaminated leachate, which could last for 30-50 years. Generally, leachate may contain large amounts of organic matter (biodegradable, but also refractory to biodegradation), as well as ammonia-nitrogen, heavy metals, and chlorinated organic and inorganic salts, which are a significant threat to the surrounding soil, groundwater, and even surface water (Renou et al. 2008; Robinson 2008).

Literature has revealed that heavy metals aggregate in the water and are hazardous to human well-being. Some are cancer-causing, teratogenic, and mutagenic and can cause neurological and behavioral changes. Thus, heavy metal contamination remediation deserves attention (Goel 2006).

It poses potential health risks because wastewater may contain microorganisms or chemical pollutants that can adversely affect the health of those working on wastewater farms, consumers of vegetables produced using wastewater, and neighboring communities, often leading to gastrointestinal disease (Shuval et al., 1986; Habbari et al., 2000). However, there are no detailed research findings, and there is a lack of reliable information on the actual health impacts of wastewater from the leachate of open dumping areas.

Survey results from 53 cities in developing countries indicated that the main drivers of wastewater reuse in urban irrigations are increasing urban water demand, food demand, market incentives, and lack of alternative water sources (Raschid-Sally and Jayakody, 2008). The use of wastewater in agriculture has both positive and negative potential impacts on crop production, public health, soil resources, and ecosystems (Hussain et al., 2002; Scott et al., 2004). However, no specific study and research findings indicate the policy options that recommend the practice of wastewater use for agriculture in the city and downstream areas.

5.2 Methodology and Instrumentation

5.2.1 Study area

The study focuses on the effect of Koshe's open dump site that pollutes the water river of the Addis Ababa city administration. The wastewater sample is collected during the Cold/wet and Warm/dry seasons.

To conduct sample tests of the leachate from the Kosh/Reppie open dump site of Addis Ababa city, the following three samples of wastewater have been taken for laboratory tests. The wastewater sample was taken during the wet/cold season and the dry/warm season. The first phase sample was taken in August 2022, and the second phase was taken on December 2022.

In both seasons, wastewater samples were taken before entering the Koshe dump site, and the second sample of wastewater was taken directly from the leachate of the Koshe/Repphi dump site. The third sample of the wastewater was taken after entering the surface water of the little Akaki River crossing Addis Ababa city (Figure 5.1). Laboratory tests were conducted based on the collected wastewater samples of the two seasons to be analyzed against the international permissible limit/standard. The study area of the wastewater sample is located in the following figure 5.1, and the location is (32°46'57.4" N, 96°56'19.0" W)

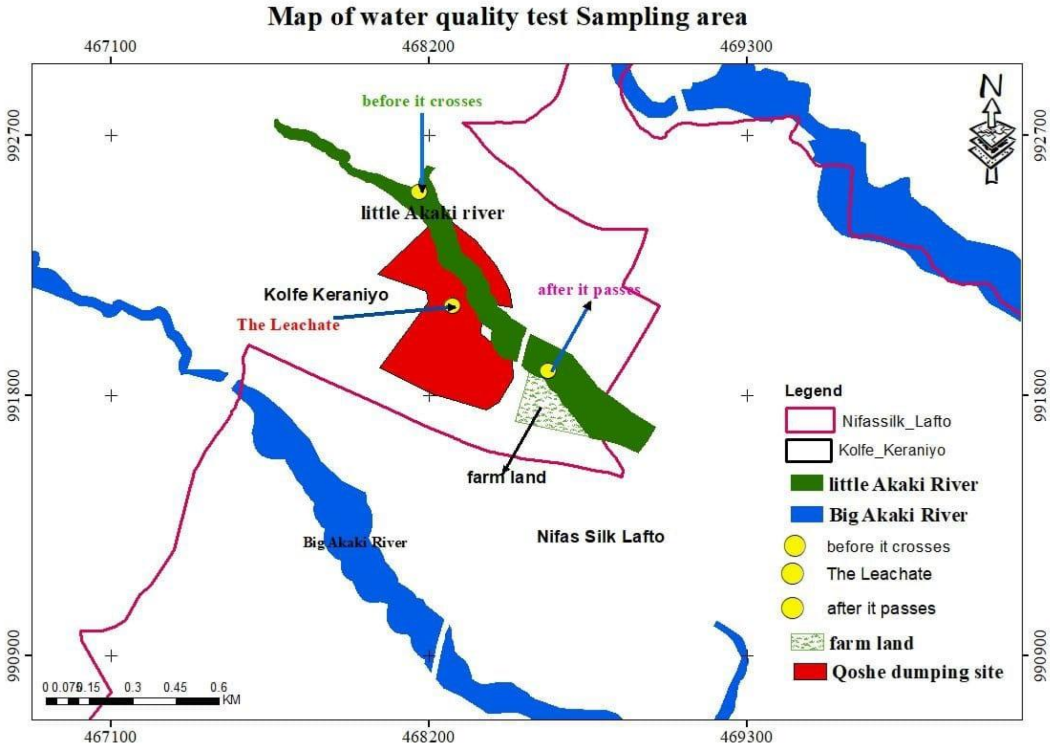


Figure 5-1 Location of wastewater collection area at Koshe dumping site and Little Akaki river

5.2.2 Methodology

BOD (Biochemical Oxygen Demand) was determined by respiratory sensor method or biological testing laboratory SOP/MO 37.01 within 5 days. COD (Chemical Oxygen Demand) was determined by CELL 212 /BCTL/SOP/MO 35 or biological testing laboratory. Moreover, TDS (Total Dissolved Solids) was determined by Ethiopian standard 609 measurements. Finally, pH was determined by Ethiopian standard ISO 10523/2001 at 25-degree centigrade solution. The Wastewater laboratory test methods and specifications are summarized in Table 5.1.

The concentrations of the potentially toxic trace elements in the wastewater samples like Chromium (Cr), Lead (Pb), Copper (Cu), Zink (Zn), Nickel (Ni), and Mercury (Hg) were determined using MP AES (Micro Plasma Atomic Emission Spectroscope) and ICP MS (Inductively Coupled Plasma Mass Spectroscopy). The Wastewater laboratory test methods and specifications for the heavy metals are summarized in Table 5.1

Table 5-1 Wastewater sample laboratory Test Methodology

No	**Parameter**	**Instrument/Methodology**
1	Ph	Ethiopian Standard ISO 10523/2001 at 25-degree centigrade solution
2	BOD	Respiratory Sensor Method or Biological Testing Laboratory SOP/MO 37.01 within 5 days.
3	COD	CELL 212 /BCTL/SOP/MO 35 or biological testing laboratory
4	TDS	Ethiopian standard 609 measurements.
5	Chromium, Lead, Copper, Zink, Nickel, and Mercury	MP AES (Micro Plasma Atomic Emission Spectroscope) and ICP MS (Inductively Coupled Plasma Mass Spectroscopy).

The collected wastewater samples were immediately brought to the laboratory and kept in a cold room at a temperature below 4°C until analyzed (Figure 5.2). All the samples were analyzed for selected relevant physicochemical parameters and key heavy metals according to internationally accepted procedures and standard methods. The various physicochemical parameters examined in wastewater and leachate include pH, TDS, BOD, and COD, and the key heavy metals analyzed include Chromium (Cr), Lead (Pb), Copper (Cu), Zink (Zn), Nickel (Ni) and Mercury (Hg).

a) Upper stream River b) Leachate from Koshe dump Site

C) Sample Laboratory test procedure d) Downstream River (Little Akaki)

Figure 5-2 Leachate sample collection area for water pollution laboratory taste (2022)

5.3 Results and Discussion

5.3.1 Evaluation of Biochemical and Heavy Metals at Koshe Dump Site

Due to improper solid waste disposal trends at the Koshe dump site, the water pollution level of Akaki River was evaluated to determine the levels of various heavy metals present in the river water and Koshe dumpsite further to identify the potential ecological and public health risks. Accordingly, the laboratory result of the concentration of pH, BOD, COD, and TDA values of the wastewater before entering the leachate (Upper stream), the dumpsite (Leachate), and after being Mixed with Akaki river (downstream) during dry and wet season were critically presented and analyzed against the values of WHO Permissible limit.

Similarly, the laboratory result of the concentration of heavy metals like Copper (Cu), Lead (Pb), Nickel (Ni), Chromium (Cr), Zink (Zn), and Mercury (Hg) values of the wastewater before entering the leachate (Upper stream), the dumpsite (Leachate) and after it was Mixed with Akaki river (downstream) were critically presented and analyzed during wet and dry seasons against the standard of WHO Permissible limit.

5.3.2 Analysis of Biochemical Concentration during Wet Season

Accordingly, the laboratory result of the leachate sample indicated in Table 5.2 for pH Value, COD, BOD, and TDS was found to be 560mg/L, 672mg/L and 22,446mg/L respectively, exceeding the permissible limits of EEPA and WHO standards. The laboratory results of the concentration of COD and TDS after they were Mixed with Akaki River (downstream) were 416mg/L and 800mg/L, respectively, exceeding the permissible limits of EEPA and WHO standards.

Leachate is the liquid residue resulting from the various chemical, physical, and biological processes taking place within the landfill. Landfill leachate is generated by excess rainwater percolating through the waste layers in a landfill. A combination of physical, chemical, and microbial processes in the waste transfer pollutants from the waste material to the percolating water (Christensen and Kjeldsen, 1989).

Table 5-2 Biochemical Laboratory results of wastewater from Koshe dump site (August 2022)

Parameter	Upper stream	Dumpsite/ Leachate	Lower stream mg/L	WHO Permissible limit in mg/L
pH	8.13	7.17	7.12	6.5-8.5
BOD (Biochemical Oxygen Demand) in mg/L	97	560	97	500
COD (Chemical Oxygen Demand) in mg/L	160	672	416	150 (EEPA) 250-500 (WHO)
TDS (Total Dissolved Solids) in mg/L	432	22446	800	200-500

A) pH Value

According to Table 5.2, the laboratory result of wastewater during the wet season of August 2022 indicated that pH values of 8.13, 7.17, and 7.12 were recorded from the upper stream, the leachate, and the downstream river, respectively. A higher pH value (8.13) was recorded from the upper stream sample, which indicated that the upper stream was more alkaline than the leachate sample. A lower pH value was recorded from the downstream Akaki River sample site.

In a similar study conducted by Barjinder et al. (2013), a leachate sample collected from the Jamalpur landfilling site of Ludhiana City, Punjab, India, has shown seasonal implications on the leachate quality. Accordingly, the pH values of leachate samples of the landfill site during the rainy/wet season were 10.3 as compared to pH values of 9.8 during the winter season. Furthermore, the pH values of the Koshe open dump site leachate in this study were 8.4pH which is similar to the finding of the study conducted by Hunachew and Sandip (2011) at Addis Ababa City Koshe dump site with a pH value of 8.17.

According to Haile and Abiye (2012), the pH of leachates from the Koshe Open dumping site ranges between 5.3 and 8.5, with a high Total Dissolved Solid (TDS) that reaches a value of 8,880 mg/L. The high concentration of degradable wastes manifests in the form of high Chemical Oxygen Demand (3,380–23,950 mg/L) and Biological Oxygen Demand, which ranges between 1,760 and 12,210 mg/L. The results demonstrate that the leachates from Koshe open dump are composed of concentrated organic pollutants, which characterize the source as dominated by organic wastes. It was found that the leachates from the Koshe open dumping site contain a high concentration of Biological Oxygen Demand, Chemical Oxygen Demand, chloride, and sulfate, besides a high concentration of nickel and zinc in the surrounding soil and river water (Haile and Abiye, 2012).

B) Concentration of BOD

According to Table 5.2, the BOD values of the wastewater before entering the leachate (Upper stream) and after it was Mixed with Akaki River (Lower stream) during the month of August were found to be 97mg/L which were below the recommended values of WHO Permissible limit of 500 mg/L. BOD is the measure of the biodegradable organic mass of leachate, which indicates the landfill's maturity, which typically decreases with time (Qasim and Chiang 1994). A similar study conducted in the Addis Ababa city of Koshe dump site has also shown that the concentration BOD was 720mg/L which was a very high concentration as compared to this study (Woldeyohanis et al.,2024)

The BOD measured values recorded for the leachate samples in this study were considerably below the permissible standard limit of 500mg/L. This may be due to the reason that with time the solid waste material gets degraded, and the waste constituents percolate down along with rainwater, thus polluting groundwater nearby to MSW landfill site.

BOD value varies according to the age of landfills. For new landfills, BOD values were 2000-30000 mg/l; for mature landfills, BOD values varied from 100-200 mg/L (Tchobanoglous 1993). BOD gives an idea about the presence of biologically active organisms in the water body (Shoeb et al. 2022; Aminul et al.2018) that it indicates pollution whose higher values indicate high pollution and vice versa.

Similarly, according to Figure 5. 3, the laboratory result for BOD and COD, after it mixed with the Akaki River (Lower stream) during the wet season of August, were found to be below the recommended values of the WHO Permissible limit of 500 mg/L except for the result of TDS which were found to be above the recommended values of WHO Permissible limit of 500 mg/L.

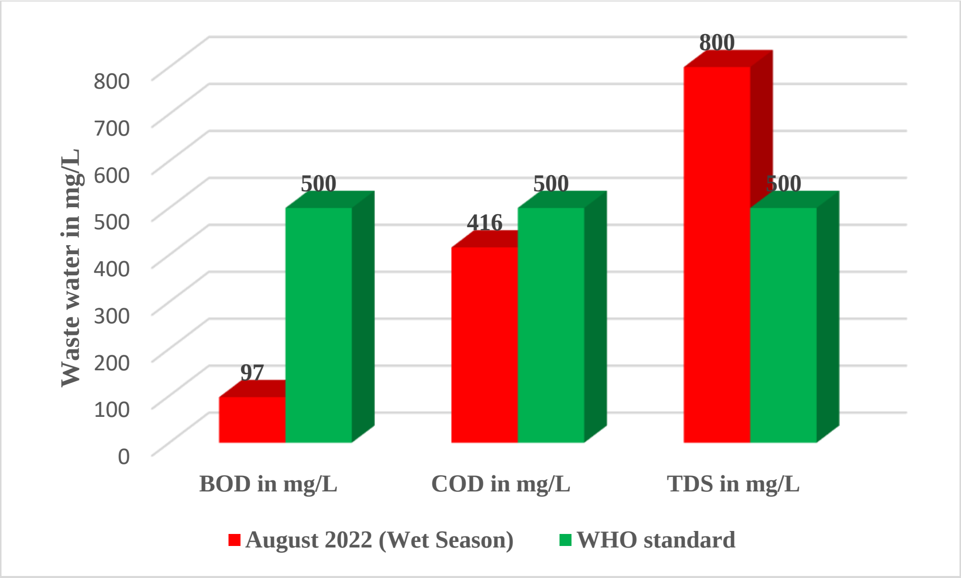


Figure 5.3 Biochemical concentration of Koshe dump site leachate mixed with little Akaki river of Addis Ababa city during the wet season.

According to Figure 5.3, the BOD values of the wastewater after being mixed with the Akaki River (Lower stream) during the wet season of August were found to be 97mg/L, below the recommended values of the WHO Permissible limit of 500 mg/L. BOD is the measure of the biodegradable organic mass of leachate, which indicates the landfill's maturity, which typically decreases with time (Qasim and Chiang 1994).

The BOD measured values recorded for the leachate samples in this study were considerably below the permissible standard limit of 500mg/L. This may be because, with time, the solid waste material gets degraded, and the waste constituents percolate down along with rainwater, thus polluting groundwater nearby to MSW landfill site.

BOD value varies according to the age of landfills. For new landfills, BOD values were 2000-30000 mg/l; for mature landfills, BOD values varied from 100-200 mg/L (Tchobanoglous 1993). BOD gives an idea about the presence of biologically active organisms in the water body (Shoeb et al. 2022; Aminul et al.2018) that it is an indicator of pollution whose higher values of BOD indicate high pollution and vice versa.

C) Concentration of COD

According to Table 5.2, the COD values of the wastewater before entering the leachate (Upper stream) and after it was Mixed with Akaki River (Lower stream) during August were found to be 160mg/L and 416mg/L, which were above the recommended value of EEPA of 150mg/L and below WHO Permissible limit of 500mg/L. The COD concentration of Lapite dumpsite in Nigeria, Ibadan city resulted in 3520 mg/L, a higher concentration than this study. (Oketola and Akpotu,2015).

According to Figure 5.3, the COD values of the wastewater after it was mixed with Akaki River (Lower stream) during the wet season of August were found to be 416mg/L which was below the recommended value of EEPA of 150mg/L whereas below the WHO Permissible limit of 500mg/L. According to Sharma et al. 2020, the low COD in the wet season is associated with high undecomposed material load in the river due to runoff. As the dry seasons set in, the water level reduces, causing increased temperature thus, increased microbial activity, which further reduces dissolved oxygen in the water.

On the other hand, the study conducted by Abagale, F.K.(2021) on pollutants in Wastewater in the Tamale Metropolis of Ghana indicated that the average concentration of COD released into the stream at Zagyuri River averaged 132.78 mg/l and 143.75 mg/l for the dry and wet seasons respectively. This figure has indicated that COD concentration in the wet season was recorded higher than in the dry season.

The TDS values of the wastewater after being mixed with the Akaki River (Lower stream) during August were found to be 800mg/L which was found to be above the recommended values of the WHO Permissible limit of 500 mg/L.

A study conducted by Boanu et al. 2022 indicated similar TDS results were recorded in some sites during the wet season, and high TDS in the wet season is connected mainly to runoff that carries soluble particles from nearby fields and streams, leading to a higher concentration of TDS than the dry season.

D) Concentration of TDS

The TDS values of the wastewater before entering the leachate (Upper stream) and after it was Mixed with Akaki River (Lower stream) during August were found to be 432mg/L and 800mg/L, respectively, which were found to be above the recommended values of WHO Permissible limit of 500 mg/L.

This is because high rainfall and water flow dilute the pollutants than during the dry season, contributing to a higher concentration of TDS. Higher TDS in the rainy season means more runoff that carries soluble particles from the nearby river is added, and more minerals to the local water supply are added, resulting in a higher concentration of TDS in the wet season.

5.3.3 Analysis of Heavy Metals during Wet Season

The laboratory test result for wastewater during the wet season of August 2022 indicated that heavy metal concentration of Chromium, lead, Nickel, and Mercury was 0.4mg/L, 0.031mg/L, 0.1mg/L and 0.01mg/L exceeding the WHO permissible limit of 0.050 mg/L, 0.010mg/L, 0.020mg/L and 0.001mg/L respectively (Figure 5.4).

The concentration of Chromium, lead, Nickel, and Mercury were 0.4mg/L, 0.031mg/L, 0.1mg/L and 0.01mg/L exceeding the WHO permissible limit of 0.050 mg/L, 0.010mg/L, 0.020mg/L and 0.001mg/L respectively. Higher concentration of Chromium, lead, Nickel, and Mercury was due to hospital and Leather industry waste near the Koshe dumpsite of Addis Ababa, discharging the chemical to the Akaki River directly.

Whereas the concentration of the Zinc and Copper after the Leachate was Mixed with Akaki water of the study area resulted in 0.9mg/L and 0.1mg/L, respectively, which is below WHO p. Consequently, the water of the stream has been polluted physically and chemically through the indiscriminate disposal of solid waste and discharge of leachate. The entrance of this leachate to the adjacent river water, especially near the dump site and downstream Akaki River, magnifies the problem compared with the upper stream of the river from the dump site (Figure 5.4).

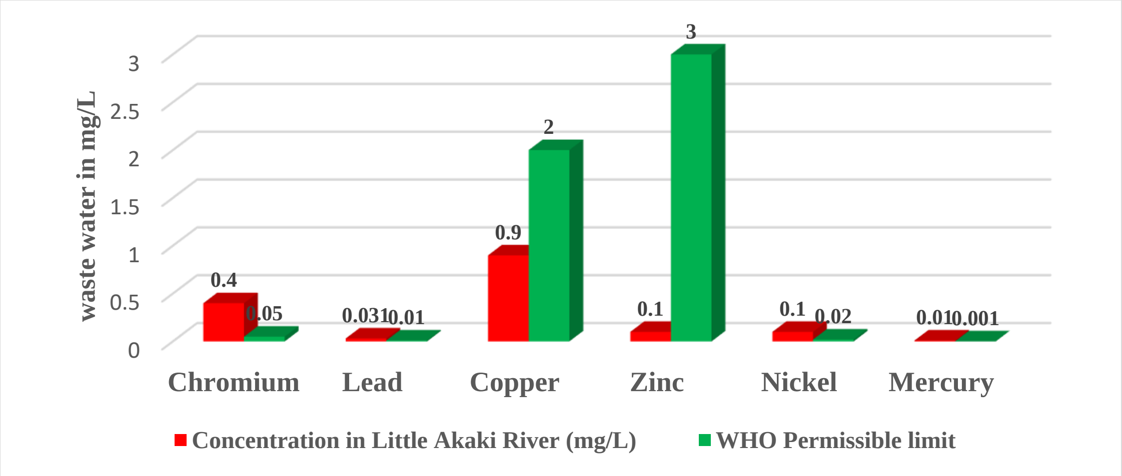


Figure 5.4 Concentration of Heavy metals of Koshe dump site mixed with Little Akaki river during Wet season

Beyene and Banerjee (2011) have also identified that the laboratory test result of the heavy metal concentration of Zn was 0.15mg/L which was below the WHO permissible limit of 3.00mg/L and more than four times lower than this study. On the other hand, the study conducted by Oketola and Akpotu (2015) in Nigeria, Lapite dumpsite at 50 years old Lapite dumpsite leachate and the downstream river revealed that the concentration of Zinc in the downstream river was 1.61mg/L which was more than this study.

According to this study, the concentration and laboratory result of Nickel (Ni) downstream of Akaki River during the wet season of August 2022 was 0.1mg/L, which was greater than the WHO permissible limit of 0.02mg/L. (Figure 5.4). Higher nickel concentrations might be due to indiscriminate disposal of nickel-containing solid wastes such as electroplating, zinc base casting, and storage battery in open dump sites near the river. A similar study conducted by Beyene and Banerjee (2011) has identified that the laboratory test result of Nickel concentration at Koshe open dumps site of Addis Ababa city was 0.1437mg/L, which was above the WHO permissible limit of 0.020mg/L.

The concentration of Lead downstream of Akaki River during the wet season of August 2022 was found to be 0.031mg/L, above the WHO permissible limit of 0.01mg/L. In addition, it contained high lead value than the permissible limits of the Ethiopian EPA standard of 0.05 mg/L. High Lead concentration might be due to the quantity and constituents of municipal solid waste containing lead contents such as electronic waste, lead batteries, lead-based paints, pipes, and plastics disposed of in the dump site. (Figure 5.4).

According to Beyene and Banerjee (2011), the laboratory test result of the heavy metal concentration of wastewater at the Koshe open dumps site of Addis Ababa city for Lead (Pb) was 0.1714mg/L, which was above the WHO permissible limit of 0.01mg/L,

The concentration of Chromium (Cr) at the downstream Akaki River during the wet season of August 2022 was found to be 0.4mg/L, which was above the WHO permissible limit of 0.050mg/L. Beyene and Banerjee (2011) have identified that the laboratory test result of heavy metal concentration of wastewater at Koshe open dumps site of Addis Ababa city for Chromium was 0.86091mg/L, which was above the WHO permissible limit of 0.05mg/L. (Figure 5.4).

The concentration of Mercury at the downstream Akaki River during the wet season of August 2022 was found to be 0.01mg/L, which was above the WHO permissible limit of 0.001mg/L. The concentration of Zinc (Zn) downstream of Akaki River during the wet season of August 2022 was found to be 0.1mg/L, which was below the WHO permissible limit of 3.0mg/L. Similarly, the concentration of Copper (Cu) downstream of Akaki river during wet season of August 2022 was found to be 0.9mg/L, below the WHO permissible limit of 2.0mg/L. (Figure 5.4)

Once heavy metals like Copper, Nickel, Chromium, and Zinc enter the food chain, large concentrations may accumulate in the human body. If the metals are ingested beyond the permitted concentration, they can cause serious health disorders Babel and Kurniawan, (2004). Therefore, it is necessary to treat metal-contaminated wastewater prior to its discharge into the environment.

5.3.4 Analysis of Biochemical during the dry season

According to Table 5.3 indicated below, various physio-chemical parameters like pH value, Total Dissolved Solids (TDS), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and heavy metals like Iron (Fe), Lead (Pb), Chromium (Cr), Copper (Cu), Zinc (Zn) and Nickel (Ni) were analyzed to determine pollution potential of leachate discharge from MSW landfill site to the little Akaki river during dry season.

Table 5-3 Biochemicals Laboratory test result of wastewater from Koshe dump site (February 2023)

Parameter	Before entering the Dump site in mg/L Upper stream	Dumpsite Leachate in mg/L	Mixed with Water River in mg/L Lower stream	WHO Permissible limit in mg/L
pH.	7.4	8.4	8.1	6.5-8.5
BOD (Biochemical Oxygen Demand	151	163	139	500
COD (Chemical Oxygen Demand	667	928	806	150 (EEPA) 250-500 (WHO)
TDS (Total Dissolved Solids)	584	4134	742	200-500

A) pH Value

According to table 5.3, the laboratory results of wastewater during the February 2023 dry season were recorded at 7.4pH, 8.4pH, and 8.1pH at the upper stream, the leachate, and the downstream river, respectively. Higher pH (8.5) value was recorded from the leachate sample, which indicated that the leachate was alkaline, and this was typical of the sample from aged wastes (Beyene and Banerjee,2011; Oketola and Akpotu, 2015). Lower pH was recorded from the Upper stream sample site.

Higher pH values of 8.3- 9.10 were recorded from the stabilized leachate of semi aerobic landfill (Bashir et al. 2008). Leachate generally has a pH between 4.5 and 9 (Christensen et al. 2001). The pH of young leachate is less than 6.5, while old landfill leachate has a pH higher than 7.5 (Abbas et al. 2009). The Koshe Open dump site leachate and downstream river have recorded pH values of 8.4 and 8.1, respectively, implying that it has a characteristic of 50-year-old landfill leachate.

B) Concentration of BOD

The BOD values of the wastewater before entering the leachate (Upper stream), the leachate, and after it was Mixed with Akaki River (Lower stream) during February 2023, were found to be 151mg/L 163 and 139mg/L, respectively, which were below the recommended values of WHO Permissible limit of 500 mg/L. The BOD measured values recorded for the leachate samples in this study were considerably below the permissible standard limit of 500mg/L.

