UNIVERSITY OF NAIROBI

Assessment of Air Pollution and Prevalence Levels of Respiratory Diseases in Mukuru Informal Settlement in Nairobi City, Kenya.

By

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July 2023.

DECLARATION

I declare that this thesis is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people's work or my own work has been used, this has been acknowledged and referenced in accordance with the University of Nairobi's requirements.

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I dedicate this research work to my parents and siblings for the moral and financial support they offered me to pursue it.

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ABSTRACT

Air pollution is one of the major environmental issues globally and is more pronounced in Sub-Saharan Africa (SSA). It is associated with adverse health effects, including respiratory diseases that have led to high morbidity and mortality rates. The urban population in SSA is further concentrated in the slums and more often it uses highly polluting fuels for cooking. This has caused the release of elevated levels of pollutants into the environment. The study was aimed at determining households and ambient $PM_{2.5}$, and CO levels in densely populated Mukuru slum and control site during the rainy and dry seasons The meteorological conditions that prevailed and prevalence levels of respiratory diseases in the communities were also evaluated. Outdoor and indoor $PM_{2.5}$ levels were collected for 24 hours for three consecutive days at each site using Harvard impactors with the preconditioned polytetrafluoroethylene filters. They were then analyzed using the gravimetric technique. Ambient and household CO levels were also sampled at each site using a portable lascar easy CO data logger. The ambient mean levels of $PM_{2.5}$ and CO were compared with those of the WHO air quality guidelines. During the same period, the incidences of respiratory diseases in the communities were obtained from the community health facilities. The $PM_{2.5}$ levels ($\mu g/m^3$) in the households in the Mukuru slum ranged from 8 to 151 and 50 to 274, with overall means of 61.4±43.6 and 137±56.9 during the dry and rainy seasons, respectively. The control site had relatively lower indoor $PM_{2.5}$ with mean levels ($\mu g/m^3$) of 19±9.2 and 19 ± 7.6 ranging from 13 to 30 and 12 to 27 during the dry and rainy seasons, respectively. On the other hand, the outdoor $PM_{2.5}$ levels ($\mu g/m^3$) ranged from 13 to 77 and 20 to 64 with overall means of 38.85±17.7 and 37±14.9 during the same period. In all cases, the mean ambient $PM_{2.5}$ levels at each site exceeded the WHO air quality guideline of 15 ug/m^3 over the 24-hour period. The household CO levels in the slums ranged from 0.45 to 13.42 ppm and 0.95 to 32.47 ppm with means of 4.48±3.50 ppm and 12.22±10.52 ppm during the dry and the rainy season, respectively. The CO levels (ppm) in the ambient air ranged from 0.04 to 1.50 and 0.001 to 1.02 with means of 0.35±0.29 ppm and 0.46±0.35 ppm during the same period. The ambient CO levels were all within the 24-hr WHO set limits of 3.5 ppm. On the contrary, the control site had both household and ambient CO levels that were less than 0.001 ppm for both seasons except for the latter during the rainy season. The prevalence levels of respiratory diseases from the Mukuru communities were higher than the control. It ranged from 36.9 to 46.7% and 30.6 to 43.8% whereas for the control health facility had 25.4 and 32.2% during the dry and rainy seasons, respectively. The study recommends continuous monitoring of air pollution and environmental health -driven policies to reduce the levels of $PM_{2.5}$ and household CO.

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LIST OF ABBREVIATIONS/ACRONYMS

AAP   Ambient Air Pollution

BC   Black Carbon

COPD   Chronic Obstructive Pulmonary Disease

US EPA   United States Environmental Protection Agency

HAP   Household Air Pollution

LMICs   Low- and Middle-Income Countries

LPG   Liquefied Petroleum Gas

NEMA   National Environment Management Agency

PAHs   Polycyclic Aromatic Hydrocarbons

PM   Particulate Matter

PM_{10}   Particulate Matter with an Aerodynamic Diameter of Less or Equal to 10 Microns

$PM_{2.5}$ Particulate Matter with an Aerodynamic Diameter of Less or Equal to 2.5 Microns

PTFE   Polytetrafluoroethylene

SSA   Sub Saharan Africa

USA   United States of America

UV-VIS-IR   Ultraviolet–Visible Infrared Spectroscopy

VOCs   Volatile Organic Compounds

WHO   World Health Organization

CHAPTER ONE

1. INTRODUCTION

1.1 Background Information

Air pollution is a major societal problem that affects the air quality through the release of contaminants from natural and anthropogenic sources. The natural sources include volcanic eruptions, wildfires, and dust storms. The latter sources could be due to industrial emissions that may include the release of carbon (II) oxide and other organic compounds. The other sources are combustion of fossil fuels from vehicles and release of gases such as sulphur (IV) oxide (SO_2) and compounds of nitrogen (NOx) and also the agricultural activities that may include the use of pesticides, and fertilizers. In addition, the waste disposals in the landfills releases methane whereas the open burning of wastes releases CO, carbon (IV) oxide (CO_2), compound of nitrogen (NOx), and polycyclic aromatic hydrocarbons (PAHs) which are harmful to the human and environment.