This may be because, with time, the solid waste material gets degraded, and the waste constituents percolate down along with rainwater, thus polluting groundwater nearby to MSW landfill site. BOD value varies according to the age of landfills. For new landfills, BOD values were 2000-30000 mg/l; for mature landfills, BOD values varied from 100-200 mg/l (Tchobanoglous 1993)

Barjinder et al. (2013) identified that leachate sample collected from the Jamalpur landfilling site of Ludhiana City, Punjab (India) has shown the BOD values were 495 mg/l, 512 mg/l, and 596 mg/l during winter, summer, and rainy season respectively.

According to the study conducted by Abagale, F.K. (2021), pollutants in Wastewater in the Tamale Metropolis of Ghana indicated that the average concentration of BOD released into the stream at Zagyuri River was 92.98 mg/l and 103.54 mg/l for the dry and wet seasons respectively.

C) Concentration of COD

The COD values of the wastewater before entering the leachate (Upper stream) and after it was Mixed with Akaki River (Lower stream) during February 2023 were found to be 667mg/L and 806mg/L which were above the recommended value of EEPA of 150 and the recommended values of WHO Permissible limit of 500 mg/L. The higher value of COD implies a greater amount of oxidized organic material in the sample that reduces dissolved oxygen levels and endangers the surface water bodies/river life. Both BOD and COD are indicators of the environmental pollutants of wastewater/surface water bodies.

Whereas according to the study conducted by Barjinder et al. (2013), leachate samples collected from the Jamalpur landfilling site of Ludhiana City, Punjab (India), the COD values for leachate samples of the landfill site were 2535 mg/L, 2612 mg/L, and 2935 mg/L during winter, summer, and rainy season, respectively. The COD-measured values recorded for the leachate samples in this study were considerably lower than the previous study. This may be because, with time, the solid waste material gets degraded, and the waste constituents percolate down along with rainwater, thus polluting groundwater nearby to MSW landfill site. (Bashir et al 2008; Tatsi et al 2003).

D) Concentration of TDS

The TDS values of the wastewater before entering the leachate (Upper stream) and after it was Mixed with Akaki River (Lower stream) during February 2023 were found to be 584 mg/L and 742mg/L respectively, which were found to be above the recommended values of WHO Permissible limit of 500 mg/L. (Table 5.3).

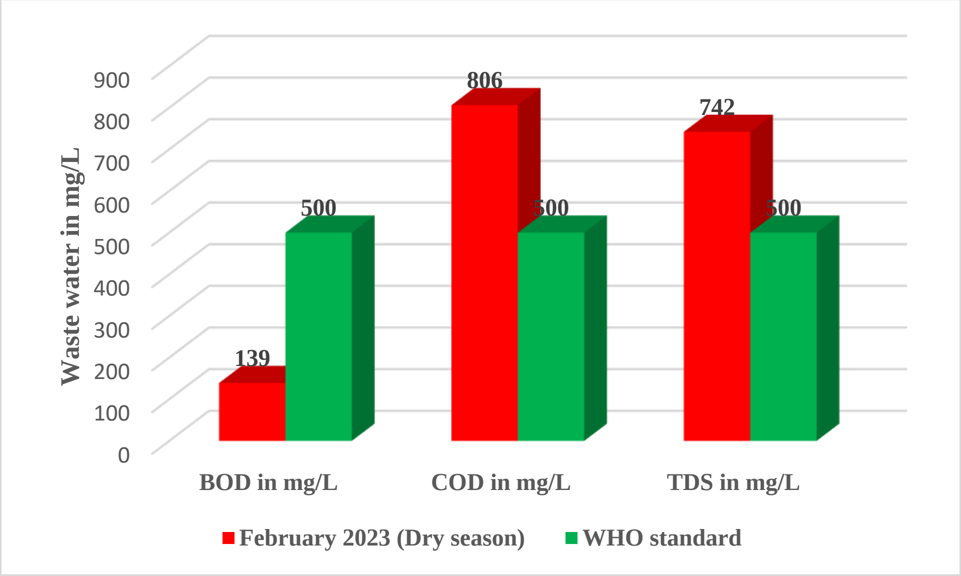


Figure 5.5 Biochemical concentration of Koshe dump site leachate in the little Akaki River of Addis Ababa city (Dry season)

The laboratory result for COD and TDS after being mixed with Akaki River during the wet season of August was found to be above the recommended values of the WHO Permissible limit of 500 mg/L except for the result of BOD, which was found to be below the recommended values of WHO Permissible limit of 500 mg/L(Figure 5.5).

The BOD values of the wastewater after being mixed with the Akaki River (Lower stream) during the dry season of February 2023 were found to be 139mg/L, below the recommended values of the WHO Permissible limit of 500 mg/L. The COD values of the wastewater, after it was mixed with Akaki River (Lower stream) during the dry season of February 2023, were found to be 806mg/L which was above the recommended value of EEPA of 150mg/L and WHO Permissible limit of 500mg/L (Figure 5.5).

The higher value of COD during the dry season implies a greater amount of oxidized organic material in the sample that reduces dissolved oxygen levels and endangers the surface water bodies/river life deposited in the river during the past rainy season. COD represents the amount of oxygen required to completely oxidize the organic waste constituents chemically into inorganic end products (Sharma et al., 2020).

Unlike the concentration of BOD, the concentration of both COD and TDS were found to be above the recommended values of the WHO Permissible limit of 500 mg/L. The TDS values of the wastewater, after it mixed with Akaki River (Lower stream) during the dry season of February 2023, were found to be 742mg/L, above the recommended values of the WHO Permissible limit of 500 mg/L. (Figure 5.5)

5.3.5 Analysis of Heavy Metals during the Dry Season

The laboratory test result for wastewater during the month of February 2023 indicated that heavy metal concentrations of Nickel, Mercury, Lead, and Chromium after the Leachate was Mixed with the Akaki water river resulted in 0.2mg/L, 0.008mg/L, 0.17mg/L and 0.2mg/L respectively which is more than WHO permissible limit. WHO permissible limit of metal concentration for Nickel, Mercury, Lead, and Chromium is 0.001mg/L, 0.020mg/L, 0.01mg/L, and 0.050 mg/L, respectively (Figure 5.6). Higher concentration of Chromium, lead, Nickel, and Mercury was due to hospital and Leather industry waste near the Koshe dumpsite of Addis Ababa, discharging the chemical to the Akaki River directly.

Whereas the concentration of the Zinc and Copper after the Leachate was Mixed with Akaki water of the study area resulted in 0.1mg/L and 0.2mg/L, respectively, which is below the WHO permissible limit of 3.0 mg/L and 2.0 mg/L. The concentration of Zinc and Copper during the dry season is also the same and lower than the WHO permissible limit (Figure 5.6).

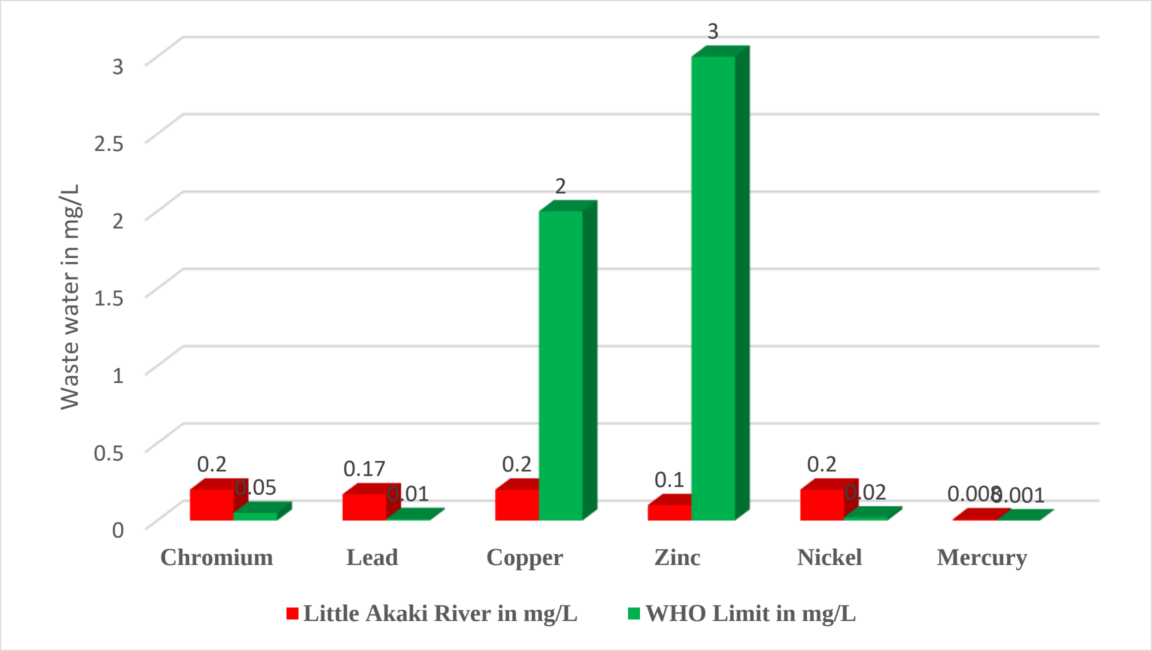


Figure 5.6 Concentration of Heavy metal of Koshe dump site mixed with Akaki River during Dry season (February 2023)

The laboratory test result for wastewater during February 2023 indicated that the heavy metal concentration of Nickel after the Leachate Mixed with the Akaki water river resulted in 0.2mg/L, which was more than the WHO permissible limit. WHO permissible limit of metal concentration for Nickel was 0.001mg/L (Figure 5.6).

The laboratory test result for wastewater during February 2023 indicated that the heavy metal concentration of Lead after the Leachate was Mixed with the Akaki water river was 0.17mg/L, more than WHO permissible limit. WHO's acceptable metal concentration limit for Lead was 0.010mg/L (Figure 5.6).

According to Figure 5.6, the laboratory test result for wastewater during February 2023 indicated that the heavy metal concentration of Chromium after the Leachate was Mixed with the Akaki water river was 0.2mg/L, which was more than WHO permissible limit. WHO's acceptable metal concentration limit for Chromium was 0.050 mg/L. The laboratory test result for wastewater during February 2023 indicated that the heavy metal concentration of Mercury after the Leachate was Mixed with the Akaki water river was 0.001mg/L which was more than WHO permissible limit. WHO permissible limit of metal concentration for Mercury was 0.008 mg/L.

A study by Esakku (2003) on heavy metals in a Municipal solid waste dumpsite in India revealed that the concentrations of Hg, Cr, and Pb exceed the limits set by the standards set up by the Government of India. Another study by Mehreteab Tesfai and Silke (2009) at the Asmara landfill in Eritrea revealed that except for Hg, all the analyzed heavy metals (Pb, Cu, Ni, Fe, and Zn) in the landfill site showed values above the permissible limits of WHO (2009). In particular, the average concentrations of Cu and Pb in the landfill site at Asmara were nine-fold and four-fold greater than the allowable limits, respectively.

Once heavy metals like Copper, Nickel, Chromium, and Zinc enter the food chain, large concentrations may accumulate in the human body. If the metals are ingested beyond the permitted concentration, they can cause severe health disorders Babel and Kurniawan, (2004). Therefore, it is necessary to treat metal-contaminated wastewater before its discharge into the environment.

5.3.6 Seasonal Comparison of Water Pollution

5.3.6.1 Seasonal Comparison of Biochemical Concentration

According to this study, the laboratory result for BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), and TDS (Total Dissolved Solids) downstream of Akaki River during the wet season (August 2022) showed that 97mg/L, 416MG/L, and 800mg/L respectively exceeding the permissible limits of EEPA and WHO standards except for BOD below the WHO standards. (Figure 5.7).

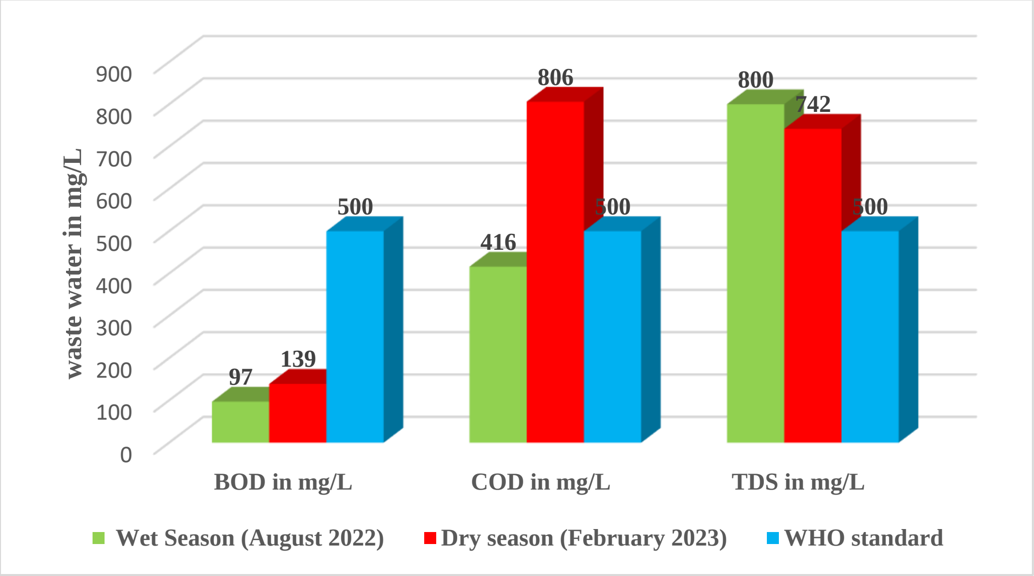


Figure 5.7 Seasonal comparison of Biochemical concentration of leachate mixed with little Akaki river of Addis Ababa city

The laboratory result for BOD (Biochemical Oxygen Demand) downstream of Akaki River during the wet and dry seasons of the month has resulted in 97mg/L and 139mg/L, respectively, below the permissible standard of WHO of 500mg/L with a higher concentration of BOD during the dry season as compared to wet season (Figure 5.7). This could have resulted from less dissolved oxygen in the water due to consumption by heavily multiplied microorganisms. Besides, in the dry season, water volume, velocity, and temperature are low, supporting the multiplication of life.

The laboratory result for COD (Chemical Oxygen Demand) downstream of Akaki River during the wet and dry seasons of the month has resulted in 416mg/L and 806mg/L, respectively, in that concentration of COD during the wet season was below the permissible limit of WHO standard of 500mg/L whereas, the concentration of COD during the dry season was exceeding the allowable limits of WHO standards of 500 mg/L. (Figure 5.7). This study has identified that the COD values of the wastewater Mixed with the Akaki River have a higher concentration of BOD during the dry season than the wet season (Figure 5.7). The Higher COD values in the dry season indicate a significant amount of oxidizable material deposited in the river during the past rainy season.

The laboratory results for TDS during the wet and dry seasons of the month have resulted in 800mg/L and 742mg/L, respectively, exceeding the permissible limits of WHO standards of

500mg/L with a higher concentration of TDS during the wet season than the dry season. (Figure 5.7). The wastewater laboratory analysis for downstream Akaki River results showed that both BOD and COD results were very high during the dry season. Still, TDS concentration was higher in the wet season than in the dry season of the month (Figure 5.7).

The study conducted on Seasonal Variation in Biochemical Oxygen Demand and Chemical Oxygen Demand in Terengganu River Basin, Malaysia, showed that the BOD and COD concentrations ranged from 0.67 to 6.52 mg/L during the wet season and 1.52 to 21.00 mg/L during dry season respectively. Water quality analysis showed that BOD was high in the dry season but COD in the wet season. (Kamarudin et al 2020).

5.3.6.2 Seasonal Comparison of Heavy Metals Concentration

Seasonal comparison of heavy metals concentration during this study showed a remarkable difference during both seasons. Accordingly, the laboratory result of heavy metal concentrations for Nickel, Mercury, Lead, and Chromium downstream of Akaki River during the wet season (August 2022) were 0.01mg/L, 0.1mg/L, 0.031mg/L and 0.4mg/L respectively, exceeding the permissible limits of WHO standards (Figure 5.8).

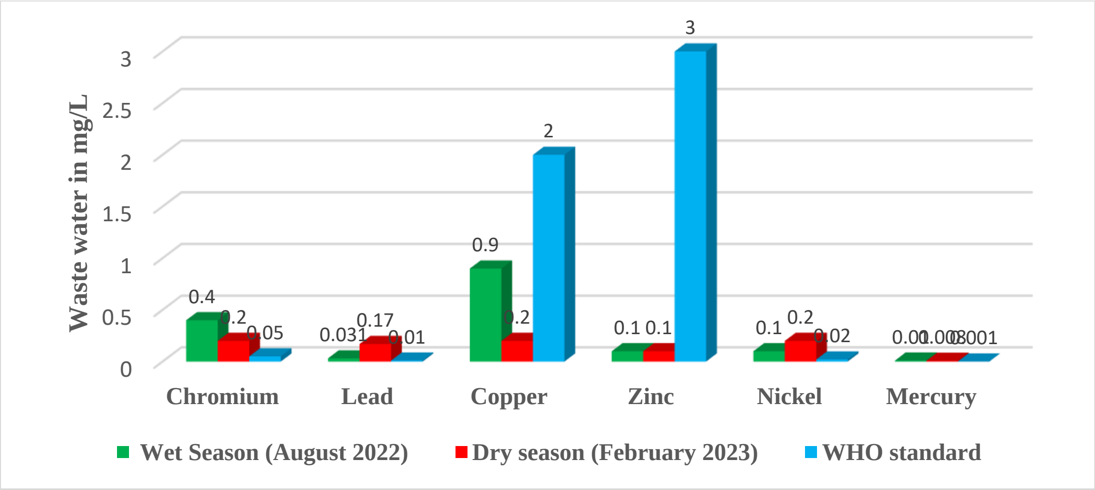


Figure 5.8 Seasonal comparison of heavy metals concentration of Koshe dump site mixed with the little Akaki river of Addis Ababa city

Whereas the laboratory result for wastewater during the dry season (February 2023) indicated that heavy metal concentrations of Nickel, Mercury, Lead, and Chromium after the Leachate was Mixed with Akaki water river resulted in 0.2mg/L, 0.008mg/L, 0.17mg/L and 0.2mg/L respectively which is more than WHO permissible limit. The wastewater laboratory analysis for downstream Akaki River result showed that the concentration of Nickel and Lead was lower during the rainy/wet season than the dry season. But the concentration of Mercury and Chromium was higher during the rainy than in the dry season. (Figure 5.8).

The study conducted to identify seasonal implications in Gazipur District, north of the capital, Dhaka, near a Multi-Industry Zone in Bangladesh; the laboratory result for irrigation water, soil, and vegetables were recorded lower concentrations of heavy metals (Zn, Cr, Cu, and Pb) in the wet season than the dry season (Ahmed et al. 2019). The reason for lower concentrations of heavy metals in the wet season than dry season for irrigation water was in the wet season heavy rainfall dilutes the irrigation water, which lowers the heavy metal concentrations.

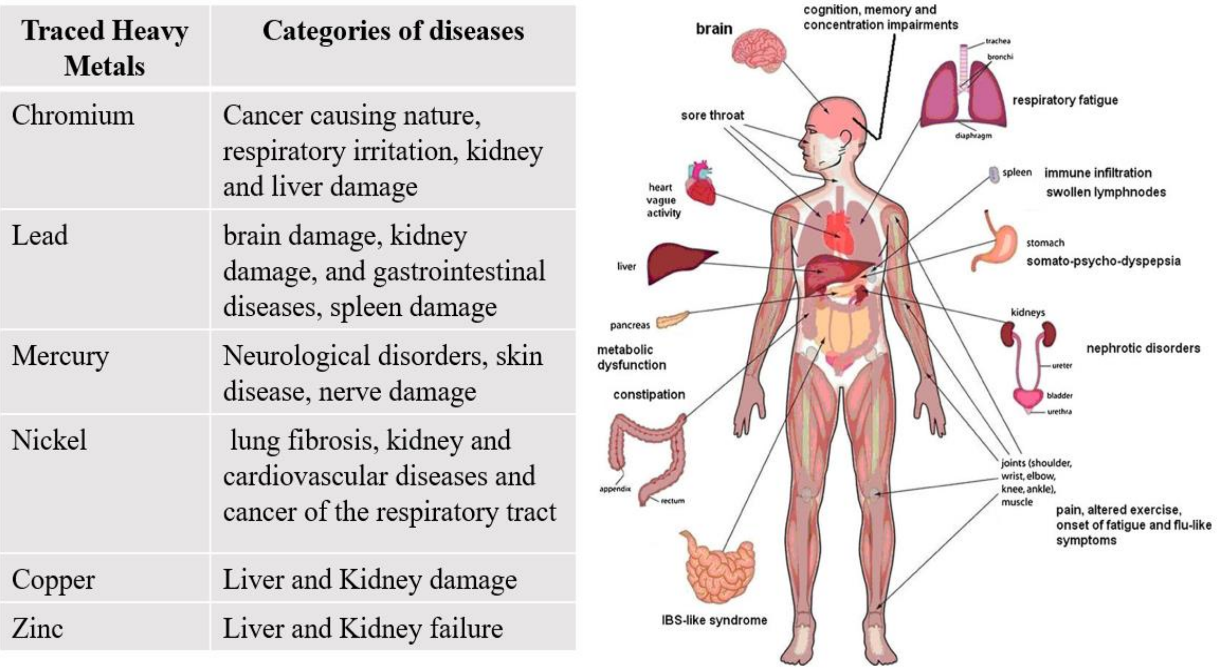
Dudal et al. (2005) stated that during the wet season, the mobility of heavy metals along with soluble organic matter might be affected by heavy rainfall events and result in low concentrations of heavy metals since rainfall occurs in the wet season, which dilutes the irrigation water, making the heavy metal concentrations lower than in the dry season.

5.3.7 Analysis of Heavy Metals and its Implications on Health

The concentration of heavy metals like Copper (Cu), Lead (Pb), Nickel (Ni), Chromium (Cr), Zink (Zn), and Mercury (Hg) in the dump site and downstream river are very harmful because of their non-biodegradable nature, long biological half-lives and their potential to accumulate in different body parts (Sharma et al., 2007).

A few severe health problems may develop because of excessive uptake of dietary heavy metals such as Chromium (Cr) and Lead (Pb) in the human body (Oliver, 1997). Furthermore, consuming heavy metal-contaminated food can seriously deplete some essential nutrients in the body, causing a decrease in immunological defenses, growth retardation, impaired psycho-social behavior, disabilities associated with malnutrition, and a high prevalence of upper gastrointestinal cancer.

As a result of poor solid waste management, cities of most African countries, including Addis Ababa, were becoming dumping grounds for electronic and other hazardous wastes containing Lead, Chromium, Nickel, Mercury, cobalt, etc. Furthermore, small-and large-scale industries located in urban areas often dispose of their wastes along with municipal solid wastes. These heavy metals significantly affect the health of human beings, living organisms, and natural environments (Amadi et al., 2010) when their concentrations are above the standard threshold. Exposure to heavy metals may cause blood and bone disorders, kidney damage and decreased mental capacity, and neurological damage.



Traced Heavy Metals	Categories of diseases
Chromium	Cancer causing nature, respiratory irritation, kidney and liver damage
Lead	brain damage, kidney damage, and gastrointestinal diseases, spleen damage
Mercury	Neurological disorders, skin disease, nerve damage
Nickel	lung fibrosis, kidney and cardiovascular diseases and cancer of the respiratory tract
Copper	Liver and Kidney damage
Zinc	Liver and Kidney failure

Figure 5. 9 Major diseases due to heavy metal concentration in river water (Bjorklund et al., 2019)

According to Figure 5.9 presented above, prolonged consumption of unsafe concentrations of heavy metals through foodstuffs may lead to the chronic accumulation of heavy metals in the kidney and liver of humans, disrupting numerous biochemical processes, leading to cardiovascular, nervous, kidney, and bone diseases (Jarup, 2003). Heavy metals are generally not removed even after wastewater treatment at sewage treatment plants and thus cause a risk of heavy metal contamination of the soil and, subsequently, the food chain. Human populations ' intake of heavy metals through the food chain has been widely reported worldwide (Muchuweti et al., 2006).

Water pollution is a significant concern in Ethiopia’s capital, Addis Ababa, where large amounts of wastewater from residential areas, commerce, industry, and Koshe dump site are discharged untreated into local streams and the Big and Little Akaki rivers in which communities downstream depend on for watering livestock, growing crops, and domestic purposes. Sixty percent of the produce consumed within the city is cultivated using river water.

Lead is a cumulative toxin that primarily affects the blood, nervous system, and kidneys. In the blood at high concentrations, lead inhibits red blood cell formation and eventually results in anemia (Jomova and Valko, 2010). The effects of high lead concentrations on the nervous system can vary from hyperactive behavior and mental retardation to seizures and cerebral palsy. As the kidneys are the primary route for lead excretion, lead tends to accumulate in these organs, causing irreversible damage.

Sharma et al. (2009) have generated data on heavy metal pollution in and around Varanasi city of India, and associated health risk assessment for the consumer‘s exposure to the heavy metals. They proposed the hypothesis that the transportation and marketing of vegetables in contaminated environments may elevate the levels of heavy metals in vegetables through surface deposition. Heavy metals have a toxic impact, but detrimental effects become apparent only when long-term consumption of contaminated vegetables occurs (Rafiqual et al., 2013).

In Bangladesh, food safety is a significant health concern. In the country, most foodstuffs are thought to be contaminated with heavy metals and not safe for human ingestion (Sultana et al. 2017). Due to unplanned industrialization and urbanization in the country, wastewater contaminated with heavy metals is continuously released into irrigation canals; thus, soil and crops are contaminated with heavy metals, and many people consume the contaminated crops after they have been transported and sold in retail markets (Ikeda et al. 2000), and thus face the risk of health problems.

Although certain heavy metals are essential to plant nutrients, plants grown in contaminated soil accumulate high levels of heavy metals, causing a high prevalence of upper gastrointestinal cancer (Türkdo et al. 2003). Heavy metals are highly toxic because of their nonbiodegradable nature and their potential accumulation in the human body (Ahmad and Goni, 2010). Vegetables grown in contaminated soil absorb heavy metals and store them in their tissues, causing adverse clinical problems, including physiological disorders, in people who eat the vegetables because the body has no mechanism to eliminate the heavy metals (Arora et al. 2008).

The occurrence of heavy metals in landfills leachate has been investigated in a major municipal area in Uyo, Nigeria. The elemental compositions of impacted surface water and sediment samples were determined. Analyses were conducted using standard analytical procedures and methods. The results indicated that leachate, surface water, and sediment samples all had elevated levels of heavy metals, implying a significant influence of seeping leachate from the dumpsites (Essien et al., 2022). In the case of Nigeria, untreated wastewater is discharged from Koshe's open dump site to the nearby river of Little Akaki River of Addis Ababa.

5.4 Conclusion

The concentration of BOD, COD, and TDS in the Koshe dumpsite sample area for downstream Akaki River during the wet season (August 2022) was found to be lower than that of the dry season (February 2023). Accordingly, the concentration of BOD, COD, and TDS in the Koshe dumpsite sample area for downstream Akaki River during the wet season (August 2022) was 97mg/L,416mg/L, and 800mg/L, respectively. The concentration of BOD, COD, and TDS in the Koshe dumpsite sample area for downstream Akaki River during the dry (February 2023) season was 139 mg/L, 806 mg/L, and 742 mg/L, respectively.

The higher value of COD during the dry season implies a greater amount of oxidized organic material in the sample that reduces dissolved oxygen levels and endangers the surface water bodies/river life. The Higher value of COD values in the dry season indicates a significant amount of oxidizable material deposited in the river during the past rainy season (Sharma et al. 2020). According to this study, the Qopshe dump site leachate sample was found to have a higher concentration of heavy metals content Chromium, Lead, Nickel, and Mercury at leachate and downstream Akaki River was exceeding the permissible limits of WHO standards except for Zinc and Copper. Of all the pollutants, greater attention has been given to Potentially Toxic Elements (PTEs) like Chromium, lead, Nickel, and Mercury.

The concentration of Chromium, lead, Nickel, and Mercury were 0.4mg/L, 0.031mg/L, 0.1mg/L and 0.01mg/L exceeding the WHO permissible limit of 0.050 mg/L, 0.010mg/L, 0.020mg/L and 0.001mg/L respectively. Higher concentration of Chromium, lead, Nickel, and Mercury was due to hospital and Leather industry waste near the Koshe dumpsite of Addis Ababa, discharging the chemical to the Akaki River directly. The entrance of this leachate to the adjacent Little Akakai River water, especially near the dump site and downstream, magnifies the problem compared with the upper stream of the river from the dump site. Consequently, the stream's water has been polluted physically and chemically through the indiscriminate disposal of solid waste and discharge of leachate.

Of all the pollutants, greater attention has been given to Potentially Toxic Elements (PTEs). Usually, these PTEs are present in trace levels in naturally produced water, but the critical challenge is that some of these PTEs are equally toxic even at low concentration levels (Mazza et al. 2015).

Furthermore, this study has identified that currently, no pollution control method is being practiced at the Koshe open dump site and the downstream rivers. Therefore, the author strongly recommends the present Koshe dump dumpsite be left and treated accordingly to minimize the impact of persistent heavy metals in the area to be used for further economic use of the land.

CHAPTER SIX

Analysis of the Health Prevalence of the Communities Living Around the Koshe Open Dump Site of Addis Ababa City

Abstract

Like all cities of developing countries, Addis Ababa is experiencing higher population growth due to rapid urbanization and rural-to-urban migration, resulting in improper municipal solid waste management and practices. For these reasons, the current Koshe open dump site became part of the city and is located close to populated residential areas, which has emerged as one of the causes of public health risks impacting the livelihood of the communities around the Municipal Solid Waste disposal site.

However, a descriptive study design and mixed method involving qualitative and quantitative approaches were employed to investigate and evaluate the impact of improper Solid waste management on the public health of the communities living around the Koshe open dump site. The wet and dry season patient cards were analyzed to determine the impact of improper solid waste management on air and water pollution in the community living near the Koshe dump site. Data were analyzed from Alert Hospital, 1.5 kilometers near the Koshe dump site, and Menelik Hospital, 12 kilometers from the Koshe dump site.

The study revealed that, during the wet season, out of the total 658 medically diagnosed patients in Alert Hospital, 239 (36.3%) cards were directly related to solid waste management in August 2022. In contrast, only 61(14.8%) were directly related to improper solid waste management in Menelik Hospital. Similarly, during the dry season, out of the total 1632 diagnosed patient cards in Alert Hospital, 638(39.09%) of patient cards diagnosed were directly related to disease with solid waste mismanagement in February 2023.

In August 2022, the study showed that 147(62%) patient cards in Alert Hospital were identified as air pollution-related diseases. Whereas, in Menelik Hospital, 31(36%) patient cards were identified as air pollution-related diseases. In Alert Hospital, 87(36%) patient cards were identified as water pollution-related diseases. In Menelik Hospital, 9(15%) patient cards were identified as water pollution-related diseases.

The study has shown that the trends of solid waste-related diseases in Alert Hospital were much higher than those identified in Menelik Hospital, which is far from the Koshe dump site. Besides, from the identified sample patient cards, solid waste-related medicinal prescriptions have accounted for about 33% and 30% of all medications cost based on the selling price of hospital and private pharmacies, respectively.

Consequently, around 20 percent of the total population from Kolfe Keranio and Nefas Silk Lafto sub-cities of Addis Ababa city were estimated to live near the Koshe open dump site, which was highly exposed to clinically identified health risks like respiratory diseases, eye diseases, gastrointestinal diseases, and skin diseases.

Keywords: Eye diseases, Respiratory diseases, Gastrointestinal diseases, Skin diseases, solid waste-related diseases, cost of Medication.

6.1 Introduction

Exposure to a landfill is associated with health problems such as respiratory symptoms, irritation of the skin, nose, and eyes; gastrointestinal problems; fatigue; headache; psychological disorders; and allergies (Vrijheid,2000). However, some studies conducted by social scientists have examined the social consequences of the present urban waste management issues, yet few of these studies examined the health implications of people living in close proximity to waste dumpsites. (Nabegu 2010, Nwanta et al. 2010).

Elizabeth et al. reported that indiscriminate waste dumping practices caused the increasing incidence of diarrhea and waterborne diseases among under children in Odukpani, Akamkpa, and Biase Local Government Area of Cross River State, Nigeria.

The U.S. Public Health Service identified diseases such as cholera, malaria, dengue fever, respiratory infection, and asthma as the major health problems associated with improper municipal solid waste management. Moreover, the U.S. Public Health Service identified 22 human diseases that are linked to improper solid waste management. (Tchobanoglous et al. 1993).

According to the previous study, residents who live closer to landfill sites are more likely to suffer from medical issues such as asthma, infections, diarrhea, stomachache, recurrent flu, cholera, malaria, cough, skin irritation, cholera, diarrhea, and TB than those who live further away (Vrijheid 2000; Bridges et al. 2000; Brender 2011; Njoku et al. 2019. According to the study, the major problems reported by the people near the Siliguri landfill are stomach-related problems, skin rashes, wounds, frequent fever, and diarrhea. Besides, some of the respondents also report respiratory problems like asthma and cough, mainly due to the bioaerosol exposure linked to various respiratory disorders.

Various diseases have been linked to the illegal disposal of municipal solid waste (MSW) (Reinhart 1993; Sharholy et al. 2008). People who live in a garbage-strewn neighborhood are more likely to have malaria, diarrhea, and respiratory diseases (Zohoori and Ghani 2017). Individuals may also be exposed to a variety of diseases and other toxins if they use contaminated MSW water for drinking, bathing, and irrigation purposes (Alam and Ahmade, 2013). People living near garbage disposal facilities are more likely to suffer from respiratory symptoms, skin, nose, and eye irritation, gastrointestinal issues, fatigue, headaches, psychological issues, and allergies (Gouveia and Prado, 2010; Abul, 2010).

Residents who live near an open dumping site are more likely to get respiratory ailments (Sankoh et al. 2013; Njoku et al. 2019). Bioaerosols and biological substances emitted from garbage sites can induce respiratory disorders like asthma, chronic obstructive pulmonary disease (COPD), and breathing disorders (Kret et al., 2018). Aside from biological agents and volatile organic compounds generated by landfills, emissions from automobiles, trucks, and bulldozers utilized in the landfill site can also contribute to excessive emissions (Vimercati et al. 2016). Such emissions have harmed human health (Njoku et al., 2019).

The US Public Health Service identified 22 human diseases that are linked to improper solid waste management (Hanks, 1967. Cited in Tchobanoglous et al., 1993). Previous research shows that people living closer to landfill sites suffer from medical conditions such as asthma, cuts, diarrhea, stomach pain, reoccurring flu, cholera, malaria, cough, skin irritation, cholera, diarrhea, and tuberculosis more than people living far away from landfill sites (Thada 2012; Bridges et al. 2000; Sankoh et al.2013; Brender et al. 2011).

6.2 Methodology and Instrumentation

In two rounds, secondary data on patient cards were collected from Alert Hospital and Menelik Hospital in August 2022 and February 2023. During the first round, 1088 patient cards from Alert and Menelik Hospital were collected and evaluated against the prevalence of solid waste-related diseases. During the second round, 2632 patient cards from Alert and Menelik Hospital were collected and assessed against the prevalence of solid waste-related diseases.

In the first round, the Socio-Demographic Characteristics of the reviewed 1088 patient cards were identified using SPSS 21 version software by their Age, Sex, and Hospital Settings. Similarly, in the second round, the Socio-Demographic Characteristics of the reviewed 2632 patient cards were identified using SPSS 21 version software by their Age, Sex, and Hospital Settings.

In both rounds, the reviewed patient card was analyzed for Solid waste-related diseases and diseases related to air and water pollution. Furthermore, the cost implication of the patient's medication for solid waste-related diseases was evaluated.

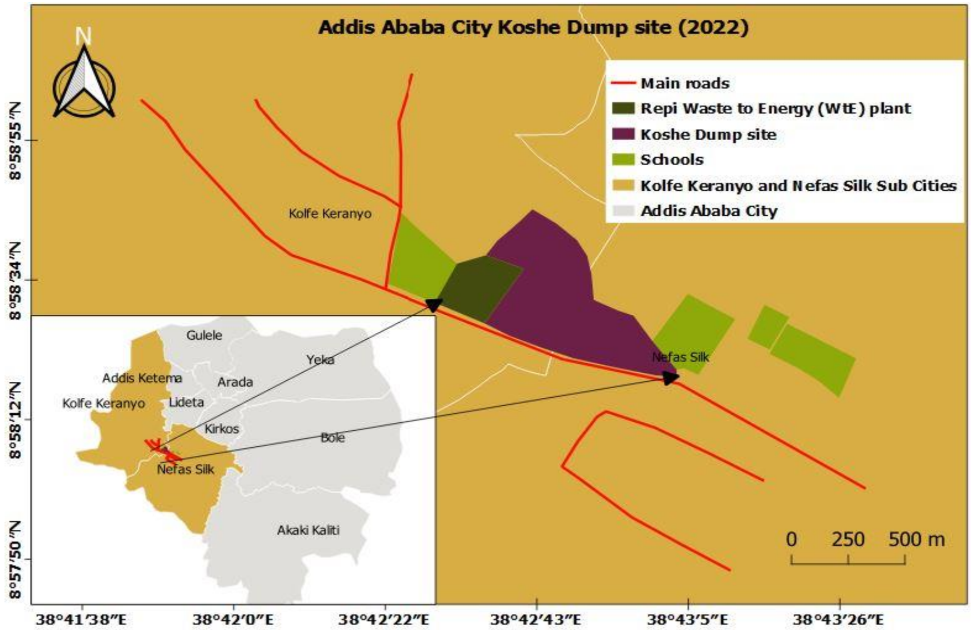


Figure 6-1 Map of Addis Ababa City and Koshe dump site 2022.

The yellow color identified two sub-cities of Addis Ababa city, namely Nefas Silk Sub city and Kolfe Keranio sub-city, with a total population of 844,311, which accounts for 27% of the total Addis Ababa city population of 3,103,999. Koshe dump site is located at the center of the two sub-cities, and communities living nearby the Koshe dump site are estimated to be 20% of Addis Ababa city. All are directly exposed to solid waste-related diseases (Figure 6.1).

Table 6-1 Population size and area in square km. (Source: CSA projection, 2013)

No	Name of sub-cities	Number of Population	Area in Sq. Km
1	Akaki Kality	205,385	118.08
2	Nifas Silk Lafto	358,359	68.3
3	Kolfe Keranio	485,952	61.25
4	Gulele	303,226	30.18
5	Lideta	228,547	9.18
6	Kirkos	250,665	14.62
7	Arada	239,638	9.91
8	Addis Ketema	289,344	7.41
9	Yeka	392,781	85.98
10	Bole	350,102	122.08
Total	**10 Sub cites**	**3,103,999**	**526.99**

6.3 Result and Discussions

To evaluate and determine the impact of improper Solid waste management on the public health of the communities living around the Koshe open dump site, two round patient cards (August 2022 and February 2023) were collected and analyzed to critically analyze the impact of improper solid waste management on the community living nearby the Koshe dump site.

The two round patient cards were collected and analyzed from Alert Hospital (1km near to Koshe dump site and Menelik II Hospital (12 km far away from the Koshe dump site) for a clear understanding of the implication of improper solid waste management on public health. The first-round data was collected in August 2022, and 1088 patient cards were reviewed from Alert Hospital and Menelik Hospital. Whereas the second-round data was collected in February 2023, and 2632 patient cards were reviewed from Alert Hospital and Menelik Hospital.

6.3.1 Wet Season Analysis (August 2022)

6.3.1.1 Socio-Demographic Characteristics of the patient

Table 6-2 Socio-Demographic Characteristics of the reviewed patient cards August 2022

Variables		**Alert Hospital No [%]**	**Menelik Hospital No [%]**	**Total No [%]**
Sex	Female	362 (53.7)	186 (44.9)	548 (50.4)
	Male	312 (46.3)	228 (55.1)	540 (49.6)
Age (Years)	<10	56 (8.3)	20 (4.8)	76 (7.0)
	10-19	79 (11.7)	37 (8.9)	116 (10.7)
	20-35	238 (35.3)	155 (37.4)	393 (36.1)
	36-50	140 (20.8)	82 (19.8)	222 (20.4)
	51-65	80 (11.9)	72 (17.4)	152 (14.0)
	>65	81 (12.0)	48 (11.6)	129 (11.9)
Hospital Setting	Pediatrics OPD	143 (21.2)	53 (12.8)	196 (18.0)
	Adult OPD	527 (78.2)	328 (79.2)	855 (78.6)
	Adult Inpatient	2 (0.3)	29 (7.0)	31 (2.8)
	Pediatrics Inpatient	2 (0.3)	4 (1.0)	6 (0.6)

In this preliminary study, 1088 patient cards were reviewed from Alert Hospital and Menelik Hospital operating in Addis Ababa city. More than half (61.9%) of the cards were reviewed from Alert Hospital, which is considered as the case hospital given its proximity to Koshe, an open landfill area where the final solid waste from Addis Ababa city has been disposed of in an unscientific way. In the same manner, more than one-third (38.1%) of the patient cards were reviewed from Menelik Hospital, located around the center of Addis Ababa, far away from the Koshe waste disposal site (Table 6.2).

Half (50.4%) of the reviewed cards from Alert and Menelik Hospital belonged to female patients; similarly, more than half (56.5%) of the cards represented patients in the age group of 20-50 years. According to different study findings, children and females are more vulnerable to solid waste-related diseases than male patients. Lack of inadequate solid waste management services significantly affects the urban poor, women, and children, who are vulnerable to health hazards. Moreover, its effects are also reflected in reduced productivity, low income and poor quality of life, and deteriorated environment (World Bank, 1999).

A vast majority (78.6%) of the cards were reviewed by Adult Outpatient (OPD) Department, followed by pediatrics OPD, which accounted for one-fifth (18.0%) of the reviewed cards (Table 6.2).

6.3.1.2 Solid Waste Related Diagnosis

According to Table 6.2, out of the total 1088 reviewed patient cards, 1069 (98.3%) have a clear medical diagnosis to classify the identified medical diagnosis into two categories: solid waste related or non-solid waste related. Out of the total 1069 diagnosed patient cards,658 patient cards, or 97.6%, were medically diagnosed at Alert Hospital, whereas 411 patient cards, or **99.3%,** were medically diagnosed at Menelik Hospital. The remaining 19 patient cards (1.7%) were not diagnosed with any categories of diseases.

Accordingly, a well-trained medical doctor classified the identified medical diagnosis into solid waste-related or non-solid waste-related categories where 300 patient cards, or 28.1% of the diagnosis, appeared to have a direct relation with solid waste diseases in both hospitals, whereas 769 patient cards or 71.9% were categorized as non-Solid waste-related diseases. (Table 6.2).

In Alert Hospital, solid waste-related diseases Account for 36.3%, whereas in Menelik Hospital, solid waste-related diseases Account for 14.8%. Gouveia and Prado (2010) highlighted that in several health surveys, a wide range of health problems, including respiratory systems, irritation of the skin, eyes, and nose, gastrointestinal problems, psychological disorders, and allergies, have been discovered.

Table 6-3 Medical Diagnosis related to solid waste management issues (August 2022)

Variables		**Alert Hospital in No ([%)**	**Minilik Hospital in No (%)**	**Total in No (%)**
Medical Diagnosis	Yes, diagnosed	658 (97.6)	411(99.3%)	1069 (98.3)
	Not diagnosed	16 (2.4)	3 (0.7)	19 (1.7)
Solid Waste Related Diagnosis	Solid waste-related diseases	239 (36.3)	61 (14.8)	300 (28.1)
	Non-Solid waste related diseases	419 (63.7)	350 (85.2)	769 (71.9)
Detail category				
Diseases related to Air pollution	Respiratory Ds	105 (43.90)	22 (36.1)	97 (32.3)
	Eye Ds	42 (17.60)	24 (39.3)	66 (22.0)
Diseases related to water pollution	Gastrointestinal Ds	26 (10.90)	6 (9.8)	32 (10.7)
	Skin Ds	61 (25.50)	3 (4.9)	64 (21.3)
	Others	5 (2.1)	6 (9.8)	41 (13.7)

Communities near landfills and open dump sites are susceptible to health impacts associated with exposure to landfill and uncontrolled dump sites. Moreover, the urban poor suffer most from life-threatening conditions deriving from deficient Solid Waste Management (Zurbrügg, 2003). The health problems investigated from different literature include respiratory diseases, skin infections, eye irritation, gastrointestinal problems, and Diarrhea. (Mataloni et al., 2016). From the above research, several epidemiological studies have investigated whether there is a higher-than-usual incidence of adverse health events such as cancer, asthma, and respiratory infections in populations living near landfill sites. (Mataloni *et al.*,2016; Rusaik, 2016; Khan *et al.*, 2017; Esphylin *et al.*, 2018).

According to Table 6.3, the identified medical diagnosis in Alert Hospital showed that 239 patient cards, or 36.3% of the reviewed patient cards, were diagnosed as Solid Waste Related diseases in communities living around the Koshe open dump site of the city. At the same time, the identified medical diagnosis in Menelik Hospital showed that 61 patient cards, or 14.8%, were found to be diagnosed as Solid Waste Related diseases (Table 6.3). Patients diagnosed with Solid waste-related disease in Alert Hospital were found to be more than two folds than patients diagnosed at Menelik Hospital with diseases like gastrointestinal infection, eye diseases, asthma, respiratory diseases, and skin irritation.

This study was in line with the study of Abul (2010), which states that diarrhea, asthma, branchiate infection, and skin irritation as common diseases that frequently occur around solid waste dumping sites. The report of UNEPA (2006) also showed that the foul odor and leachate released from dumpsites severely affect the people settled around or next to dumpsites.

Moreover, (Gouveia and Prado, 2010) highlighted that in several health surveys, a wide range of health problems, including respiratory systems, irritation of the skin, eyes, and nose, gastrointestinal problems, psychological disorders, and allergies, have been discovered.

This study has also identified that the vast majority (78.6%) of Adult Outpatient (OPD) Departments and pediatrics OPD, which accounted for one-fifth (18.0%) of the patient settled around or population living close to the Koshe dump site, were at risk from this unscientific disposal of solid waste where there is no proper waste disposal method, especially the pre-school children, women and adults living for longer time around the slum areas of the dumpsite. Figure 6.2 explains the situations of the community living around Koshe dump site areas.


a) Koshe dump site right entrance b) Koshe dump site left entrance


c) Private vehicles Dumping the waste d) Koshe dump site at the backside


e) An elementary school near Koshe. f) Students attending school without masks


g) Leachate from Koshe dump site h) Children living in Koshe dump site

i) Residents at Koshe dump site   j) community Housing status at Koshe dump site

Figure 6-2 The situation of the communities living around the Koshe dump site (2023)

6.3.1.3 Diseases Related to Air Pollution

According to Figure 6.3, Out of 239 Patient cards diagnosed in Alert Hospital for Solid waste-related diseases, 147(61.5%) patient cards were identified as air pollution-related diseases such as lung diseases, asthma, lower and upper respiratory diseases, and eye-related diseases. Whereas, out of 61Patient cards diagnosed in Menelik Hospital for Solid waste related diseases, 31(36%) patient cards were identified as air pollution-related diseases with all types of respiratory disease except the patients for eye-related diseases where Menelik hospital was serving as eye specialty and referral hospital at country level.

The above research finding has indicated that the prevalence of air pollution-related diseases in Alert Hospital was found to be higher than the prevalence of air pollution-related diseases in Menelik Hospital by two folds.

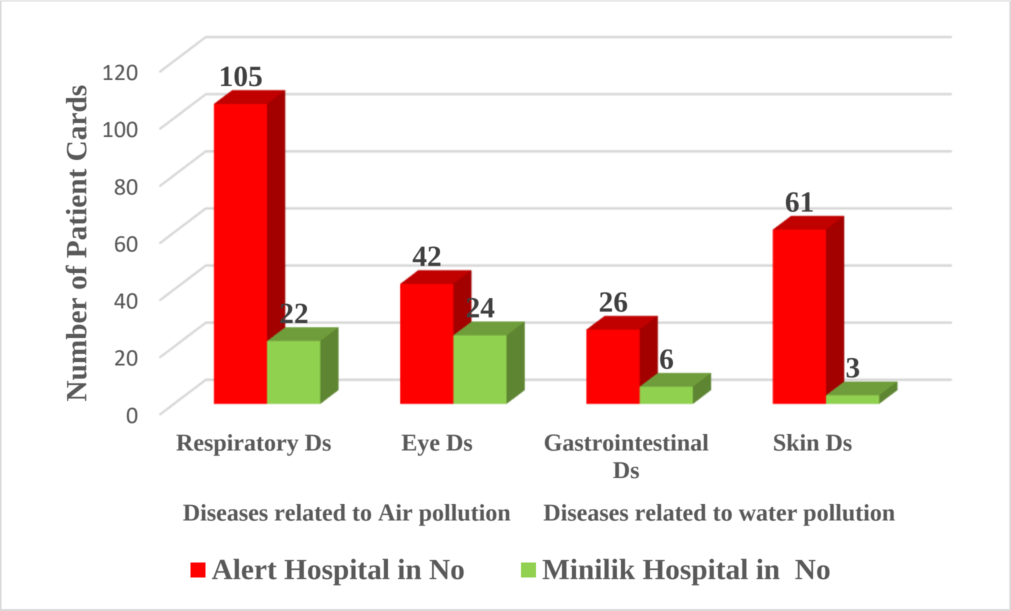


Figure 6-3 Trends of diseases related to Air pollution (August 2022)

In Menelik Hospital, patient cards diagnosed with Aye disease accounted for 24 patient cards or 39.3% because eye-related diseases were diagnosed and treated from all parts of the country because the hospital was serving as an Ethiopian eye specialty referral hospital (Figure 6.3).

A study conducted by Mataloni et al. (2016) reported that the public who live within 5 km of a landfill site are exposed to health risks as they tend to get lung cancer and deaths and hospitalizations for respiratory diseases. Khan et al. (2016) also reported that a higher proportion of households in St. Louis County residents in the Bridgeton Landfill, Missouri, United States area have other respiratory symptoms than in the comparison area households, including wheezing, gasping for air, heaviness in breathing, and increased effort to breathe and sore throats.

Another study has identified that residents living next to dumpsites are usually affected by Psychological/Emotional impacts like stench, the sight of marauding scavenging animals, and social stigma. Moreover, for those who live closer to the dumping sites, the nuisance of scavenging animals and birds may affect their emotional and psychological health. Heavy metal poisoning has also been associated with mental disorders. (Ziraba et al., 2016).

Exposure to PM2.5, a form of air pollution composed of inhalable particulate matter smaller than 2.5 μm in aerodynamic diameter, is linked to asthma, ischemic heart disease, type II diabetes, lung cancer, and other deleterious health effects. These particles are emitted from vehicles, coal-burning power plants, waste incineration, and other anthropogenic and natural sources. Thus far, most academic research, monitoring, and media attention regarding PM2.5 exposure has been largely focused on the United States, Europe, and, recently, China. Additional research is vital and urgent for other regions where air pollution levels might be even higher (Garima et al., 2022).

Disease-specific analysis reveals that Lower Respiratory Tract Infection (LRTI), Chronic Obstructive Pulmonary Diseases (COPD), Lung Cancer, Ischemic Heart Disease (IHD), and stroke were the cause of 3850, 8316, 4375, 10291, and 10617deaths respectively in 2012 (WHO, 2016). WHO further reported that in 2012 crude death rate due to ambient air pollution was 24 per 100,000 population. In 2016 the crude death rate was 103.4 per 100,000 population due to Ambient air pollution (WHO, 2021).

6.3.1.4 Diseases Related to Water Pollution

According to Figure 6.4, Out of 239 Patient cards diagnosed in Alert Hospital for Solid waste-related diseases, 87(36.40%) patient cards were identified as water pollution-related diseases such as Gastrointestinal and skin-related diseases. Of 61 patient cards diagnosed in Menelik Hospital for Solid waste-related diseases, 9(14.75%) were identified as water pollution-related diseases. This data indicated that Patients diagnosed with Water pollution-related disease (87) in Alert Hospital were found to be more than nine folds more than patients at Menelik Hospital, implying that communities living around the Koshe dump site were more susceptible to water pollution-related disease originated from improper solid waste disposal at the dumping area.