Air pollution has been ranked globally as the greatest threat to human health (WHO, 2016). It is estimated that it claimed 7 million premature deaths of the world population in 2012 (Muindi *et al.,* 2016a). This has been attributed to high concentrations of $PM_{2.5}$ in the ambient air whereas 4.3 million deaths were as a result of household air pollution. Furthermore, high levels of these pollutants are experienced in Sub-Saharan Africa (SSA) which have inadequate infrastructure in health systems as compared to developed countries (Bauer *et al.*, 2019). $PM_{2.5}$ is the particulate matter with an aerodynamic diameter of less or equal to 2.5 micrometers and has a greater impact on human health due to its ease of penetration to the respiratory tract (Okello, 2018) as compared to PM_{10} with an aerodynamic diameter of less or equal to 10 micrometers.

The impact of air pollution is much greater in low and middle-income countries (LMICs) as compared to high-income countries (HICs). This is attributed to LMICs having limited monitoring capacities of air pollution due to the lack of resources, and insufficient regulatory framework, and policies to guide the monitoring processes (Egondi *et al.*, 2018). Lack of employment in these countries has the increased population living in informal settlements (urban slums). The socio-economic status of the slum population and their inability to access quality health services put them at a greater risk of urban air pollution. In addition, they tend to live

closer to the industrial hubs and along the roads which are the major sources of these pollutants (Egondi *et al.*, 2013). This greatly increases the number of health-related complications and premature deaths among the vulnerable groups living in the slums (Ngo *et al.,* 2015).

1.1.1 Sources of Air Pollution in Densely Populated Communities

The major sources of ambient air pollution in densely populated communities in the developing countries like Kenya include the industrial operations shown in Figure 1.1 involving the release of toxic chemicals to the environment.

Figure 1. 1: Industrial emissions
Source: (Muniafu & Otiato, 2010)

In these settings, there is inability to manage wastes hence they are openly burnt to reduce on the volumes which also releases some harmful pollutants such as CO, black carbon (BC), and particulate matter (PM) in the environment. Figure 1.2 shows open burning of waste around the slum areas in Nairobi.

Figure 1. 2: Open burning of waste around the slums
Source: (Dhegati, 2017).

The uncontrolled waste disposal of these wastes in the cities leads to air pollution in the areas close to the dumpsites. Most densely populated communities live adjacent to the dumpsites especially in Kenya, which exposes them to unpleasant smells and hazardous pollutants. The major dumpsite in Kenya is the Dandora dumpsite (Figure 1.3).

Figure 1. 3: Dandora dumpsite
Source: (Muniafu & Otiato, 2010)

Vehicular emissions from diesel-powered engines are also common sources of air pollution especially for the people living close to the roads (Ndwiga *et al.,* 2014). The incomplete combustion of fuels leads to the release of CO and BC which contribute to the particulate matter in the ambient air that result in human health complications. These pollutants also have an impact on indoor air pollution levels due to their capability of infiltrating into the households adjacent to the sources.

In developing countries, including Kenya, are compounded by rapid industrialization and an increase in urban population through rural-urban migration in search of opportunities. This leads to limited or no provision of social amenities to take care of the increase in population resulting in the proliferation of informal settlements (Dianati *et al.*, 2019). Poor urban planning where the residential areas are in close proximity to the industrial settings poses a threat to human health as a result of the industrial emissions. This gradually increases the pollutants in the ambient air in urban areas (Egondi *et al.*, 2018).

Moreover, in Kenya, the urban slum dwellers largely depend on unclean fuels. The incomplete combustion of these fuels releases CO and BC which are the main sources of household pollutants (Muindi *et al.*, 2016a). Smoking of cigarettes also contribute to the increased levels of indoor air pollution caused by the smoke particles. The household setups in the informal settlements are mainly single rooms that are overcrowded and poorly ventilated (Muindi *et al.*, 2016a). This is as a result of low economic status of the inhabitants. The level of social insecurity as a result of poverty is the reason for the poorly ventilated households*(Sanbata et al.*, 2014). The slum areas are also overcrowded as a result of high population. The roads are unpaved which contributed to the elevated levels of dust particles in the air.

1.1.2 Health Effects of Air Pollution

Indoor and outdoor air pollution have adverse effects on human health especially in children and pregnant women (Agarwal *et al.*, 2018). Air pollution is associated with serious health outcome such as premature births, low birth weight or miscarriages (Muindi *et al.,* 2016a). Previous studies have shown a relationship between air pollution and the health effects of people living in polluted areas. Children are the vast majority affected by air pollutants because they are more susceptible to acute respiratory infections. This is because their lungs are not fully developed thus pollutants can easily penetrate. In addition, they have low immune system as compared to adults, high rate of respiration, and their lung have large surface area as compared to their body weights (Egondi *et al.*, 2018). Furthermore, smoking causes an acute lower respiratory infection in children including the risk of allergic infections such as asthma (Mannucci & Franchini, 2017).