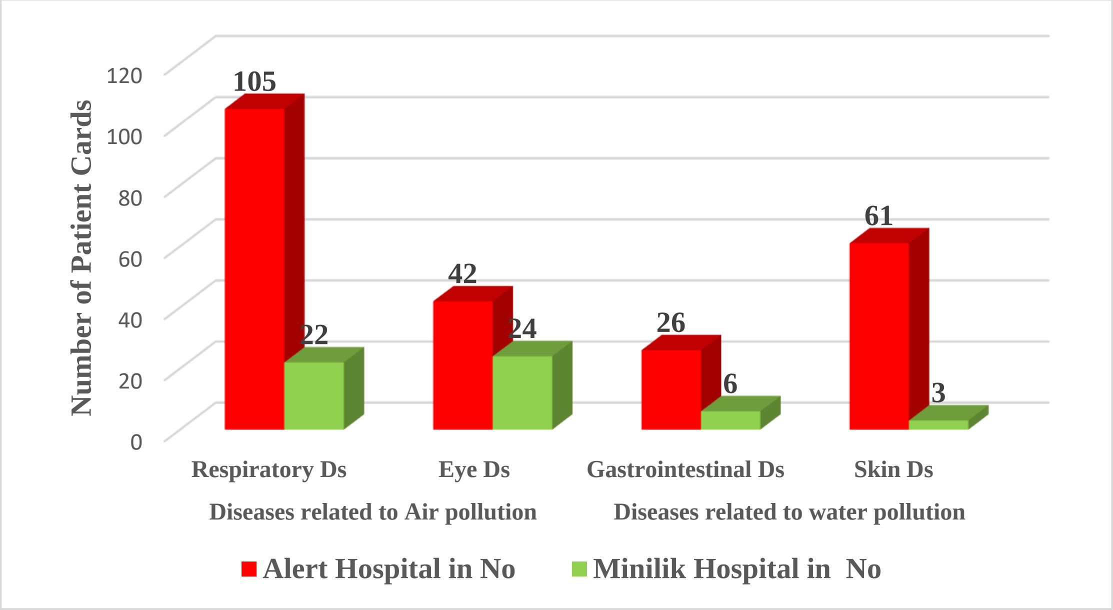


Figure 6-4 Diseases related to water pollution

According to Figure 6.4, Infections related to water pollution were 87 in Alert Hospital, whereas only 9 patient cards were identified in Menelik Hospital. Moreover, the number of patient cards for skin disease was 61 in Alert Hospital and 3 in Menelik Hospital, which directly implies Koshe's open dump site in the communities around.

The study conducted by UNDP has shown that the intake of heavy metals can lead to illness in humans and animals. Thus, the carcinogenic effects of continuous consumption of fruits and vegetables loaded with heavy metals such as Pb, Cu, and Zn are known. This may be related to the incidence of gastrointestinal cancer and cancer of the pancreas, urinary bladder, or prostate (UNDP, 2006). The sad thing about the pollution of the environment with heavy metals is that they can only be transformed from one oxidation state or organic complex to another.

Due to their non-biodegradable and persistent nature, heavy metals are accumulated in vital organs in the human body, such as the kidneys, bones, and liver. They are associated with numerous severe health disorders (Duruibe et al., 2007). Individual metals exhibit specific signs of their toxicity. Lead, Hg, Zn, Cu, and Cr poisoning have been implicated in gastrointestinal disorders, diarrhea, stomatitis causing a rust-red color to stool, ataxia, paralysis, depression, and pneumonia (Duruibe et al., 2007).

6.3.1.5 Cost of Medications during Dry Season

The identified medical diagnoses were categorized into diseases related to air pollution and water pollution (eye diseases, respiratory diseases, gastrointestinal diseases, skin diseases, and other diseases). Comparing the situation between the two hospitals, a considerable variation in the occurrences of waste-related health problems appeared in this study, where 36.3% of diagnoses in Alert Hospital and 14.8% in Menelik Hospital directly relate to solid waste management. Similarly, patients' cards were reviewed for medications prescribed to help manage their respective medical conditions (Table 6.4).

Table 6-4 The Cost of Medication at Alert and Menelik Hospital in USD (August 2022)

Variables	Number	Unit Cost	Total cost
The total cost of Medication Prescribed			
Cost at Hospital	1069	1.21	1293.49
Cost at Private	1069	2.24	2394.56
The total cost for Diagnosis related to Solid Waste			
Cost at Hospital	300	1.43	429
Cost at Private	300		729

NB: One USD was converted at ETB 52.00 of the current foreign currency exchange market price.

According to Table 6.4, the total cost of medication prescribed for 1069 medically diagnosed patients was USD 1293.49 based on the selling price of Government pharmacies and USD 2394.56 based on the selling price of privately owned pharmacies.

From the total cost, the share of 300 medications prescribed for diagnosis related to Solid Waste diseases was found to be USD 429.00 based on the selling price of Government pharmacies at the Hospital. Similarly, the share of medication prescribed for Diagnosis related to solid waste was found to be USD 729.00 based on the selling price of privately owned pharmacies (Table 6.4).

Thus, it can be understood that from the identified sample patient cards, solid waste-related medicinal prescriptions have accounted for about 33% and 30% of all medications cost based on the selling price of hospital and private pharmacies, respectively.

The purchase of medicines for both government and private hospitals implied that the city government was accountable for supplying medication facilities occurred due to the improper solid waste management practices diagnosed in Alert Hospital and Menelik Hospital visiting for medication.

6.3.2 The Dry Season analysis (February 2023)

6.3.2.1 Socio-Demographic Characteristic

In this preliminary study, 2632 patient cards were reviewed from Alert Hospital and Menelik the II Hospital operating in Addis Ababa city, and out of which 50.4% were reviewed belonged to female patient cards and 49.6% belonged to male patient cards.

Alert Hospital was considered as the case Hospital given its proximity to Koshe and an open landfill area where the final solid waste from Addis Ababa city has been disposed of. Whereas Menelik the II Hospital was about 15 kilometers away from the Koshe waste disposal site and considered a control Hospital.

More than half (60.4%) of the cards represented patients categorized under the age group of 20-50 years, with the majority of the productive force of the community in Addis Ababa city. Moreover, a vast majority (78.6%) of the cards were reviewed by the Adult Outpatient (OPD) Department, followed by the pediatrics Outpatient (OPD) Department, which accounted for (18.0%) of the reviewed cards (Table 6.5).

Table 6-5 Socio-Demographic Characteristics of the reviewed patient cards

Variables		**Alert Hospital No [%]**	**Minilik Hospital No [%]**	**Total No [%]**
Sex	Female	877 (53.7)	449 (44.9)	1326 (50.4)
	Male	755 (46.3)	551(55.1)	1306 (49.6)
Age (Years)	<10	135 (8.3)	48 (4.8)	183 (6.95)
	10-19	91 (11.7)	89 (8.9)	180 (6.8)
	20-35	576 (35.3)	374 (37.4)	950 (36.1)
	36-50	441 (20.8)	198(19.8)	639 (24.3)
	51-65	194 (11.9)	174(17.4)	368 (14.0)
	>65	196(12.0)	116 (11.6)	312 (11.9)
Hospital Setting	Pediatrics OPD-	346 (21.2)	128 (12.8)	474 (18.0)
	Adult OPD	1276 (78.2)	792 (79.2)	2068 (78.6)
	Adult Inpatient	5(0.3)	70 (7.0)	75 (2.8)
	Pediatrics Inpatient	5(0.3)	10 (1.0)	15 (0.6)

6.3.2.2 Solid Waste Related Diagnosis

According to Table 6.5, out of the total 2632 reviewed patient cards, 2586(98.3%) have a clear medical diagnosis to classify the identified medical diagnosis into two categories: solid waste related and non-solid waste related. Out of the 2632 diagnosed patient cards, 1593(97.6%) were medically diagnosed at Alert Hospital, which was more than two-fold of the patient card reviewed during the first-round analysis.

Out of the 2632 diagnosed patient cards, 993(99.3%) were medically diagnosed at Menelik the II Hospital, which was more than two-fold of the patient card reviewed during the first-round analysis. The remaining 46 patient cards (1.7%) were not diagnosed with any categories of diseases.

The Socio-Demographic Characteristic of the reviewed patient cards further indicates that less than 10 age categories are very small with less than 7% compared to 36% of the younger age group. Similarly, the hospital setting has indicated that pediatric inpatients are much lower at 0.6%. This was because children were more often at home and less susceptible to air pollution risks than adults.

Accordingly, a well-trained medical doctor classified the identified medical diagnosis into solid waste-related or non-solid waste-related categories. Consequently, out of the 2632 patient cards diagnosed, 740 (28.1%) of the total patient care diagnosis directly related to solid waste diseases, and 1592 (71.9%) patient cards were found to be non-Solid waste-related diseases. (Table 6.5)

Similarly, out of the total 1632 diagnosed patient cards in Alert Hospital, 638(39.09%) of patient cards diagnosed were directly related to disease with solid waste mismanagement. Whereas, out of the 1000 diagnosed patient cards in Menelik the II Hospital, 102(10.20%) of diagnosed patient cards were directly related to disease with solid waste mismanagement.

Table 6-6 Medical Diagnosis and Medications related issues (February 2023)

Variables		**Alert Hospital in No ([%)**	**Minilik Hospital in No (%)**	**Total in No (%)**
Medical Diagnosis	Yes, diagnosed	1593 (97.6)	993(99.3%)	2586 (98.3)
	Not diagnosed	39 (2.4)	7 (0.7)	46 (1.7)
Solid Waste Related Diagnosis	Solid waste-related diseases	638 (39.09)	102 (10.20)	740 (28.11)
	Non-Solid waste related diseases	994 (60.90)	898 (89.80)	2586 (98.3)
Detail category				
	Respiratory Ds	272 (42.63)	35 (34.31)	307 (41.48)

Diseases related to Air pollution	Eye Ds	128 (20.06)	40 (39.21)	168 (22.7)
Diseases related to water pollution	Gastrointestinal Ds	86 (13.47)	9 (8.82)	95 (12.83)
	Skin Ds	141 (22.1)	12 (11.76)	153 (20.67)
	Others	11 (1.72)	6 (5.88)	17 (2.29)

6.3.2.3 Diseases Related to Air Pollution

Out of 638 diagnosed patient cards for solid waste-related disease in Alert Hospital, respiratory, eye, gastrointestinal, and skin diseases account for 42.63%, 20.06%, 13.47%, and 22.1%, respectively. Whereas, out of 638 patients diagnosed patient cards for solid waste-related disease in Menelik the II Hospital, respiratory diseases, eye diseases, gastrointestinal diseases, and skin diseases account for 34.31%, 39.21%, 8.82%, and 11.76%, respectively.

In Alert Hospital, out of the 638 diagnosed patient cards, the share of Air pollution-related diseases accounts for 400(62.69%) for solid waste-related diseases. Whereas, in Menelik Hospital, the share of Air pollution-related diseases accounts for 35(34.3%) except for eye-related diseases, which served the country as a whole Aye specialty referral hospital (Table 6.6).

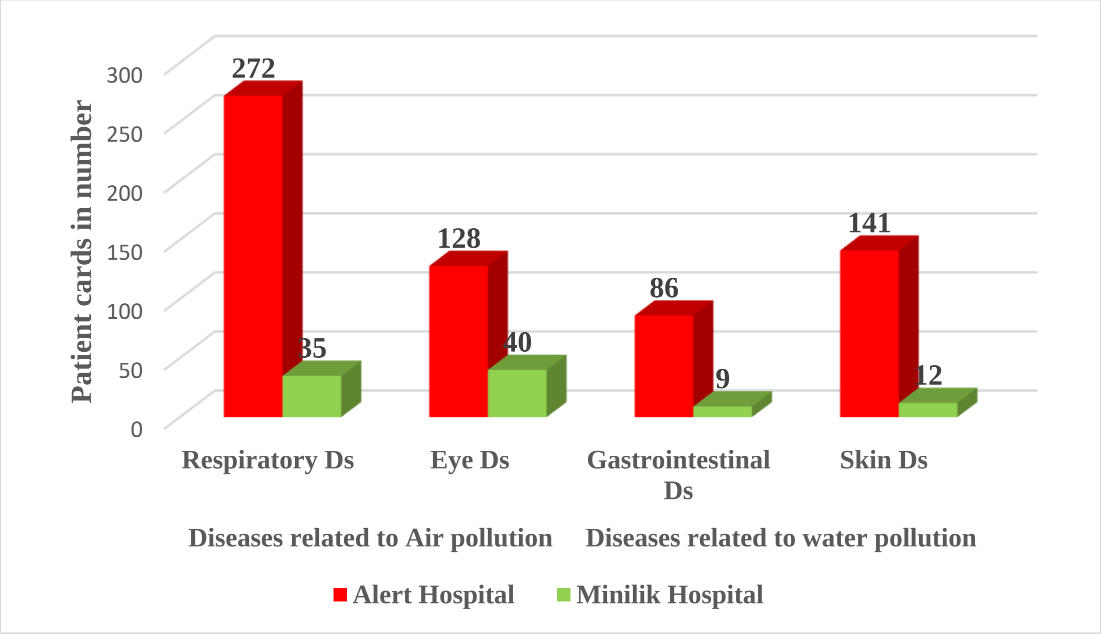


Figure 6-5 Disease related to air Pollution (February 2023)

This study indicated that the prevalence of patient cards related to solid waste diseases in Alert Hospital, except for eye diseases, was found to be higher than in Menelik Hospital in that Koshe open dump site has an adverse health impact on the communities living around the dump site(Figure 6.5).

In Menelik Hospital, patients cards diagnosed with aye disease accounted for 40(39.21%) because eye-related diseases were diagnosed and treated from all parts of the country. After all, the hospital was serving as an Ethiopian eye specialty referral hospital.

A study conducted by Mataloni et al. (2016) reported that the public who live within 5 km of a landfill site are exposed to health risks as they tend to get lung cancer and deaths and hospitalizations for respiratory diseases. Khan et al. (2016) also reported that a higher proportion of households in St. Louis County residents in the Bridgeton Landfill, Missouri, United States area have other respiratory symptoms than in the comparison area households, including wheezing, gasping for air, heaviness in breathing, and increased effort to breathe and sore throats.

Solid waste dump sites have also been proven to have a potentially higher generic risk of causing respiratory diseases to human health because it is a source of airborne pollution (Olorunfem, 2009). Airborne PM is a health concern worldwide due to adverse health effects. A previous epidemiological study demonstrated exposure to PM could intensify respiratory morbidity and mortality (Pope III et al., 1995). Several studies have revealed the health risks posed by landfill sites, such as cancer or congenital anomalies (Jarup et al., 2012; Palmer et al., 2005).

Environmental fine particulate matter (PM2.5) exposure is a major global health concern (Landrigan et al., 2018). Exposure to PM2.5 is a leading global mortality risk factor, with an estimated three to nine million attributable deaths in 2017 (Stanaway et al., 2018). Annual global welfare costs associated with premature deaths attributable to PM2.5 are projected to rise from US$3 trillion in 2015 to US$18–25 trillion in 2060 (OECD, 2016).

6.3.2.4 Diseases related to water pollution

Out of 638 diagnosed patient cards for solid waste-related diseases in Alert Hospital, respiratory, eye, gastrointestinal, and skin diseases account for 42.63%, 20.06%, 13.47%, and 22.1%, respectively. Whereas, out of 638 patients diagnosed patient cards for solid waste-related disease in Menelik the II Hospital, respiratory diseases, eye diseases, gastrointestinal diseases, and skin diseases account for 34.31%, 39.21%, 8.82%, and 11.76%, respectively (Figure 6.6).

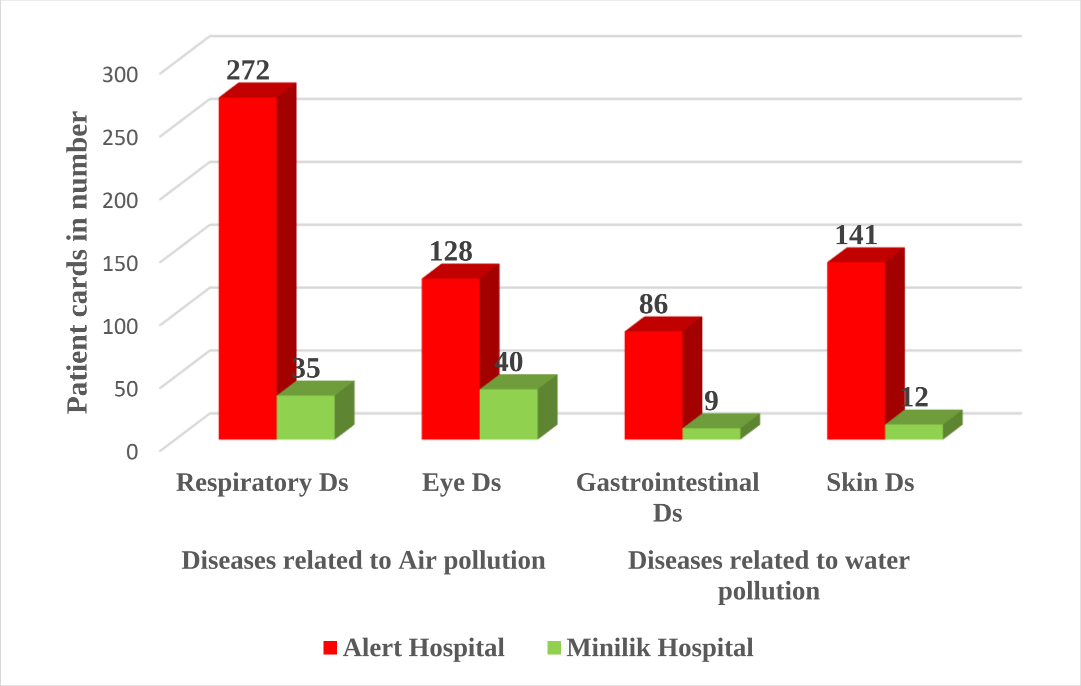


Figure 6-6 Diseases related to water pollution (February 2023)

According to Figure 6.6, Out of 638 Patient cards diagnosed in Alert Hospital for Solid waste-related diseases, 227(35.58%) patient cards were identified as water pollution-related diseases such as Gastrointestinal and skin-related diseases. Whereas, out of 102 Patient cards diagnosed in Menelik Hospital for Solid waste-related diseases, 21(20.59%) were identified as water pollution-related diseases.

This data indicated that Patients diagnosed with water pollution-related diseases in Alert Hospital accounted one folds more than those diagnosed at Menelik Hospital, implying that communities living around Koshe dump site were more susceptible to water pollution-related disease from improper solid waste disposal at the dumping area. Limoli et al. (2019) reported that illegal landfilling has adverse health effects on people living near the landfills and is more harmful to children, as their immune systems are still developing because they spend most of their time outside their homes. Upon contact with water, some contaminants dissolve and leach into the soil and contaminate the underwater table leading to water pollution.

Various health problems result from living in dump sites and slum places. According to Ooi (2007), people who reside in these places are seriously affected by the waterborne disease, cholera, and dysentery are more prevalent due to the inability to get potable water, congested living conditions, and inadequacy in accessing the quality of solid waste management from the governmental services.

6.3.2.5 Cost of Medications During the Dry Season

According to Table 6.7, the total cost of the Medications Prescribed was found to be (USD 3,094.54) based on the selling price of hospitals and (USD 5,722.65) based on the selling price of private pharmacies.

Table 6-7 The Cost of Medication (February 2023)

Variables	**Number**	**Unit Cost**	**Total cost**
The total cost of Medication Prescribed			
Cost at Hospital	2632	69.49	182,897.68
Cost at Private	2632	117.41	309,023.10
The total cost for Diagnosis related to Solid Waste			
Cost at Hospital	740	71.13	52,636.20
Cost at Private	740	185.88	137,551.20

NB: One USD was equivalent to ETB 54.00 of the current foreign currency exchange market price.

From the total cost, the share of medication prescribed for diagnosis related to Solid Waste was found to be (USD 52,636.20) based on the selling price of hospitals. Similarly, the percentage of medication prescribed for Diagnosis related to solid waste was found to be (USD137,551.02) based on the selling price of private pharmacies. Thus, it can be understood that solid waste-related medicinal prescriptions have accounted for 28.8% and 44.5% of all medications cost based on the selling price of hospital and private pharmacies, respectively (Table 6.7)

Few of these studies examined the environmental and health implications of solid waste disposal for people living in proximity to waste dumpsites (de Hoogh et al., 2011; Gouveia and Prado, 2010). Open dumpsites in developing urban cities involve in discriminate disposal of waste. They are uncontrolled and pose major health threats affecting urban cities' landscapes. The UNEPA (2006) stated that wastes that are not managed properly, especially solid waste from households and the community, are a serious health hazard and lead to the spread of infectious diseases.

The OECD report estimated that air pollution will increase healthcare costs from US$ 21 billion in 2015 to US$ 176 billion in 2060, and the productivity loss due to workers' sickness or absence is projected to increase from 1.2 billion to 3.7 billion **(**OECD, 2018). Air pollution reduces the productivity of healthy workers, and the annual productivity loss of healthy workers in the industry caused by ambient air pollution is estimated at US $90 million annually. The treatment and time costs of illness attributed to air pollution are estimated at US $130 million (World Bank, 2018).

6.3.3 Trend Analysis of Solid Waste-Related Disease in Addis Ababa City

According to Figure.6.7, the trends of solid waste-related diseases in August 2022 have shown that number of patients diagnosed was 239 in Alert Hospital. In contrast, only 61 patients were diagnosed in Menelik Hospital for solid waste-related diseases.

On the other hand, the trends of solid waste-related diseases have increased in February 2023 study period in that patients diagnosed with solid waste-related illness in February 2023 were 638 in Alert Hospital whereas 102 in Menelik Hospital, which indicated that the number of diagnosed patients for solid waste related diseases has increased 6-fold than that of control hospital.

Children living closer to the landfills showed higher exposure to air pollution-related diseases. They also established that the effects are reduced as the distance from the landfill increases (Xu et al. 2018). This experiment again demonstrates landfills' health impact on young children as a manifestation of pathology and as an impact on their immune system and its development.

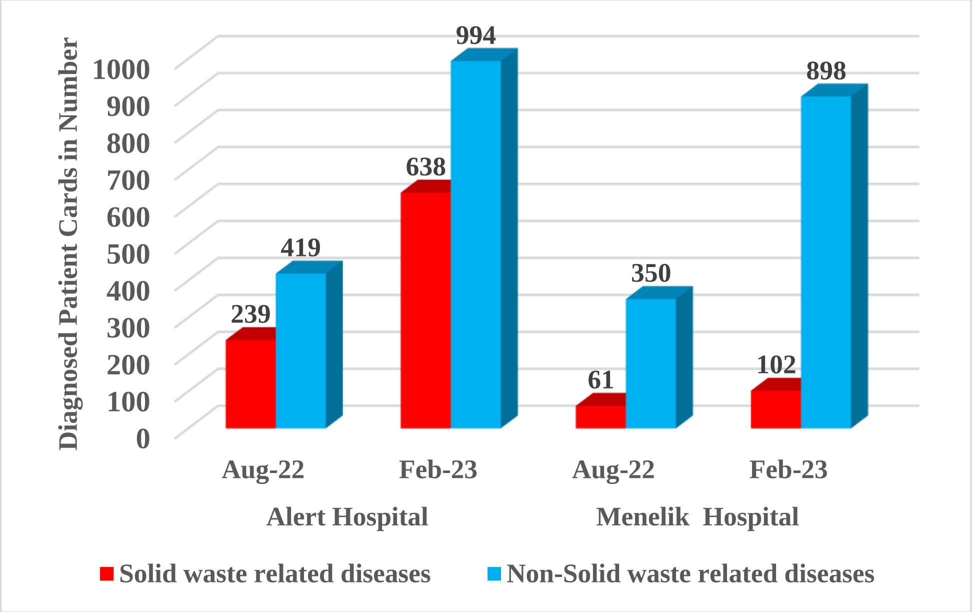


Figure 6-7 The trends of solid waste-related disease in Addis Ababa city by number

Of the 658 patient cards diagnosed in August 2022 at Alert Hospital, 239 (36.3%) were diagnosed with solid waste-related diseases. In contrast, the trends of solid waste-related disease in Alert Hospital have increased to 638(39.09%) in February 2023, more than two folds of the patient cards in August 2022. This indicated that the prevalence of solid waste-related diseases during the dry or winter season is higher than in the wet season.

On the contrary, out of the 411 patient cards diagnosed in August 2022 at Menelik hospital, 61 (15%) were diagnosed with solid waste-related diseases. In contrast, the trends of solid waste-related disease in Menelik Hospital have increased to 102 in February 2023, which is more than one folds of the patient cards in August 2022.

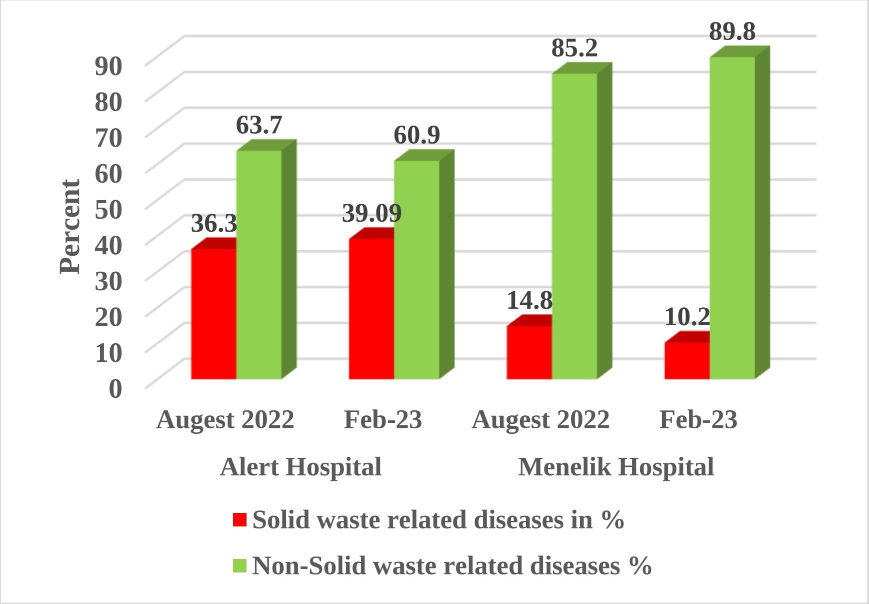
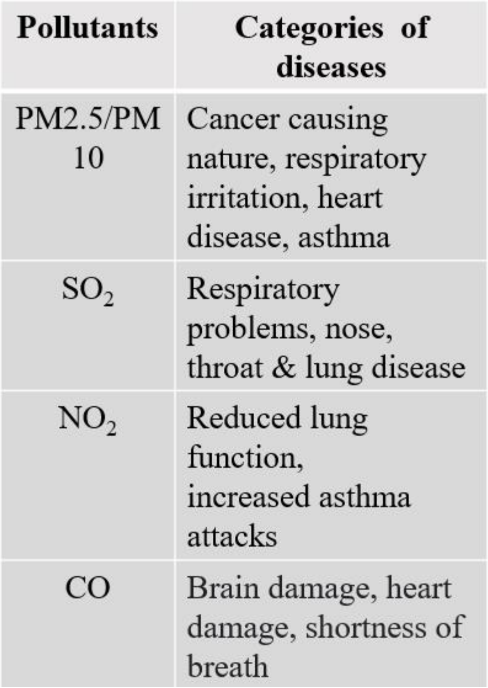


Figure 6-8 The trends of solid waste-related disease in Addis Ababa city by percent

The above data has shown that the trends of solid waste-related diseases in Alert Hospital were much higher than those identified in Menilik Hospital, 36.3% in August (wet season). In contrast, solid waste-related diseases increased to 39.09 during the dry season (February 2023). On the other hand, solid waste-related diseases in Menilik Hospital during the wet season (August 2022) were 14.8% and decreased to 10.2% during the dry season (Figure 6.8).

This study indicated that communities of Kolfe Keranio sub-cities of the Addis Ababa city living near the Koshe open dump site were highly exposed to clinically identified health risks like respiratory, eye, gastrointestinal, and skin diseases. Similarly, solid waste-related disease was higher during the dry season (February 2023) than in the wet/summer season in both hospitals.



Pollutants	Categories of diseases
PM2.5/PM 10	Cancer causing nature, respiratory irritation, heart disease, asthma
SO_2	Respiratory problems, nose, throat & lung disease
NO_2	Reduced lung function, increased asthma attacks
CO	Brain damage, heart damage, shortness of breath

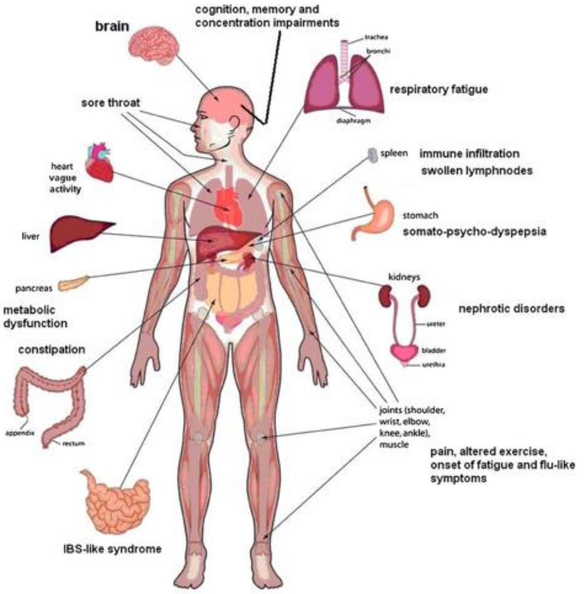


Figure 6.9 Solid waste-related diseases due to a higher level of PM/2.5 ((Bjorklund et al., (2019)

Communities near landfills and open dumps are susceptible to health impacts associated with exposure to landfill and uncontrolled dump sites. Moreover, across the cities, the urban poor suffer most from the life-threatening conditions deriving from deficient SWM (Zurbrügg, 2003). According to Figure 6.9, the health problems investigated from different literature include respiratory diseases, Brain damage, throat and lung diseases, skin infection, eye irritation, gastrointestinal problems, and Diarrhea. (Mataloni et al., 2016).

From the above research, several epidemiological studies have investigated whether there is a higher-than-usual incidence of adverse health events such as cancer, asthma, and respiratory infections in populations living near landfill sites. (Mataloni *et al.*,2016; Khan *et al.*, 2017; Esphylin *et al.*, 2018). Children living in such neighborhoods are exposed to a triple risk of infectious diseases, injury, and inhalation of dangerous fumes from the continuous burning of waste. However, due to the difficulties in quantifying the “dose” of exposure, the evidence linking residence near landfills and/or dump sites and health outcomes remains weak (Vrijheid, 2000).

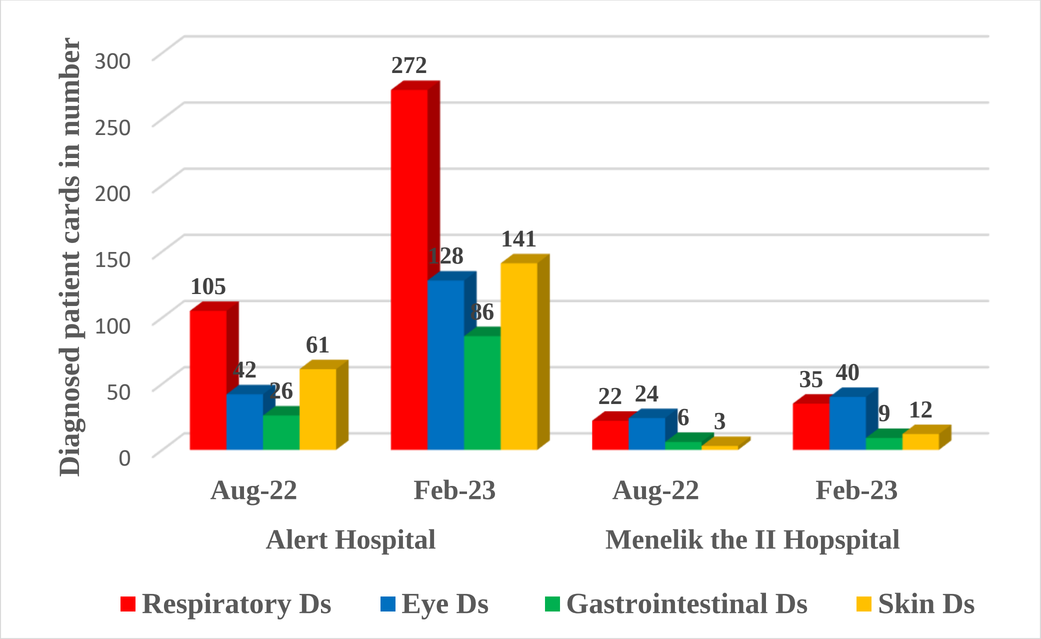


Figure 6.10 Trends of Air and water pollution-related diseases in Addis Ababa City

Figure 6.10 indicates that the prevalence of Air pollution-related diseases and water pollution-related diseases in both Hospitals has shown an increasing trend during the dry season than the summer season. Air pollution-related diseases (respiratory and eye diseases) in Alert Hospital have increased from 147 to 400 during the wet and dry seasons, respectively. Similarly, Air pollution-related diseases (respiratory and eye diseases) in Menelik Hospital have risen from 46 to 75 during the wet and dry seasons, respectively. This indicated that the prevalence of solid waste-related diseases during the dry or winter season is higher than during the wet season in Alert Hospital.

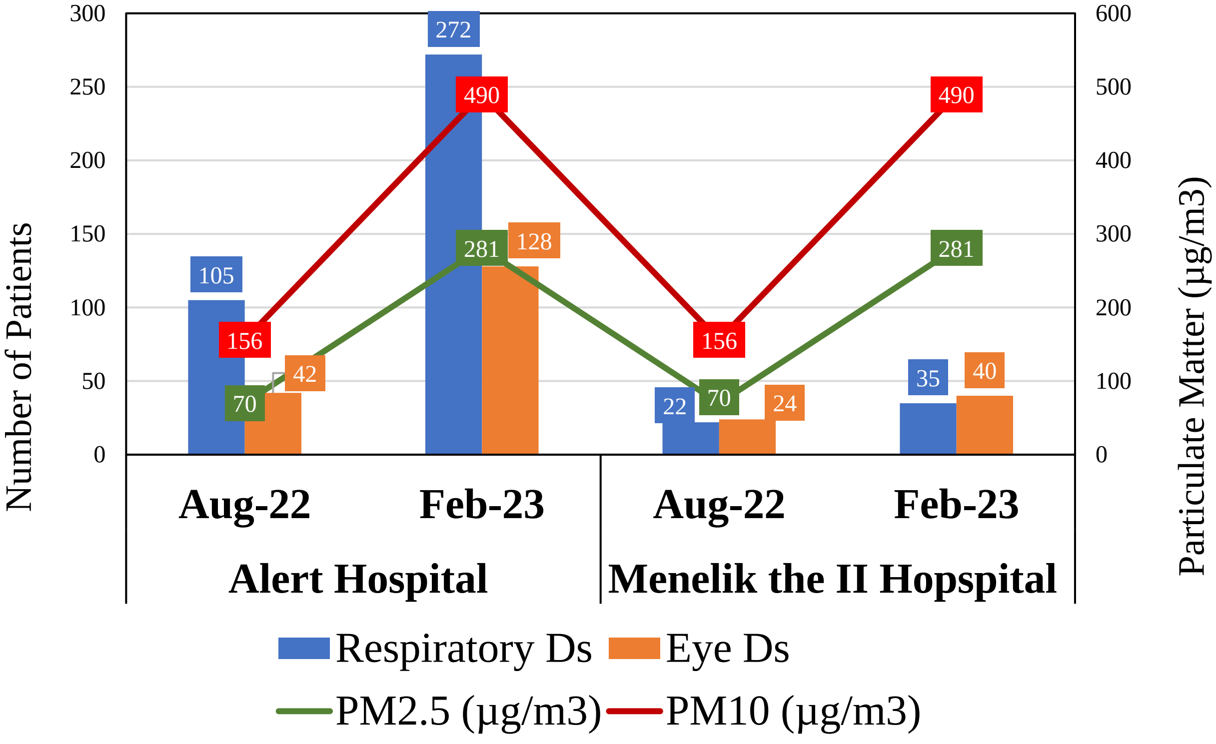


Figure 6.11 Seasonal implication of PM2.5/10 and Air pollution related Diseases

This study identified that during the wet season, patients diagnosed with air pollution-related diseases in Alert Hospital were 147 with PM2.5 and PM10 concentrations of 70µg/m^3 and156µg/m^{3,} respectively. On the contrary, during the dry season, patients diagnosed with air pollution-related diseases in Alert Hospital were 400 with PM2.5, and PM 10 concentrations were 281µg/m^3 and 491µg/m^{3,} respectively. The research finding further indicated that, as PM2.5/10 increases during the dry season, the prevalence of diseases in hospitals also increases dramatically. Exposure to high levels of air pollution increased hospitalization and deaths from cardiovascular and respiratory diseases, particularly in the elderly and those with comorbidities (Hamanaka and Mutlu, 2018).

Another study has identified that residents living next to dumpsites are usually affected by Psychological/Emotional and physical diseases like respiratory, eye, and gastrointestinal diseases. For those who live closer to the dumping sites, the nuisance of scavenging animals and birds may affect their emotional and psychological health. Heavy metal poisoning has also been associated with mental disorders. (Ziraba et al., 2016).

6.3.4 Cost Implication of the Koshe Open Dump Site

Koshe dump site areas are mainly located on the main road of the city, surrounded by slums, informal settlements, primary and secondary schools, and Reppi waste-to-energy plant. Out of the total 3,103,999 population of Addis Ababa city, Nifas Silk Lafto and Kolfe Keranio sub city have a total population of 358,359 and 485,952, respectively. The total population of the two sub-cities is 844,311, which accounts for 27% of the total 3,103,999 population of Addis Ababa city.

Hence, the Koshe dump site is found at the center of the two subsites, and communities living nearby the Koshe dump site are estimated to be 30% of the total population of the two sub-cities, which all are directly exposed to solid waste-related diseases. The communities living in all corners of the Koshe dump site were highly exposed to the impact of air and water pollution emanating from the uncontrolled dump site.

Different studies also revealed that most people who live in dump site areas often do not attain an adequate supply of clean water, inadequate accommodation, and due to improper solid waste management, they get polluted air and health deterioration (Begna Ts, 2017).

This study showed that the monthly and annual cost of medication for solid Waste related diseases from Government pharmacies and Private pharmacies for 300 patients in August 2022 was 429 USD and 5149 USD, respectively. On the other hand, the monthly and annual cost of medication for solid Waste related diseases from Government pharmacies and private pharmacies for 740 patients during February 2023 was 667,154.40 USD and 1,117,814.40 USD, respectively.

The cost of medication for solid waste-related disease during the dry season (February 2023) was found to be very much higher than the cost of medication for solid waste-related disease during the wet season (August 2023). This is because solid waste-related diseases are more aggravated during the dry season, with a relatively higher concentration of particulate matter (PM2.5/PM10).

Table 6.8 Seasonal Comparison of Cost of Medication in Alert and Menilik Hospitals

Types of cost	Wet season (August 2022)			Dry season (February 2023)		
	Number	Unit Cost	Total cost	Number	Unit Cost	Total cost
Monthly Cost at Gov. Hospital	300	1.43	429	740	75.13	55,596.20
Monthly Cost at Private pharmacy	300	2.43	729	740	125.88	93,151.20
Annual cost at Gov. Hos (*12)	300	1.43	5149	740	75.13	667,154.40
Annual cost at private Pharmacy (*12)	300	2.43	8748	740	125.88	1,117,814.40

The unit cost of medication for solid waste-related disease during the wet season (August 2022) was 1.43 USD and 2.43 USD for Government pharmacies and private pharmacies, respectively. Whereas the unit cost of medication for solid waste-related disease during the dry season (February 2023) was 75.13 USD and 125.88 USD for Government pharmacies and private pharmacies, respectively. Hence, the unit cost of medication for solid waste-related disease during the dry season (February 2023) was found to be very much higher than the cost of medication for solid waste-related disease during the wet season (August 2023).

The cost of the prescribed medicine for the patients should be supplied by the city government, which would be the ultimate burden and pressure in demanding foreign currency for the hospitals to treat solid waste-related diseases. The government highly subsidizes the supply of medicine in Ethiopia due to the poor purchasing capacity of the citizen from the market.

The implication of this cost of medication indicated that municipal solid waste in Addis Ababa city is unscientifically collected, inefficiently transported, and indiscriminately disposed of in open dumping sites, leading to public health risks with the unplanned cost of supply of medications for communities exposed to solid waste related diseases. Such unplanned cost of medication supplied for the hospitals by foreign currency would otherwise be used to contribute to covering the cost of the urban sustainable development plan.

6.4 Conclusion

This paper has shown a detailed and analytical presentation on the impact of the Koshe dump site on the communities living around the Koshe open dump site than the rest of Addis Ababa city. Among the ten Sub cities of Addis Ababa city, communities of Kolfe Keranio and Nefas Silk Lafto sub-cities are highly exposed to solid waste-related diseases, specifically diseases related to air and water pollution, and concluded as follows.

During the first round of the patient cards analysis (August 2022), solid waste-related diseases in Menelik Hospital accounted for 14.8% of the total diagnosed patients, whereas solid waste-related diseases in Alert Hospital Accounts 36.3%, which is more than two-fold higher than the control hospital. During the second round of the patient cards analysis (February 2022), solid waste-related diseases in Menelik Hospital accounted for 10.2% of the total diagnosed patients, whereas solid waste-related diseases in Alert Hospital Accounts 39.09%, which is more than three-fold higher than the control hospital. The data indicated that solid waste-related disease during February 2023 had shown an increasing trend among patients diagnosed during August 2022.

Out of 239 Patient cards diagnosed during August 2022 in Alert Hospital, 61.5% of patient cards were identified as air pollution-related diseases. Of 61 patient cards diagnosed in Menelik Hospital for solid waste-related diseases, 36% were identified as air pollution-related diseases. Out of 638 Patient cards diagnosed during February 2023 in Alert Hospital, the share of Air pollution-related diseases accounts for 62.69%. Whereas, in Menelik Hospital, the percentage of Air pollution-related diseases accounts for 34.3%, which is two-fold higher than the control hospital.

Out of 239 Patient cards diagnosed during August 2022 in Alert Hospital for Solid waste-related diseases, 36% of patient cards were identified as water pollution-related diseases. Whereas, out of 61 patient cards diagnosed in Menelik Hospital for Solid waste-related diseases, 15% were identified as water pollution-related diseases. This data indicated that Patients diagnosed with Water pollution-related diseases in Alert Hospital were found to be more than two folds than patients at Menelik Hospital. Out of 638 Patient cards diagnosed during February 2023 in Alert Hospital for Solid waste-related diseases,36% of patient cards were identified as water pollution-related diseases. Whereas, out of 102 Patient cards diagnosed in Menelik Hospital for Solid waste-related diseases, 21% of patient cards were identified as water pollution-related diseases. This data indicated that Patients diagnosed with water pollution-related disease in Alert Hospital accounted for more than folds than patients at Menelik Hospital.

This study showed that from the total medication cost, the share of medication prescribed for 740 patients diagnosed with solid waste-related diseases in February 2023 was USD1,029.55, and the unit price for a patient was a minimum of USD1.39/month. Based on the 740 sample patients diagnosed with solid waste-related diseases in both hospitals, the cost of medication for one year (12 months) treatment was estimated to be USD12,354.60/year. Accordingly, the estimation of the communities exposed to air and water pollution-related diseases was expected to be 253,293 (30%). The minimum medication cost for the estimated 30% of the communities living within a 1-kilometer radius of the Koshe dump site was USD 352,077/Month. Accordingly, the minimum annual medication cost for solid waste-related diseases in a community living within a 1-kilometer radius of the Koshe dump site was estimated to be USD 4,224,924.

CHAPTER SEVEN

Summary and Conclusions

7.1 Introduction

As the world's population grows, solid waste production increases simultaneously, with the prediction to reach 3.40 billion metric tonnes per year by 2050. In low-income countries, the total waste generated is expected to grow by more than three folds by 2050. Furthermore, low-income countries open dump about 93% of waste. In contrast, High-income countries only account for 2% of waste, indicating that improper solid waste management practices result in severe risks to human health, the environment, and livelihoods in cities of low-income countries' regions.

Inefficient and unscientific solid waste management practice in the cities of developing countries like Addis Ababa has brought uncontrolled challenges to the municipalities and government in exposing the community living near open dump sites to public health risks.

If not controlled timely, A 57-year-old municipal solid waste from the Koshe Open dump site in Addis Ababa City has become a key challenges and threats to both environment and public health risk to the community living nearby the dump site.

Several research showed that most cities in developing countries, of the total waste generated, most of them remained uncollected which is usually thrown into channels, drains, roads, streets sides, rivers, and drainage channels. Even for the collected waste, open dumping is the most common final waste disposal, which usually pollutes water and air. Therefore, such methods of final waste disposal pose significant health risks for humans living nearby open dumps.

The main objective of this study was to analyze and evaluate the impact of improper solid waste management affecting the public health of the communities living around the Koshe open dump site of the city.

7.2 Summary and Conclusions

The current study summarized an integrated and sustainable solution to improper municipal solid waste management affecting the public health of Addis Ababa city due to water and air pollution. For this purpose, a detailed trend analysis was conducted on improper solid waste management, water pollution, and air pollution, which significantly affects the community health around the Koshe open dump site.

The study identified the population growth trends in Addis Ababa city; trends of solid waste generation, composition, collection, transportation, and disposal of solid waste have been analyzed based on secondary data. The study also evaluated the trends of solid waste recycling and composting that further contribute to improper solid waste management in the city.

Eight-month ambient air quality data of Addis Ababa city was collected from twelve locations of the city, and the study has identified the seasonal implication of the pollutant's concentration and an increasing trend of PM2.5, PM10, CO, NO_2, and SO_2 concentration during the dry season than the wet season. The concentration of these gaseous pollutants was found to be the highest in Koshe open dump site implying that open dump site has significant contributors of pollutants.

Along with the study of trend analysis of improper solid waste management, wastewater analysis was conducted to test the leachate from the Koshe/Reppie open dump site of Addis Ababa City. The Koshe dumpsite leachate sample was found to have a higher concentration of heavy metals content of Chromium, Lead, Nickel, and Mercury at leachate and downstream Akaki River exceeding the permissible limits of WHO standards except for Zinc and Copper. The concentration of BOD, COD, and TDS in the Qpshe dump site sample area for downstream Akaki River during the wet season (August 2022) was found to be lower than that of the dry season (February 2023).

Furthermore, an extensive parametric study was performed to evaluate the health prevalence of the communities living around the Koshe open dump site. According to this study, Among the ten Sub cities of Addis Ababa city, communities living in Kolfe Keranio and Nefas Silk Lafto sub-cities, where the Koshe Open dump site is located at the center, are highly exposed to solid waste-related diseases in general and specifically to diseases related to air pollution and water pollution.

Based on the current study, the main results and conclusions are summarized as follows:

7.2.1 Trends of Improper Solid Waste Management

- Addis Ababa City has no appropriate solid waste management principle that scientifically quantifies and evaluates the trends of solid waste management at the generation, storage, collection, transportation, separation, and disposal stage.
- Over the last 10 years, the population of Addis Ababa city has shown an increasing trend from 3,263,000 in 2011 to 4,794,000 in 2020, with 4.36 and 4.40% growth rates, respectively. This implied that over the past ten years, the city has experienced a dramatic increase in solid waste production. The amount of solid waste generated in 2011 was 1,959,118 cubic meters and has grown to 3,701,100 cubic meters in 2019 with a more than 200 % growth rate except for the declining trend of solid waste generated in 2020 Due to the restriction of COVID 19 pandemic.
- The composition of Municipal solid wastes is changing over time in that both organic and plastic waste have shown an increasing trend during 2017-2021. Remarkably, the trends of organic waste in Addis Ababa city have risen from 64% in 2017 to 69% in 2021. Similarly, plastic waste composition has shown an increasing trend from 5.2% in 2017 to 7% in 2021. The growing trends in both organic waste and plastic waste in Addis Ababa city might have a potential source for sustainably composting technology and recycling of plastic waste.
- Waste collection increased to 81% in 2022, with an annual mean collection rate of 77%. Out of 74% of biodegradable waste, only 5% is converted into composting materials. The trucks for municipal solid waste transportation in Addis Ababa city are very limited, with the truck work efficiency of less than 40% of work truck-days capacity indicating around 20-30% of the waste is left uncollected.
- The uncollected 20-30% of municipal solid wastes are disposed of indiscriminately before arriving Koshe dumping site in the form of open burning, thrown in an open space and on the side of the street, disposed of in nearby rivers, and thrown into the drainage system of the city affecting the public health.
- This study has identified that in Addis Ababa city, only 5% of all waste generated was recycled and has not been regulated, implying the solid waste recycling practice and culture in Addis Ababa city remain very low. Similarly, very little has been done in practicing

composting to reduce the volumes of waste disposal through the processing of domestic waste into compost as there has been no well-organized and formal type of composting centers.

- The study also identified that the mean annual collection rate of 77% of solid waste generated wastes is transported directly to an uncontrolled landfill or Koshe (Reppi) open dump site, where it now lies within the heart of the city, posing a serious environmental pollution and health risk to its surrounding neighborhoods.

The detailed assessment made in this study showed that the Koshe Open dump site had been identified as a major social, economic, and environmental challenge affecting the public health in the city, which needs urgent action and alternative solutions by all concerned bodies.

7.2.2 Trends of Ambient Air Quality Status in Addis Ababa City

- The eight-month average fine PM2.5 and PM10 emissions statistics result of Addis Ababa city has shown 58µg/m^3 and 134µg/m^{3,} respectively, exceeding the standard set by the WHO limit of 15µg/m^3 and 45µg/m^{3,} respectively. The eight-month average fine PM2.5 and PM10 results of the Koshe dump site showed 204µg/m^3 and 379µg/m^{3,} respectively, exceeding the standard set by the WHO limit of 15µg/m^3 and 45µg/m^3.
- The trends of PM10 concentration results of the Koshe open dump site during the wet season (August 2022) were 156µg/m^3. However, the trends of PM10 during the dry season (December 2023) were 393 µg/m^{3,} which is more than two times greater than the emission level recorded during the wet or summer season. The trends of PM2.5 concentration results of the Koshe open dump site during the wet season (August 2022) were 70µg/m^3. However, the trends of PM2.5 concentration results during the dry season (December 2023) were 223µg/m^{3,} more than three times greater than the emission level recorded during the wet or summer season.
- Based on the PM 2.5 and PM10 data collected from Koshe open dump site over the last six months showed that it had increasing and homogeneous PM concentrations, which implied that the dumping site could have similar sources of pollutants with a large share of organic waste and plastic waste. Due to this reason, the same mitigation measures should have been implemented to reduce the increasing trend of PM concentration in the Koshe dump site.

- While PM 2.5 and PM10 data collected from other locations in Addis Ababa city had heterogeneous PM concentrations when compared to the Koshe dumping site with different types of sources contributed by heavy traffic movement, industrial emission, frequent open burning of solid waste resulted in the heterogeneity of PM concentrations among some sites.
- CO concentration of the Koshe dump site during November 2022, December 2022, January 2023, and March 2023 was 9425µg/m^3, 7823µg/m^3, 8624µg/m^{3,} and 8332µg/m^{3,} respectively, which exceeded the standard set by World Health Organization (WHO) of 4000µg/m^3. The highest concentration of CO during the dry season was because of the Ethiopian culture of open burning of solid waste each year on 21 November 2022 as an accepted norm and culture of the urban community impacting air quality and public health.
- The concentration of NO_2 at the Koshe dump site during summer (August 2022) was recorded at 121µg/m^3. In contrast, the concentration of NO_2 at the Koshe dump site during the winter or dry season of the Months (November 2022, December 2022, and January 2023) has been registered to be 136µg/m^3,142µg/m^{3,} and 139µg/m^{3,} respectively exceeding above the limit of WHO standard of 25µg/m^3.
- SO_2 concentration of the Koshe dump site during the wet season or summer (August 2022) was 310µg/m^{3,} which exceeded the standard set by the World Health Organization (WHO) of 40µg/m^3. SO_2 concentration of the Koshe dump site during winter or dry season of months (November 2022, December 2022, and January 2023) was 7000µg/m^{3,} 5943µg/m^{3,} and 6472µg/m^{3,} respectively, which exceeded the standard set by World Health Organization (WHO) of 40µg/m^3.

The increasing trends of Ambient air pollution in the Koshe dump site adversely affect the community health challenges living nearby the dumping site.

7.2.3 The Status of Water Pollution in Koshe Open Dump Site

- The laboratory result indicated that BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), and TDS (Total Dissolved Solids) downstream of Akaki River during the rainy season (August 2022) showed that 97mg/L, 416MG/L, and 800mg/L, respectively exceeding the permissible limits of EEPA and WHO standards except for BOD below the

WHO standards. Whereas the laboratory result for BOD, COD, and TDS downstream of Akaki River during the dry season (February 2023) showed that 139mg/L, 806mg/L, and 742mg/L respectively, exceeded the permissible limits of EEPA and WHO standards, except for BOD below the WHO standards.

- The wastewater laboratory analysis for downstream Akaki River results showed that both BOD and COD results were very high during the dry season, but TDS concentration was higher in the wet season than in the dry season of the month. The study has further identified that the laboratory result of heavy metal concentrations for Nickel, Mercury, Lead, and Chromium downstream of the Akaki River during the rainy season (August 2022) were 0.01mg/L, 0.1mg/L, 0.031mg/L and 0.4mg/L respectively exceeding the permissible limits of WHO standards. Moreover, the laboratory result for wastewater during the dry season (February 2023) indicated that heavy metal concentrations of Nickel, Mercury, Lead, and Chromium after the Leachate was Mixed with Akaki water river resulted in 0.2mg/L, 0.008mg/L, 0.17mg/L and 0.2mg/L respectively which is more than WHO permissible limit.

Furthermore, this study has identified that currently, there is not any pollution control method being practiced at the Koshe open dump site and the downstream rivers. Therefore, the author strongly recommends the present Koshe dumpsite be treated accordingly to minimize the impact of persistent heavy metals in the area that impacts community health.

7.2.4 Prevalence of Disease Related to Improper Solid Waste Management

- The study has identified that during August 2022, solid waste-related diseases in Menelik Hospital accounted for 14.8% of the total diagnosed patients. In contrast, solid waste-related diseases in Alert Hospital accounted for 36.3% of the total diagnosed patients, which is more than two-fold higher than the control hospital.
- Similarly, in February 2023, solid waste-related diseases in Menelik Hospital accounted for 10.2% of the total diagnosed patients. In contrast, Alert Hospital accounted for 39.09% of the total diagnosed patients, more than three-fold higher than the control hospital. The data indicated that solid waste-related disease during February 2023 had an increasing trend among patients diagnosed during August 2022. This is because ambient air pollution

level trends were higher during the dry season than the wet season, both at the city level and Koshe open dump site.

- Out of 638 Patient cards diagnosed during February 2023 in Alert Hospital, the share of Air pollution-related diseases accounts for 62.69%. Whereas, in Menelik Hospital, the percentage of Air pollution-related diseases accounts for 34.3%, two-fold higher than the control hospital.
- Out of 239 Patient cards diagnosed during August 2022 in Alert Hospital, 36% were identified as water pollution-related diseases. Out of 61 patient cards diagnosed in Menelik Hospital, 15% were identified as water pollution-related diseases. Of 638 Patient cards diagnosed during February 2023, 36% were identified as water pollution-related diseases. Whereas, out of 102 Patient cards diagnosed in Menelik Hospital, 21% were identified as water pollution-related diseases.
- Patients diagnosed with water pollution-related diseases in Alert Hospital were found to be higher than patients at Menelik Hospital. This is because the increasing trend of water and air pollution during the dry season have a significant health impact on the communities living around Koshe open dump site than other location of the city.
- The predicted number of communities exposed to air and water pollution-related diseases was estimated to be 253,293 (30%) of the total population living in the Kolfe Keranio and Nifas Silk Lafto Sub-city. The minimum annual cost of the medication for the estimated 30% of the communities living within a 1-kilometer radius of the Koshe dump site was estimated to be USD 4,224,924.

Therefore, the present study can be useful and will significantly contribute to the city municipalities, government authorities, researchers, and stakeholders working on the impact of improper solid waste management to make effective decisions in achieving an integrated and sustainable solid waste management approach.

7.3 Recommendations for Future Studies

Based on the current study, the following recommendations are proposed for future studies: This study has identified that there was improper solid waste management practice in Addis Ababa city at all stages of the waste management hierarchy, which needs careful recommendation at all stages.

- This study recommends reducing waste generation and practicing source segregation by creating awareness at each household level of Addis Ababa City on a regular basis.
- Since the share of organic waste and plastic waste constitutes more than 70% of the total waste in the city, introducing modern composting technologies to supply natural fertilizer for urban agriculture and recycling plastic waste for different purposes (Plastic Road construction, Real estate development, etc.) should be designed before disposing to Koshe dump site.
- The study recommends that to maximize the opportunity and the use of organic waste and plastic waste from the total municipal solid waste, it must be separated at the source, which will otherwise contribute to the gaseous pollutants like PM2.5, PM10, No_2 SO_2, CO, and Methane gas at Koshe Open dump.
- The study further recommends that the culture of solid waste burning in the city was found to be devastating, and hence, the municipality should be aware of the dangerous effect of open burning on the environment and public health through continuous awareness-creating strategies, which is the major source of premature death due to air pollution.
- Concerned government bodies should take immediate and fast action on either closing the Koshe open dump site or proposing another sanitary landfill as the Koshe dump site was over-saturated years and due consideration should be given before it is converted to environmental, political, social, and health risk to the society living nearby the dump site.
- Engineering-controlled sanitary landfill should be studied in collaboration with the newly launched Sheger City of Oromia regional state as the location of the city has been affected at all corners of Addis Ababa city in terms of water and air pollution.
- The study identified that in Addis Ababa city, there are very limited air quality monitoring technologies, relevant expertise, and weak institutional setup to regulate air pollution in Addis Ababa.

- The study presented measurements of multiple ambient air pollution analyses by identifying the location and seasonal implication of the pollutants' impact on the public health of Addis Ababa city for eight months. However, no detailed and multiple measurement study of ambient air pollutants has been performed so far in the city except for having an air quality management plan with little action.
- It is highly recommended to conduct annual air pollution measurements to significantly identify the implication of season-based and location-based scenarios to recommend the health risk of air pollution in the city. The proposed analytical method can be further improved by considering more variable parameters for reliable and accurate prediction.

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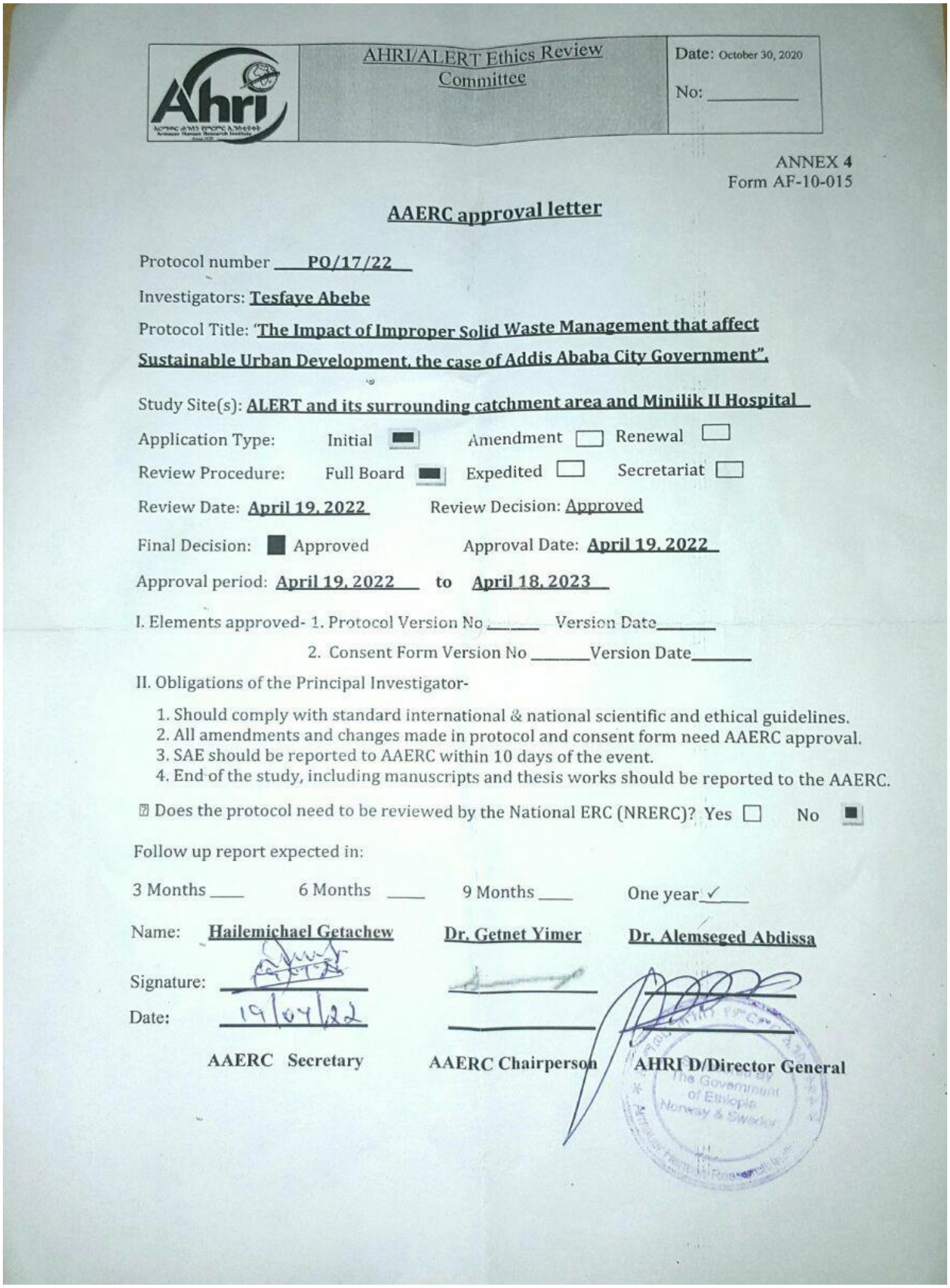
APPENDIX A

ETHICAL CLEARANCE



AHRI/ALERT Ethics Review Committee

Date: October 30, 2020

No: ______

ANNEX 4
Form AF-10-015

AAERC approval letter

Protocol number **PO/17/22**

Investigators: **Tesfaye Abebe**

Protocol Title: **'The Impact of Improper Solid Waste Management that affect Sustainable Urban Development, the case of Addis Ababa City Government".**

Study Site(s): **ALERT and its surrounding catchment area and Minilik II Hospital**

Application Type: Initial ☒ Amendment ☐ Renewal ☐

Review Procedure: Full Board ☒ Expedited ☐ Secretariat ☐

Review Date: **April 19, 2022** Review Decision: Approved

Final Decision: ☒ Approved Approval Date: **April 19, 2022**

Approval period: **April 19, 2022** to **April 18, 2023**

I. Elements approved- 1. Protocol Version No ______ Version Date______

2. Consent Form Version No ______Version Date______

II. Obligations of the Principal Investigator-

1. Should comply with standard international & national scientific and ethical guidelines.
2. All amendments and changes made in protocol and consent form need AAERC approval.
3. SAE should be reported to AAERC within 10 days of the event.
4. End of the study, including manuscripts and thesis works should be reported to the AAERC.

⍰ Does the protocol need to be reviewed by the National ERC (NRERC)? Yes ☐ No ☒

Follow up report expected in:

3 Months ____ 6 Months ____ 9 Months ____ One year ✓

Name:	**Hailemichael Getachew**	**Dr. Getnet Yimer**	**Dr. Alemseged Abdissa**
Signature:			
Date:	19/04/22		
	AAERC Secretary	**AAERC Chairperson**	**AHRI D/Director General**

Figure A.1 Ethical clearance approval letter from Alert Hospital 2022

APPENDIX B

Ambient Air Pollutant Data of Addis Ababa City

(August 2022- May 2023)

Table B.1 Ambient air pollutant data of Addis Ababa City August 2022-M 2023

A) Pollutant: Particulate Matter 2.5 in µg/m^3

No	Measured Location	Aug.	Oct	Nov 21	Dec.	Jan	March	April	May	WHO Limit	EPA Limit
1	Koshe Dump Site	70	76	338	223	281	237	218	190	15	65
2	Lebu Square	43	50	66	61	64	57	59	55	15	65
3	Megenagna Square	39	43	130	53	92	70	64	61	15	65
4	Stadium	33	43	118	57	92	68	61	59	15	65
5	Goro Square	32	38	228	49	139	89	75	71	15	65
6	Akaki Kality Square	22	28	140	74	107	69	61	53	15	65
7	Kotebe Square	15	21	49	22	23	21	20	19	15	65
8	Torhayloch Square	14	19	26	21	24	22	22	20	15	65
9	Bole Airport Square	12	15	14	15	14	17	15	15	15	65

10	Menilik Hospital Square	11	14	19	27	23	19	17	16	15	65
11	Ayat (Derartu) Square	13	14	33	18	76	45	41	35	15	65
12	Mayor Office Center	11	13	15	13	14	12	12	11	15	65
	City Average	26	31	98	53	79	61	**55**	**50**	15	65

B) Pollutant: Particulate Matter 10 in µg/m^3

No	Measured Location	Aug.	Oct	Nov 21	Dec.	Jan	March	Ap	May	WHO Limit	EPA Limit
1	Koshe Dump Site	156	224	587	393	490	427	389	355	45	150
2	Lebu Square	97	117	149	139	144	131	120	115	45	150
3	Megenagna Square	72	139	267	98	183	161	152	144	45	150
4	Stadium	86	103	217	112	184	144	137	129	45	150
5	Goro Square	48	65	391	106	249	157	134	131	45	150

6	Akaki Kality Square	103	109	273	157	215	162	146	135	45	150
7	Kotebe Square	67	80	414	90	85	83	58	51	45	150
8	Torhayloch Square	46	57	71	69	70	64	60	53	45	150
9	Bole Airport Square	43	57	58	52	55	56	51	49	45	150
10	Menilik Hospital Square	62	48	68	65	67	58	52	47	45	150
11	Ayat (Derartu) Square	43	31	38	63	146	89	68	65	45	150
12	Mayor office Center	27	46	58	50	54	50	44	41	45	150
	City Average	73	94	221	120	166	132	**118**	**110**	45	150

C) Pollutant: Carbon Monoxide in µg/m^3

No	Measured Location	Aug.	Oct	Nov 21	Dec.	Jan	March	Ap	Ma	WHO Limit	EPA Limit/ World bank
1	Koshe Dump Site	1045	1400	9425	7823	8624	8332	6256	5278	4000	10,000
2	Stadium	460	1480	9142	4641	6892	4186	3980	3188	4000	10,000
3	Akaki Kality Square	890	4950	5458	3751	4605	4778	4112	3489	4000	10,000
4	Goro Square	520	855	5333	823	3078	1967	1789	1677	4000	10,000
5	Megenagna Square	480	2160	4273	4345	4309	3235	3112	2789	4000	10,000
6	Lebu Square	493	890	934	858	894	892	767	678	4000	10,000
7	Ayat (derartu) Square	231	260	467	418	443	352	345	301	4000	10,000

8	Mayor Office Center	113	139	252	148	200	145	144	128	4000	10,000
9	Torhayloch Square	215	323	534	2400	987	655	578	556	4000	10,000
10	Menilik Hospital Square	250	302	420	654	492	397	381	323	4000	10,000
11	Kotebe Square	156	298	395	497	446	315	305	278	4000	10,000
12	Bole Airport Square	118	158	237	151	194	176	168	156	4000	10,000
	City Average	414	1101	3072	2209	2597	2119	**1828**	**1570**	4000	10,000

D) Pollutant: Nitrogen Dioxide in μg/m^3

No	Measured Location	Aug.	Oct	Nov	Dec.	Jan	March	April	May	WHO Limit	EPA Limit
1	Koshe Dump Site	121	128	136	142	139	131	128	125	25	200
2	Lebu Square	92	98	108	139	124	119	108	107	25	200
3	Megenagna Square	109	121	137	140	139	139	127	126	25	200
4	Stadium	91	97	131	141	140	139	132	125	25	200
5	Goro Square	96	114	148	138	138	137	122	118	25	200
6	Akaki Kality Square	113	135	136	138	137	136	130	127	25	200
7	Kotebe Square	93	113	137	139	138	137	133	103	25	200
8	Torhayloch Square	133	138	148	141	145	140	126	115	25	200
9	Bole Airport Square	109	123	135	134	135	136	132	128	25	200

10	Menilik Hospital Square	76	100	200	139	170	135	131	119	25	200
11	Ayat (Derartu) Square	98	120	136	135	135	136	130	128	25	200
12	Mayor office Center	92	105	105	132	119	112	109	108	25	200
	City Average	102	116	138	138	138	133	**126**	**119**	25	200

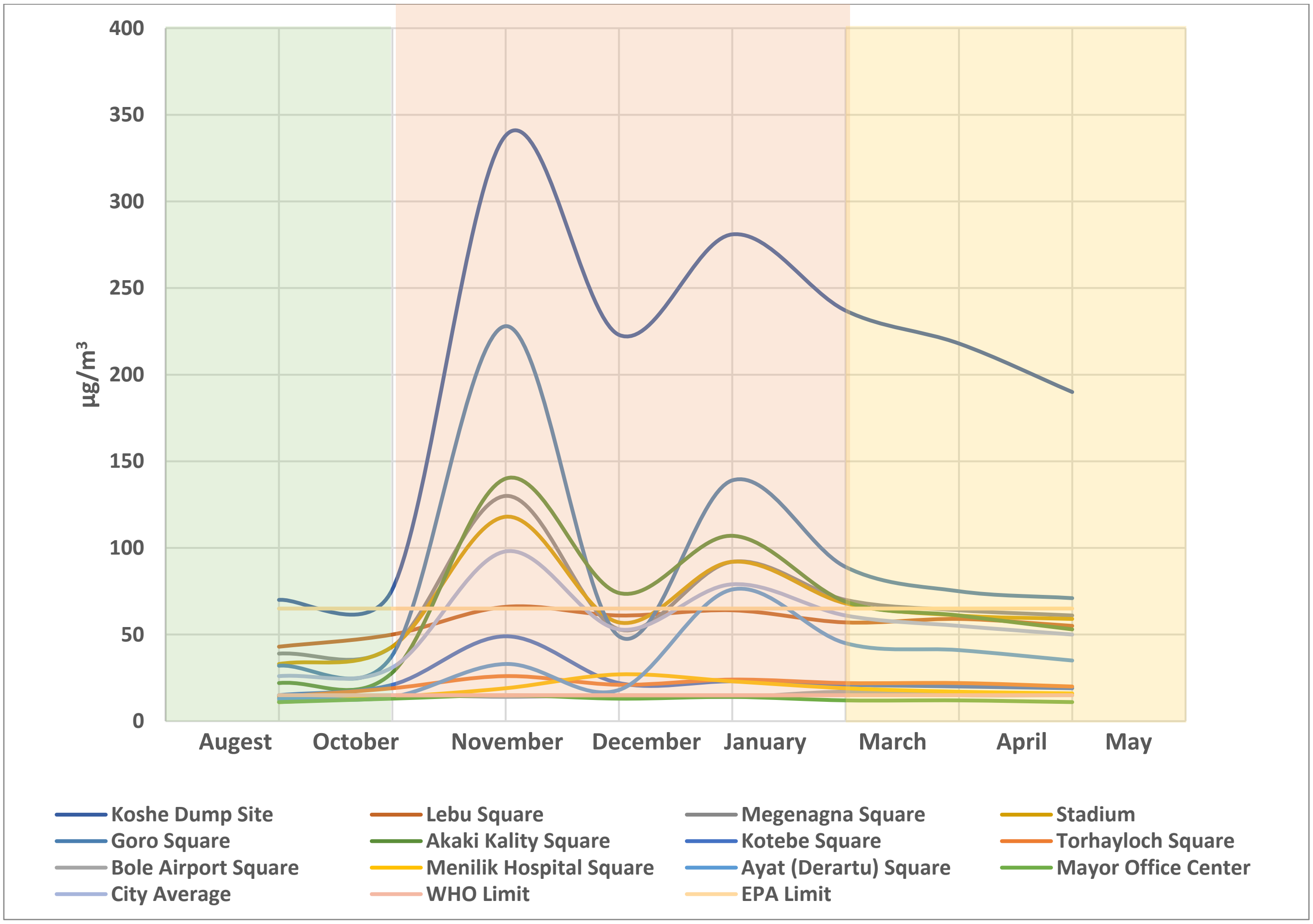
E) Pollutant: Sulfur dioxide in µg/m^3

No	Measured Location	Aug.	Oct	Nov	Dec.	Jan	March	Ap	May	WHO Limit	EPA Limit
1	Koshe Dump Site	310	350	7000	5943	6472	6329	6012	5878	40	125
2	Lebu Square	43	45	62	158	110	78	75	70	40	125
3	Megenagna Square	243	333	2043	790	1417	875	812	767	40	125
4	Stadium	41	43	1683	3945	2814	1429	1345	1225	40	125
5	Goro Square	129	142	2086	743	2829	1486	1235	1123	40	125

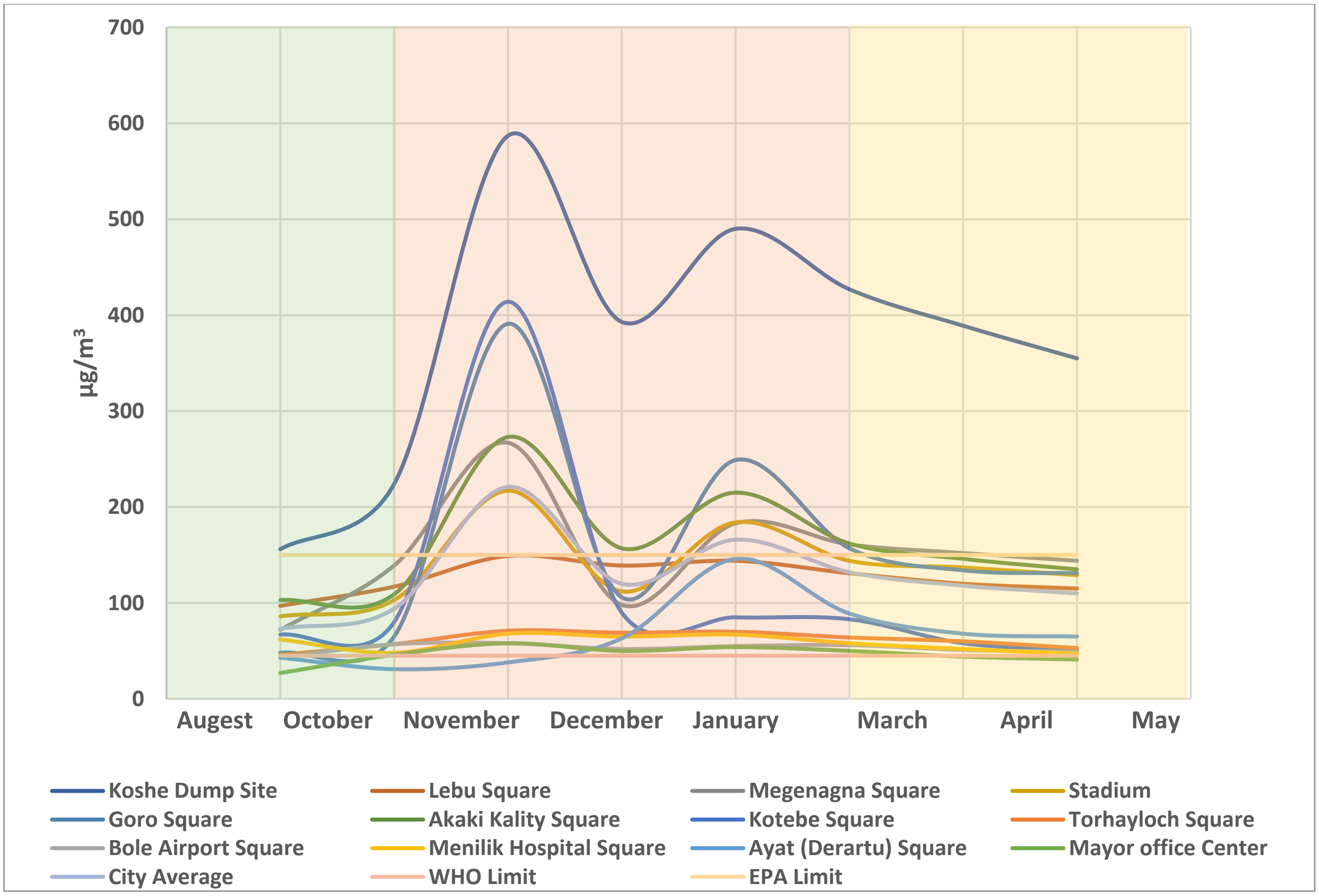
6	Akaki Kality Square	132	145	3280	2495	2888	1011	978	789	40	125
7	Kotebe Square	216	300	4100	856	578	339	335	312	40	125
8	Torhayloch Square	31	39	12	100	56	48	43	41	40	125
9	Bole Airport Square	34	36	117	98	108	72	69	65	40	125
10	Menilik Hospital Square	59	90	920	3300	2110	1100	887	769	40	125
11	Ayat (Derartu) Square	43	47	1823	117	987	517	501	345	40	125
12	Mayor office Center	64	90	90	108	99	95	72	71	40	125
	City Average	112	138	1935	1554	1706	1115	**1030**	**955**	40	125

Figure B2: The Trends of Ambient Air Quality Data of 12 locations of Addis Ababa City

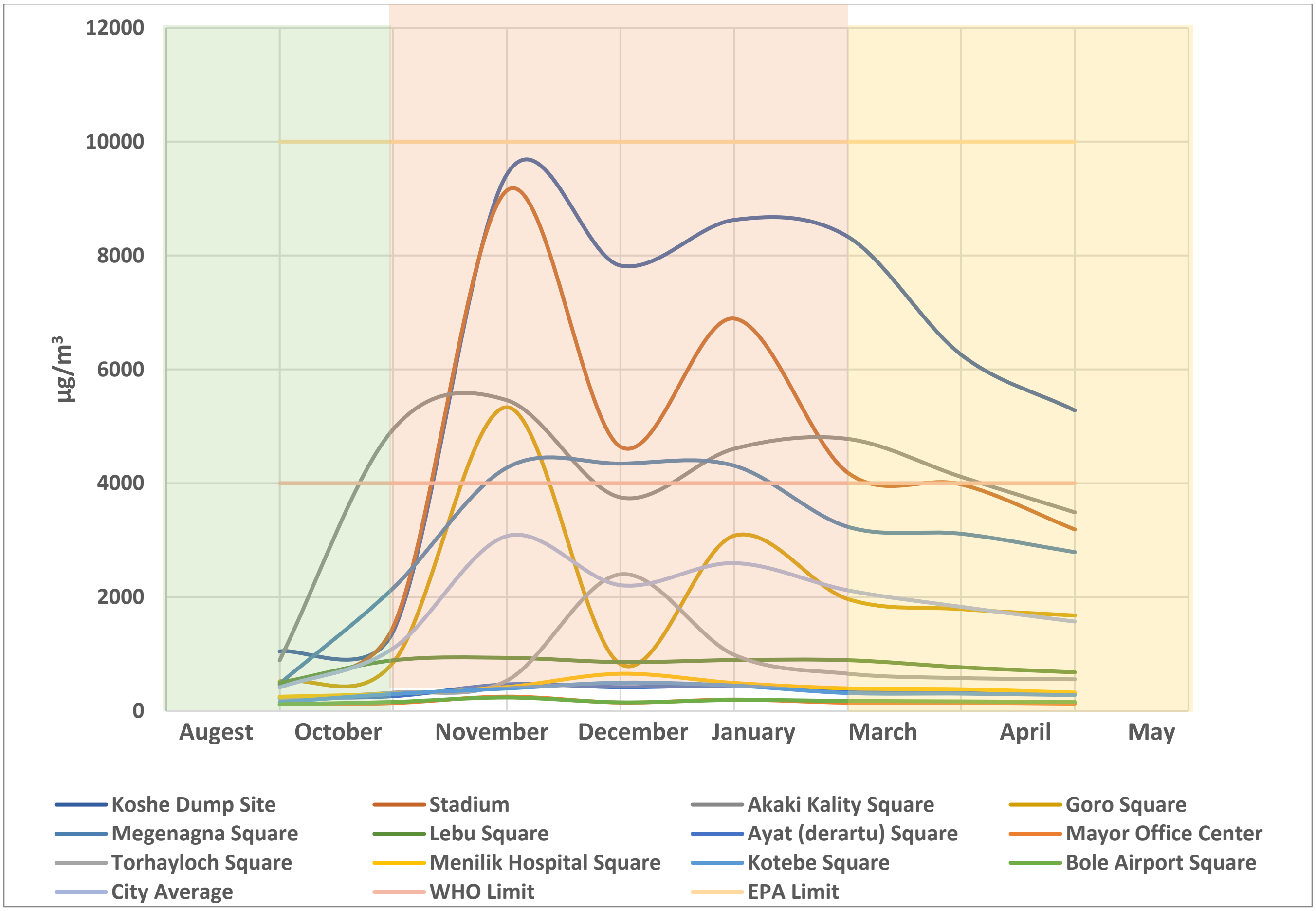
Pollutant: Particulate Matter 2.5 in µg/m^3



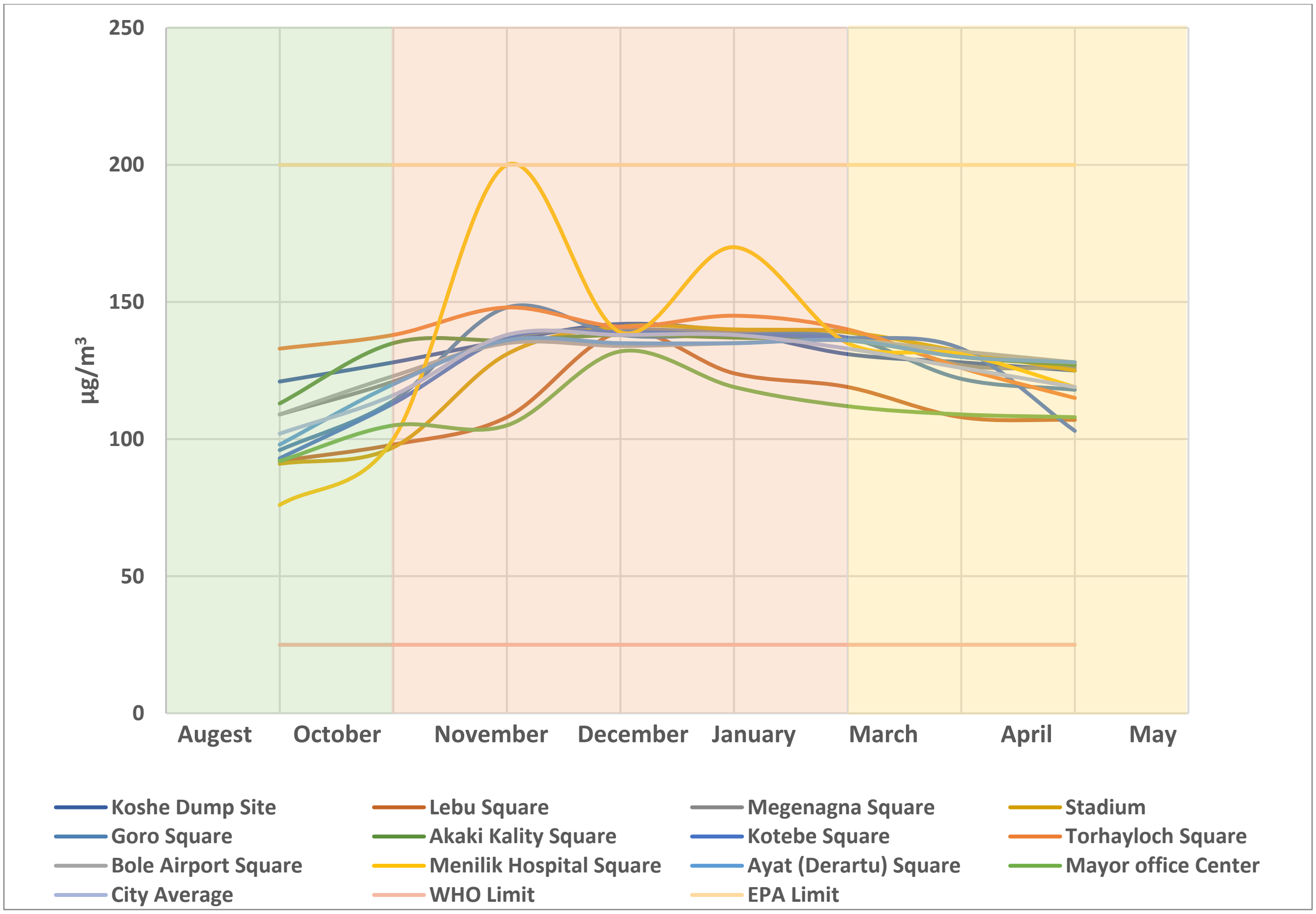
Pollutant: Particulate Matter 10 in $\mu g/m^3$



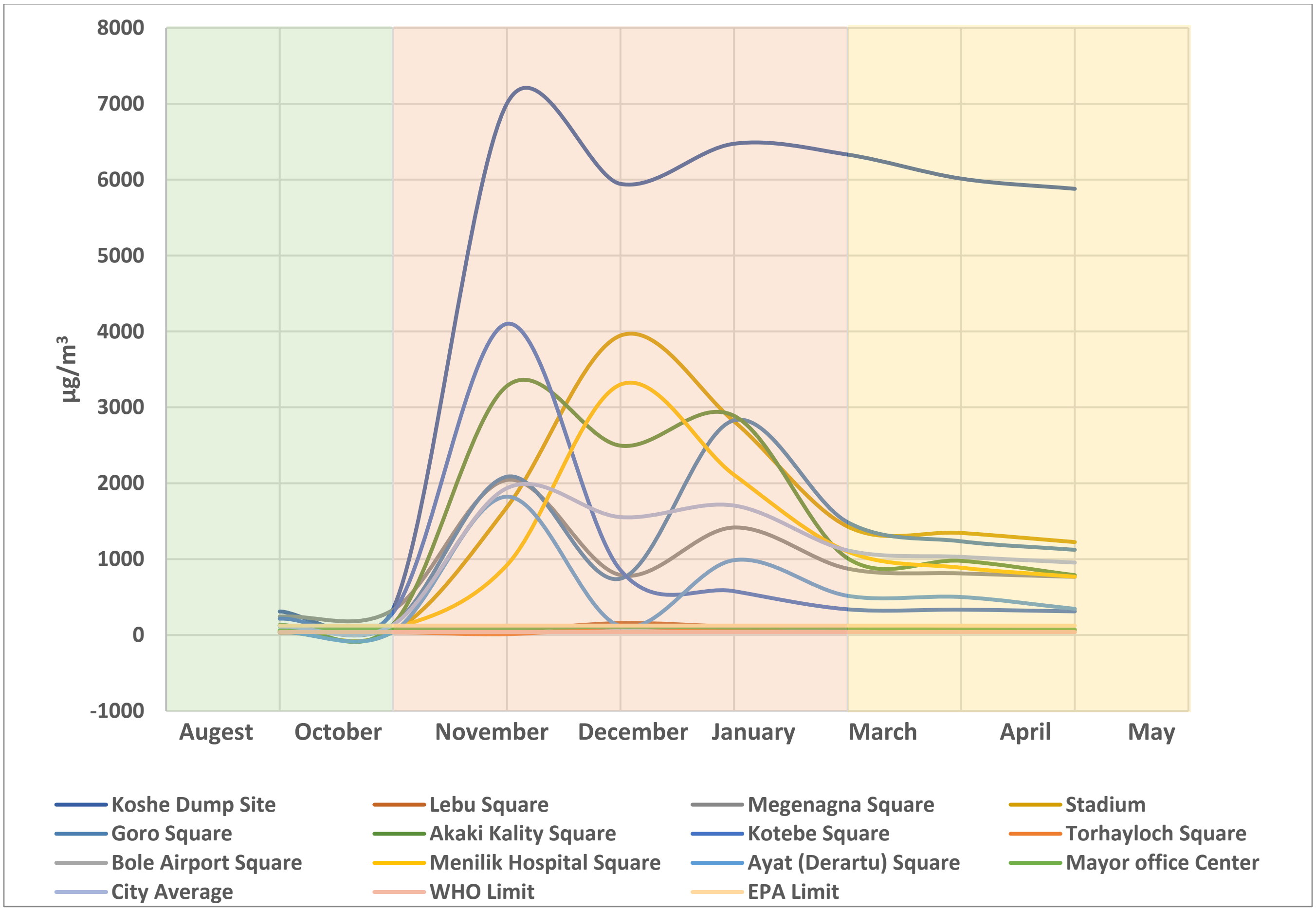
Pollutant: Carbon Monoxide in μg/m^3



Pollutant: Nitrogen Dioxide in μg/m^3

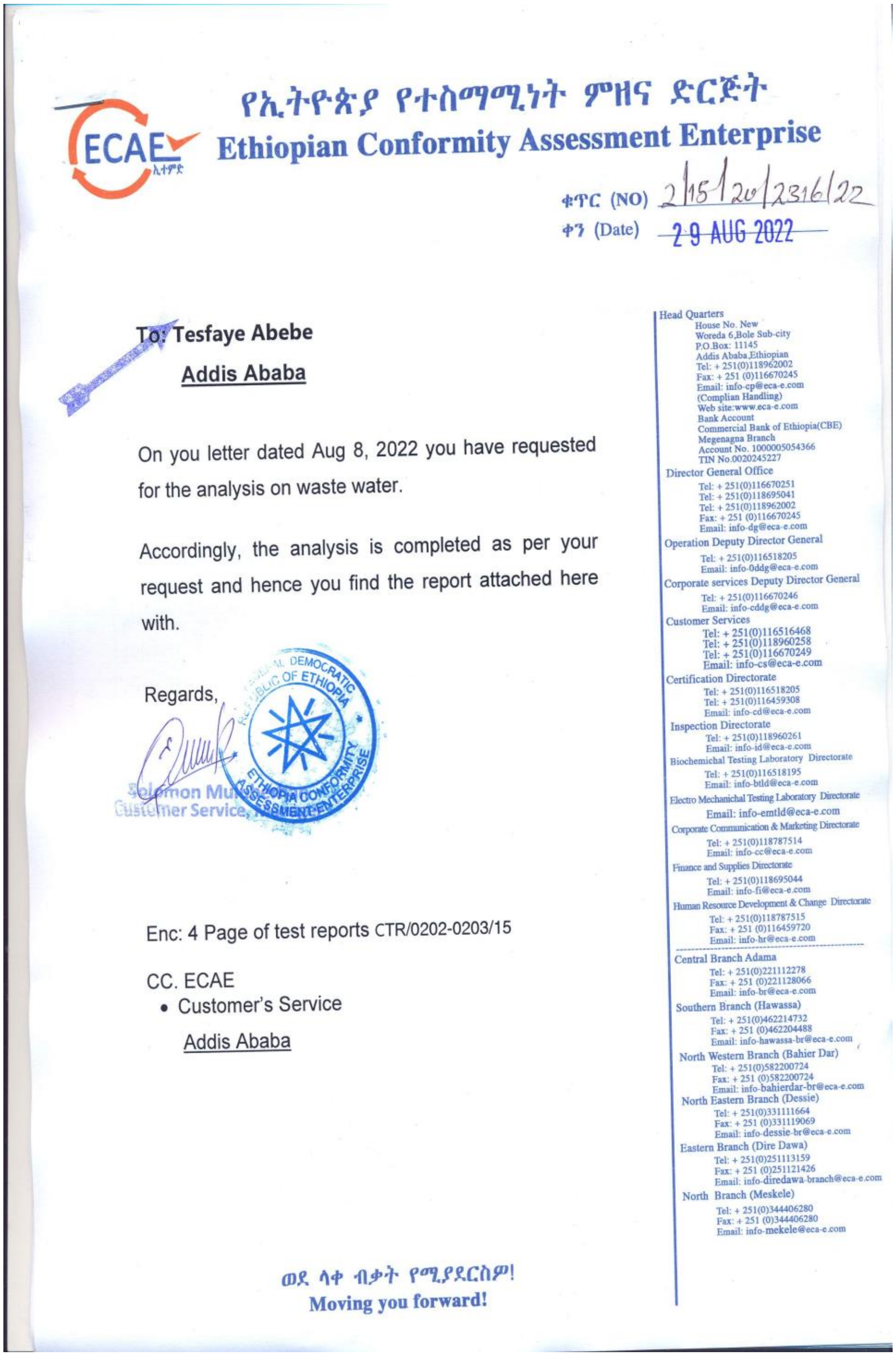


Pollutant: Sulfur Dioxide in μg/m^3



APPENDIX C

WASTEWATER LABORATORY RESULT



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Ethiopian Conformity Assessment Enterprise

ቁጥር (NO) 2/15/20/2316/22
ቀን (Date) 29 AUG 2022

To: Tesfaye Abebe
Addis Ababa

On you letter dated Aug 8, 2022 you have requested for the analysis on waste water.

Accordingly, the analysis is completed as per your request and hence you find the report attached here with.

Regards,

Solomon Mu
Customer Service,

Enc: 4 Page of test reports CTR/0202-0203/15

CC. ECAE
- Customer's Service

Addis Ababa

Head Quarters
House No. New
Woreda 6,Bole Sub-city
P.O.Box: 11145
Addis Ababa,Ethiopian
Tel: + 251(0)118962002
Fax: + 251 (0)116670245
Email: info-cp@eca-e.com
(Complian Handling)
Web site:www.eca-e.com
Bank Account
Commercial Bank of Ethiopia(CBE)
Megenagna Branch
Account No. 1000005054366
TIN No.0020245227
Director General Office
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Tel: + 251(0)118695041
Tel: + 251(0)118962002
Fax: + 251 (0)116670245
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Operation Deputy Director General
Tel: + 251(0)116518205
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Corporate services Deputy Director General
Tel: + 251(0)116670246
Email: info-cddg@eca-e.com
Customer Services
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Tel: + 251(0)118960258
Tel: + 251(0)116670249
Email: info-cs@eca-e.com
Certification Directorate
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Tel: + 251(0)116459308
Email: info-cd@eca-e.com
Inspection Directorate
Tel: + 251(0)118960261
Email: info-id@eca-e.com
Biochemichal Testing Laboratory Directorate
Tel: + 251(0)116518195
Email: info-btld@eca-e.com
Electro Mechanichal Testing Laboratory Directorate
Email: info-emtld@eca-e.com
Corporate Communication & Marketing Directorate
Tel: + 251(0)118787514
Email: info-cc@eca-e.com
Finance and Supplies Directorate
Tel: + 251(0)118695044
Email: info-fi@eca-e.com
Human Resource Development & Change Directorate
Tel: + 251(0)118787515
Fax: + 251 (0)116459720
Email: info-hr@eca-e.com
Central Branch Adama
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Fax: + 251 (0)221128066
Email: info-br@eca-e.com
Southern Branch (Hawassa)
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Fax: + 251 (0)462204488
Email: info-hawassa-br@eca-e.com
North Western Branch (Bahier Dar)
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Fax: + 251 (0)582200724
Email: info-bahierdar-br@eca-e.com
North Eastern Branch (Dessie)
Tel: + 251(0)331111664
Fax: + 251 (0)331119069
Email: info-dessie-br@eca-e.com
Eastern Branch (Dire Dawa)
Tel: + 251(0)251113159
Fax: + 251 (0)251121426
Email: info-diredawa-branch@eca-e.com
North Branch (Meskele)
Tel: + 251(0)344406280
Fax: + 251 (0)344406280
Email: info-mekele@eca-e.com

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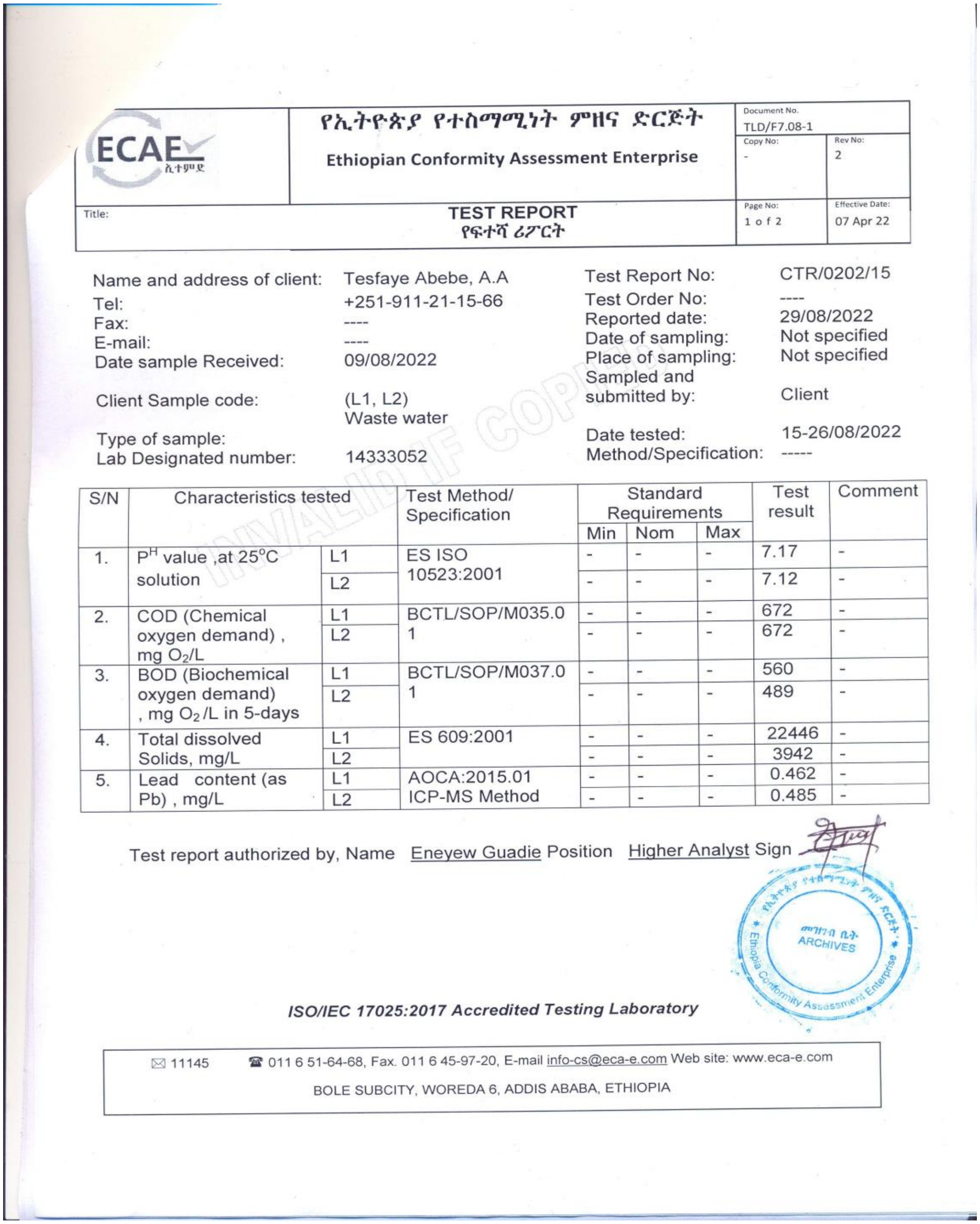
Moving you forward!



ECAE
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የኢትዮጵያ የተስማሚነት ምዘና ድርጅት

Ethiopian Conformity Assessment Enterprise

Document No.	TLD/F7.08-1
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Effective Date:	07 Apr 22

Title:

TEST REPORT
የፍተሻ ሪፖርት

Name and address of client:	Tesfaye Abebe, A.A	Test Report No:	CTR/0202/15
Tel:	+251-911-21-15-66	Test Order No:	----
Fax:	----	Reported date:	29/08/2022
E-mail:	----	Date of sampling:	Not specified
Date sample Received:	09/08/2022	Place of sampling:	Not specified
Client Sample code:	(L1, L2)	Sampled and submitted by:	Client
Type of sample:	Waste water	Date tested:	15-26/08/2022
Lab Designated number:	14333052	Method/Specification:	-----

INVALID IF COPIED

S/N	Characteristics tested		Test Method/ Specification	Standard Requirements			Test result	Comment
				Min	Nom	Max		
1.	P^H value ,at 25°C solution	L1	ES ISO 10523:2001	-	-	-	7.17	-
		L2		-	-	-	7.12	-
2.	COD (Chemical oxygen demand) , mg O_2/L	L1	BCTL/SOP/M035.01	-	-	-	672	-
		L2		-	-	-	672	-
3.	BOD (Biochemical oxygen demand) , mg O_2/L in 5-days	L1	BCTL/SOP/M037.01	-	-	-	560	-
		L2		-	-	-	489	-
4.	Total dissolved Solids, mg/L	L1	ES 609:2001	-	-	-	22446	-
		L2		-	-	-	3942	-
5.	Lead content (as Pb) , mg/L	L1	AOCA:2015.01 ICP-MS Method	-	-	-	0.462	-
		L2		-	-	-	0.485	-

Test report authorized by, Name Eneyew Guadie Position Higher Analyst Sign

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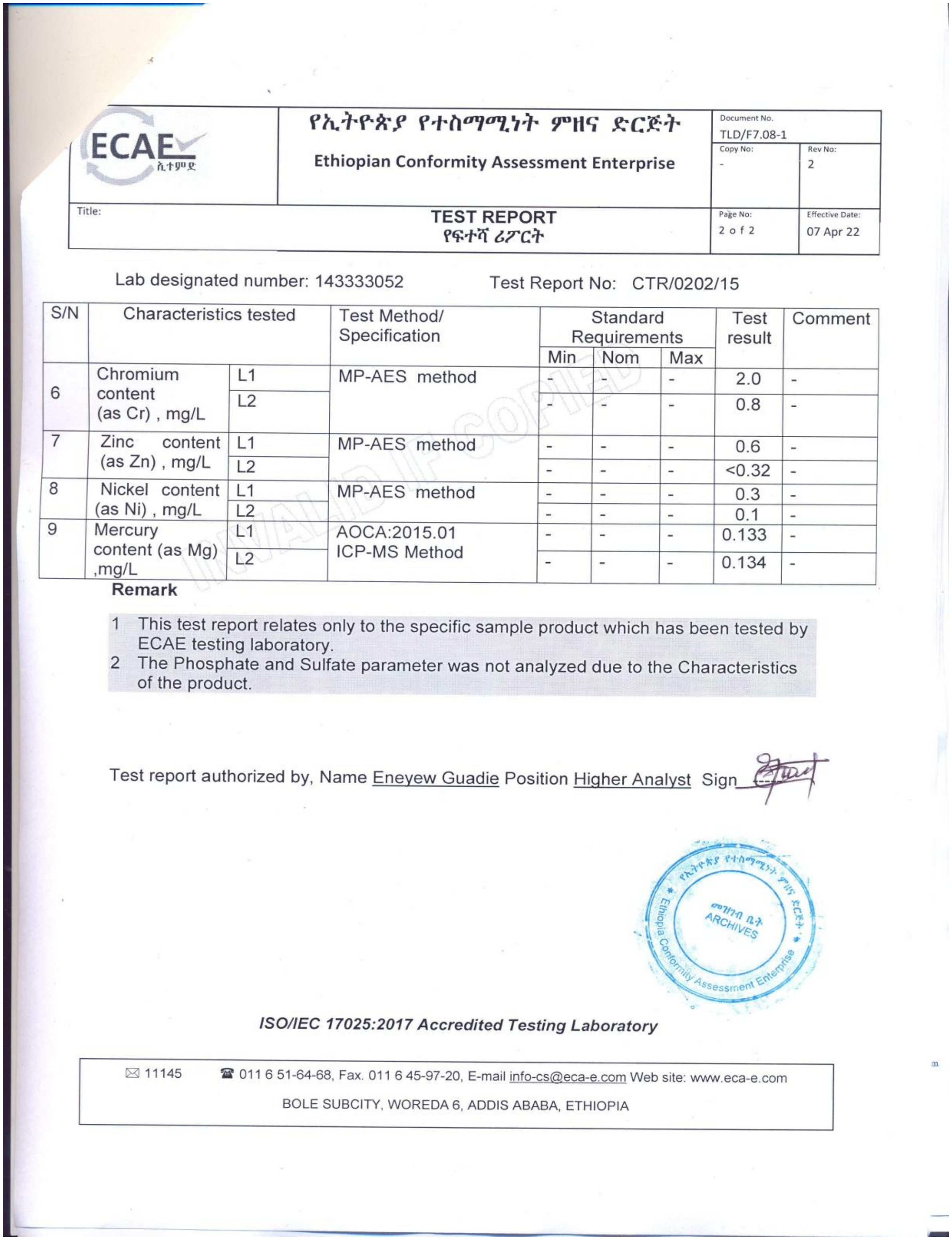

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Ethiopian Conformity Assessment Enterprise

Document No. TLD/F7.08-1
Copy No: -
Rev No: 2

Title:

TEST REPORT
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Page No: 2 of 2
Effective Date: 07 Apr 22

Lab designated number: 143333052   Test Report No: CTR/0202/15

S/N	Characteristics tested		Test Method/ Specification	Standard Requirements			Test result	Comment
				Min	Nom	Max		
6	Chromium content (as Cr) , mg/L	L1	MP-AES method	-	-	-	2.0	-
		L2		-	-	-	0.8	-
7	Zinc content (as Zn) , mg/L	L1	MP-AES method	-	-	-	0.6	-
		L2		-	-	-	<0.32	-
8	Nickel content (as Ni) , mg/L	L1	MP-AES method	-	-	-	0.3	-
		L2		-	-	-	0.1	-
9	Mercury content (as Mg) ,mg/L	L1	AOCA:2015.01 ICP-MS Method	-	-	-	0.133	-
		L2		-	-	-	0.134	-

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Remark

1. This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.
2. The Phosphate and Sulfate parameter was not analyzed due to the Characteristics of the product.

Test report authorized by, Name Eneyew Guadie Position Higher Analyst Sign

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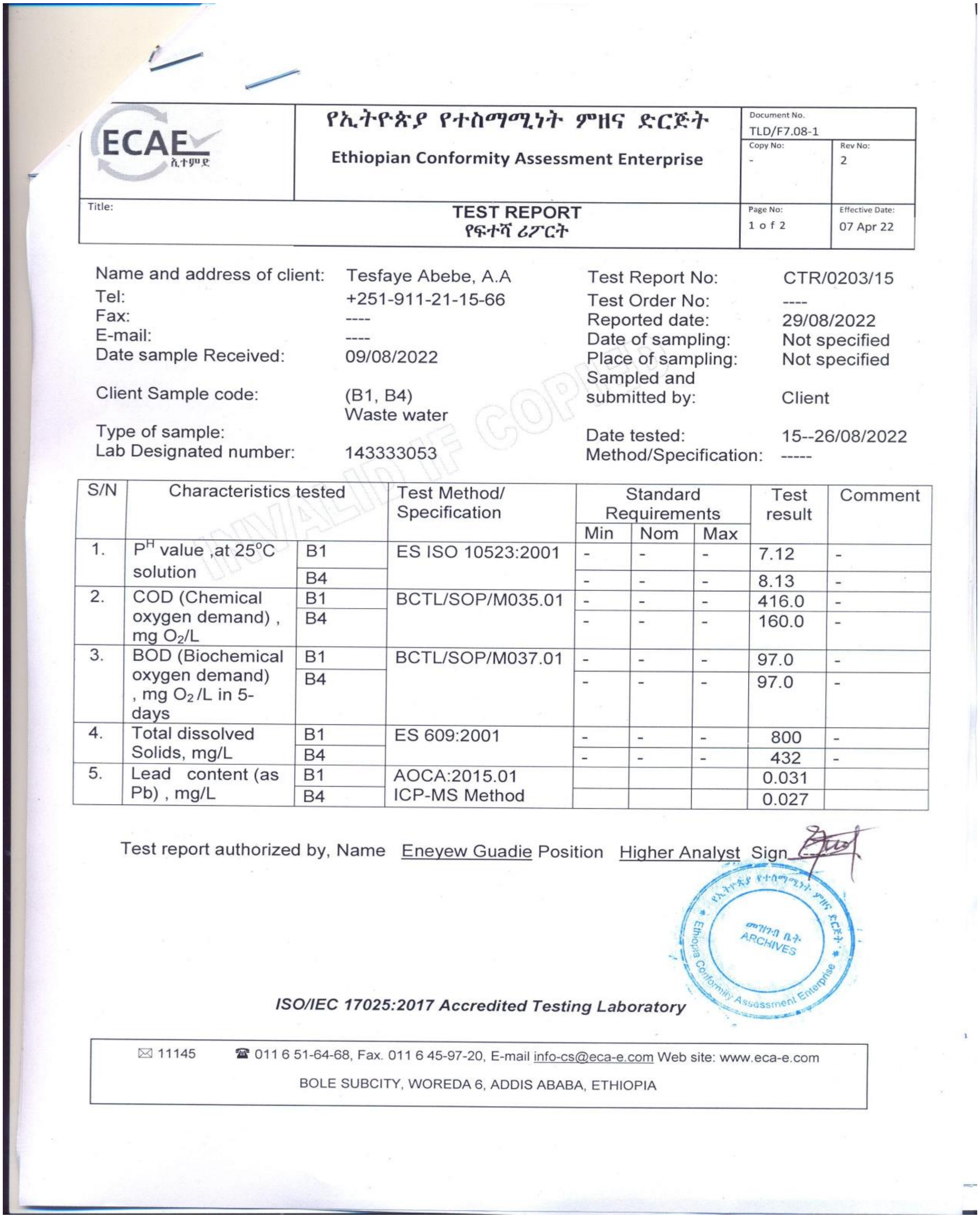

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Ethiopian Conformity Assessment Enterprise

Document No. TLD/F7.08-1
Copy No: -
Rev No: 2

Title: **TEST REPORT**
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Page No: 1 o f 2
Effective Date: 07 Apr 22

Name and address of client: Tesfaye Abebe, A.A
Tel: +251-911-21-15-66
Fax: ----
E-mail: ----
Date sample Received: 09/08/2022
Client Sample code: (B1, B4)
Type of sample: Waste water
Lab Designated number: 143333053

Test Report No: CTR/0203/15
Test Order No: ----
Reported date: 29/08/2022
Date of sampling: Not specified
Place of sampling: Not specified
Sampled and submitted by: Client
Date tested: 15--26/08/2022
Method/Specification: -----

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S/N	Characteristics tested		Test Method/ Specification	Standard Requirements			Test result	Comment
				Min	Nom	Max		
1.	P^H value ,at 25°C solution	B1	ES ISO 10523:2001	-	-	-	7.12	-
		B4		-	-	-	8.13	-
2.	COD (Chemical oxygen demand) , mg O_2/L	B1	BCTL/SOP/M035.01	-	-	-	416.0	-
		B4		-	-	-	160.0	-
3.	BOD (Biochemical oxygen demand) , mg O_2/L in 5-days	B1	BCTL/SOP/M037.01	-	-	-	97.0	-
		B4		-	-	-	97.0	-
4.	Total dissolved Solids, mg/L	B1	ES 609:2001	-	-	-	800	-
		B4		-	-	-	432	-
5.	Lead content (as Pb) , mg/L	B1	AOCA:2015.01 ICP-MS Method				0.031	
		B4					0.027	

Test report authorized by, Name Eneyew Guadie Position Higher Analyst Sign

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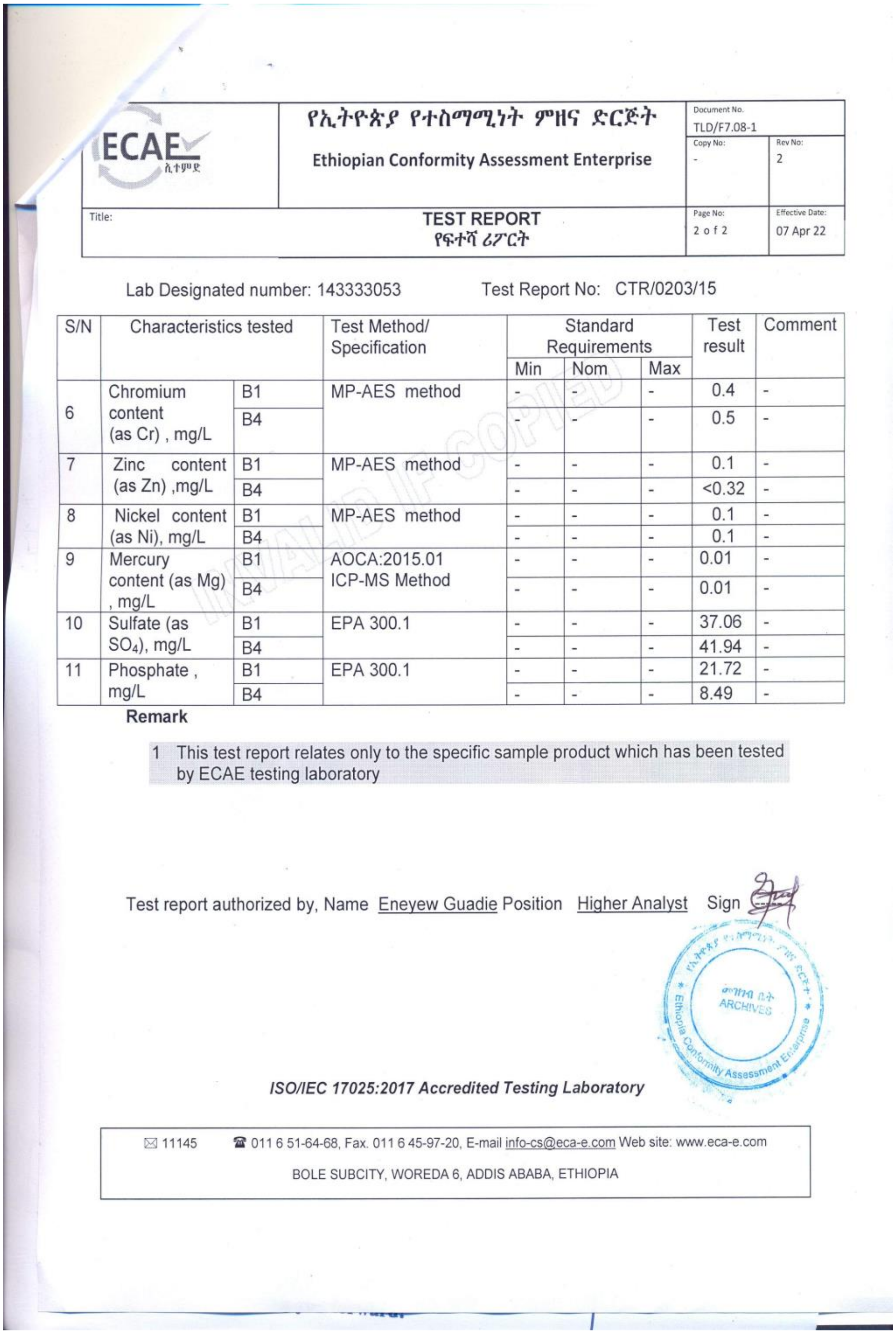

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Title:	**TEST REPORT** የፍተሻ ሪፖርት	Page No: 2 o f 2	Effective Date: 07 Apr 22

Lab Designated number: 143333053 Test Report No: CTR/0203/15

S/N	Characteristics tested		Test Method/ Specification	Standard Requirements			Test result	Comment
				Min	Nom	Max		
6	Chromium content (as Cr) , mg/L	B1	MP-AES method	-	-	-	0.4	-
		B4		-	-	-	0.5	-
7	Zinc content (as Zn) ,mg/L	B1	MP-AES method	-	-	-	0.1	-
		B4		-	-	-	<0.32	-
8	Nickel content (as Ni), mg/L	B1	MP-AES method	-	-	-	0.1	-
		B4		-	-	-	0.1	-
9	Mercury content (as Mg) , mg/L	B1	AOCA:2015.01 ICP-MS Method	-	-	-	0.01	-
		B4		-	-	-	0.01	-
10	Sulfate (as SO_4), mg/L	B1	EPA 300.1	-	-	-	37.06	-
		B4		-	-	-	41.94	-
11	Phosphate , mg/L	B1	EPA 300.1	-	-	-	21.72	-
		B4		-	-	-	8.49	-

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Remark

1 This test report relates only to the specific sample product which has been tested by ECAE testing laboratory

Test report authorized by, Name Eneyew Guadie Position Higher Analyst Sign

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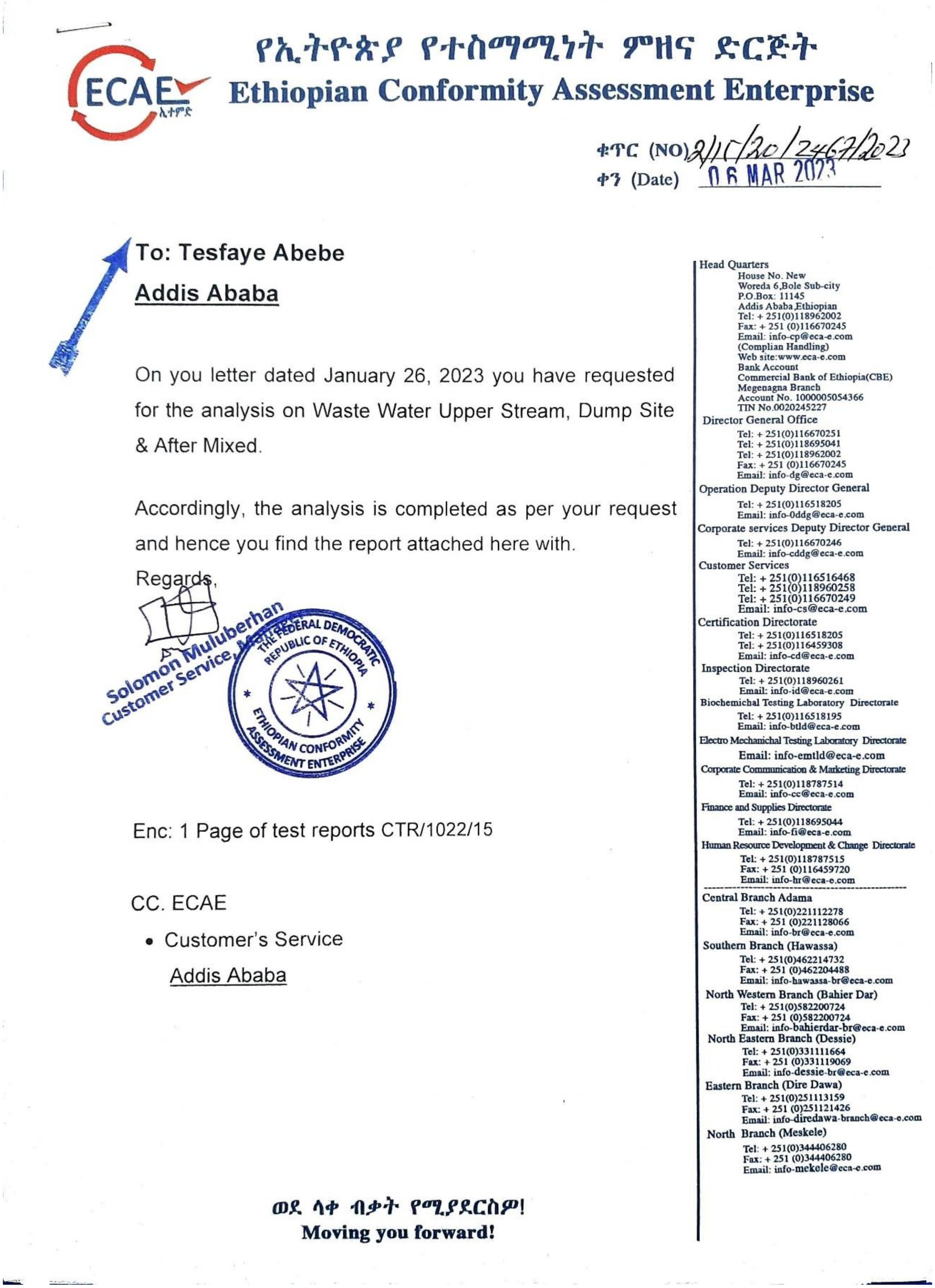

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Ethiopian Conformity Assessment Enterprise

ቁጥር (NO) 2/1C/20/2467/2023
ቀን (Date) 06 MAR 2023

To: Tesfaye Abebe
Addis Ababa

On you letter dated January 26, 2023 you have requested for the analysis on Waste Water Upper Stream, Dump Site & After Mixed.

Accordingly, the analysis is completed as per your request and hence you find the report attached here with.

Regards,

Solomon Muluberhan
Customer Service Manager

Enc: 1 Page of test reports CTR/1022/15

CC. ECAE

- Customer's Service
  Addis Ababa

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Woreda 6,Bole Sub-city
P.O.Box: 11145
Addis Ababa,Ethiopian
Tel: + 251(0)118962002
Fax: + 251 (0)116670245
Email: info-cp@eca-e.com
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Web site:www.eca-e.com
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Account No. 1000005054366
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Email: info-0ddg@eca-e.com
Corporate services Deputy Director General
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Email: info-cddg@eca-e.com
Customer Services
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Tel: + 251(0)118960258
Tel: + 251(0)116670249
Email: info-cs@eca-e.com
Certification Directorate
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Tel: + 251(0)116459308
Email: info-cd@eca-e.com
Inspection Directorate
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Email: info-id@eca-e.com
Biochemichal Testing Laboratory Directorate
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Electro Mechanichal Testing Laboratory Directorate
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Corporate Communication & Marketing Directorate
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Email: info-fi@eca-e.com
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Fax: + 251 (0)344406280
Email: info-mekele@eca-e.com

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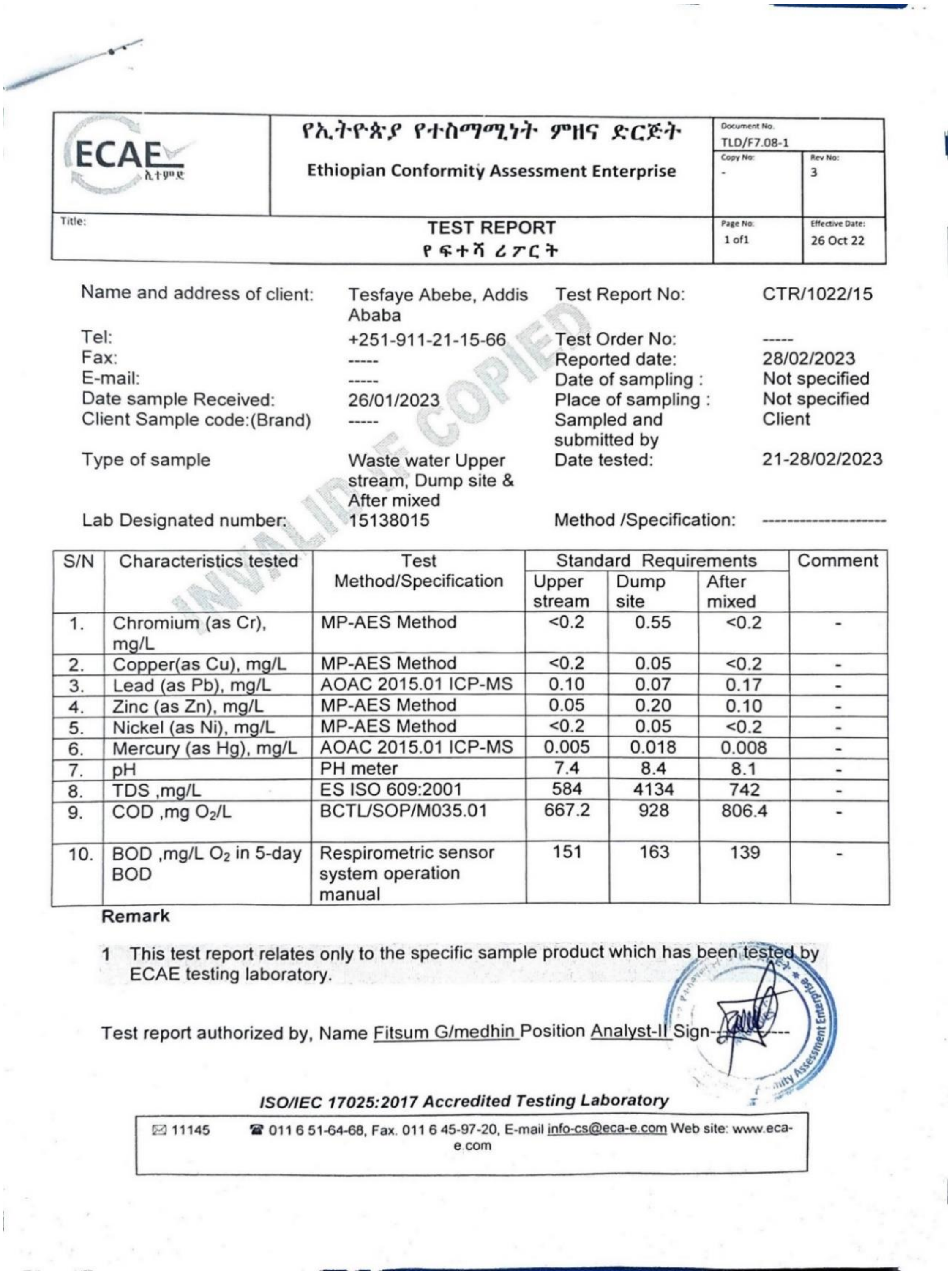
Moving you forward!

Figure C.1 Wastewater sample laboratory result August 2022



የኢትዮጵያ የተስማሚነት ምዘና ድርጅት **Ethiopian Conformity Assessment Enterprise**		Document No. TLD/F7.08-1	
		Copy No: -	Rev No: 3
Title:	**TEST REPORT** **የ ፍተሻ ሪፖርት**	Page No: 1 of1	Effective Date: 26 Oct 22

Name and address of client:	Tesfaye Abebe, Addis Ababa	Test Report No:	CTR/1022/15
Tel:	+251-911-21-15-66	Test Order No:	-----
Fax:	-----	Reported date:	28/02/2023
E-mail:	-----	Date of sampling :	Not specified
Date sample Received:	26/01/2023	Place of sampling :	Not specified
Client Sample code:(Brand)	-----	Sampled and submitted by	Client
Type of sample	Waste water Upper stream, Dump site & After mixed	Date tested:	21-28/02/2023
Lab Designated number:	15138015	Method /Specification:	--------------------

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S/N	Characteristics tested	Test Method/Specification	Standard Requirements			Comment
			Upper stream	Dump site	After mixed	
1.	Chromium (as Cr), mg/L	MP-AES Method	<0.2	0.55	<0.2	-
2.	Copper(as Cu), mg/L	MP-AES Method	<0.2	0.05	<0.2	-
3.	Lead (as Pb), mg/L	AOAC 2015.01 ICP-MS	0.10	0.07	0.17	-
4.	Zinc (as Zn), mg/L	MP-AES Method	0.05	0.20	0.10	-
5.	Nickel (as Ni), mg/L	MP-AES Method	<0.2	0.05	<0.2	-
6.	Mercury (as Hg), mg/L	AOAC 2015.01 ICP-MS	0.005	0.018	0.008	-
7.	pH	PH meter	7.4	8.4	8.1	-
8.	TDS ,mg/L	ES ISO 609:2001	584	4134	742	-
9.	COD ,mg O_2/L	BCTL/SOP/M035.01	667.2	928	806.4	-
10.	BOD ,mg/L O_2 in 5-day BOD	Respirometric sensor system operation manual	151	163	139	-

Remark

1 This test report relates only to the specific sample product which has been tested by ECAE testing laboratory.

Test report authorized by, Name Fitsum G/medhin Position Analyst-II Sign----------

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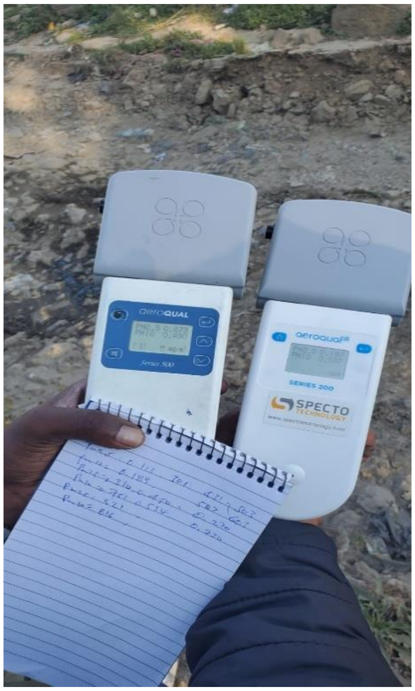
Figure C.2 Wastewater sample laboratory result (February 2023)

APPENDIX D

Site Investigation and Field Work


aeroqual
Series 500
aeroqual
SERIES 200
SPECTO
TECHNOLOGY

(a)


aeroqual
PM2.5 0.138
PM10 0.385
ppm
SERIES 200
SPECTO
TECHNOLOGY
www.spectotechnology.com

(b)

(c)

(d)

(d) (e)

(f) (g)

Figure D.1 Ambient air data collection in Addis Ababa City

(a) (b)

(c) (d)

(e) (f)

(g) (h)

Figure D.2 Sample wastewater trial in the Lab. (a), Sample wastewater trial in the lab (b), Codification of wastewater sample in lab(c), Tagging wastewater sample before laboratory test (d), Elementary school children nearby Koshe dump site (e), leachate of Koshe dump site at gate (f), leachate of Koshe dump site before entering to River (g) and Little Akaki river mixed with Leachate (h).

BIOGRAPHY

BIOGRAPHY

Mr. Tesfaye Abebe Alemu was born in Gebreguracha Town, North Show Province, Ethiopia. He completed his bachelor's degree in the field of Economics from Civil Service University in 2002. He also completed his master's degree specializing in Environment and Development from Addis Ababa University in 2009.

He worked as a senior government official at Ethiopia's regional and Federal governments in different leadership positions for more than 14 years. He served as vice head of the public sector capacity building program, civil service reform program, and Finance and Economic Development. In his academic and research work, Mr. Tesfaye has served as Director General of Oromia Regional Government Management Institute, Lecturer, and Dean of the then Public Service College of Oromia Regional Government, which currently became Oromia State University.

Mr. Tesfaye Abebe joined the University of Texas at Arlington in the Fall of 2019 to pursue Ph.D. in the Civil Engineering department specializing in the Solid Waste Institute for Sustainability (SWIS) program under the close supervision of Dr. MD Sahadat Hossain.

His professional leadership and research experiences include but are not limited to, good governance, business process re-engineering, service delivery, result-oriented monitoring and evaluation, efficiency and effectiveness of the public sector, and home-grown reform programs.

Mr. Tesfaye Abebe has achieved the "Outstanding Civil Engineering Ph.D. Student Award" in two consecutive years, 2019-20 and 2020-21, at the University of Texas at Arlington. Mr. Tesfaye was certified in Public Financial Management from Harvard University during his professional leadership period in 2008. He was also certified in Project & Program Management from RIPA

International, UK, London 2009. Moreover, He was certified in Results Monitoring and Evaluation training by The World Bank Group in 2011.

He aims to contribute and pursue African sustainable solid waste management initiatives in realizing AU’s Agenda 2063 through reforming the increasing municipal solid waste challenges to attain environmentally sustainable and climate-resilient economies within African communities. Besides this vision, Mr. Tesfaye Abebe loves participating in voluntary community service events to contribute to his social responsibilities.