In general terms, air pollution is considered among the human health risk factors owing to its health-related effects such as chronic obstructive pulmonary diseases, lung cancer, asthma, and pneumonia. Apart from the respiratory diseases, exposure to household air pollution (HAP) and ambient air pollution (AAP) has health effects on the cardiovascular system causing hypertension, coronary heart disease, and stroke (Sun & Zhu, 2019; Mannucci & Franchini, 2017). In most cases, the airborne pollutants exceed the WHO air quality limit over the 24-hour average, which can be above 1000 $\mu g/m^3$. During cooking using the dirty fuels, the concentration

usually goes higher than 10,000 µg/m^3 (Naeher *et al.*, 2013). Table 1.1 shows the WHO recommended air quality guidelines for various pollutants.

Table 1.1: WHO Air Quality Guidelines

Pollutants	WHO Air Quality Limits	
	Time average weighted	Concentration ($\mu g/m^3$)
PM$_{2.5}$	Annual average	10
	Ambient 24-hour mean	15
PM$_{10}$	24-hour mean	50
	Annual average	20
Ozone (O$_3$)	8-hour mean	100
Sulphur (IV) oxide (SO$_2$)	24-hour mean	20
Nitrogen (IV) oxide (NO$_2$)	1-hour mean	200
	Annual average	40
Carbon (II) oxide (CO)	Indoor 24 hour mean	6.1 (ppm)
	Outdoor 24 hour mean	3.5 (ppm)

Source: (Gall *et al.,* 2013a; WHO,2016; WHO 2021; WHO 2010)

1.2 Statement of the Problem

The densely populated urban settlement faces both human and environmental threats due to the increased air pollution. According to the WHO annual report, the outdoor and indoor PM$_{2.5}$ levels in the air have caused 7.8 million premature deaths worldwide (Landrigan*,* 2017). PM$_{2.5}$ is the greatest environmental risk that causes premature deaths due to respiratory diseases, stroke, cancer, and chronic pulmonary diseases (WHO, 2016). The majority of these cases (98%) are from low and middle-income countries. The highest levels of fine particles in the world have been recorded in Sub-Saharan Africa (SSA) as compared to other developed European cities (Bauer *et al*., 2019). Most large populations in Africa depend on the use of organic fuels such as wood, kerosene, and charcoal for cooking and lighting (Ngo *et al.,* 2017). The use of these organic fuels in poorly ventilated houses contributes to high rates of indoor pollution.

The increased rate of urbanization with poor planning coupled with the increase in the number of industries have great impact on the air quality of the surrounding communities. In recent years, there has been a rapid increase in the urban population in LMICs due to rural-urban migration. This has adversely led to mushrooming of slums where the air quality has been compromised leading to increased health-related complaints due to high exposure to air pollutants.

The improper waste disposals, diesel-powered engine emissions, open burning of waste in the residential areas, and residential areas located in the vicinity of sources of pollution that have poor air quality (Ngo *et al.*, 2015). Black carbon (BC), and CO are products of incomplete combustion and they make up $PM_{2.5}$ particles in the air (Anenberg *et al.,* 2012). Exposure to BC in the ambient air cause adverse health effects. It is associated with cardiopulmonary morbidity and mortality and also impacts environment leading to climate change (Janssen *et al.,* 2011). Comprehensive research on the levels of air pollution and health impacts in densely populated communities is paramount. This will inform the relevant authorities to establish suitable interventions and policies to reduce these emissions to the environment and their related health impacts.

1.3 Objectives

1.3.1 General Objective

The general objective of this study was to assess the levels of air pollutants and the related health effects in the densely populated areas in Nairobi County.

1.3.2 Specific Objectives

The specific objectives were:
  i.   To determine the levels of $PM_{2.5}$ and CO in the ambient air and households within the Mukuru informal settlement during the rainy and dry seasons
  ii.   To evaluate the relationship between ambient $PM_{2.5}$, and CO levels with the established WHO air quality standards.
  iii. To determine the prevalence levels of respiratory diseases in Mukuru informal settlement during the dry and rainy seasons.

1.4 Significance and Justification of the Study

Knowledge on the levels and sources of the air pollution especially in the use of unclean fuel for cooking in the informal settlements will assist in setting up policies in the energy sector. This will aid in the reduction of indoor air pollution and related premature deaths among communities in Mukuru informal settlements. The results of the study will also provide crucial data to assist in establishing policies and regulatory framework to mitigate industrial emissions and open burning of waste. The findings will in addition assist in establishing environmental health driven programs to reduce air pollution and hence incidences of respiratory diseases.

1.5 Scope and Limitations

The study was designed to determine the levels of $PM_{2.5}$ and CO in the ambient air and households within the communities in the informal settlement in Nairobi County during the dry and wet seasons. These levels were compared with those of the control site during the same period. The prevalence of respiratory diseases was also determined in these communities. Due to logistical challenges and financial constraints Mukuru slum was taken as representative of a densely populated informal settlements in Kenya. The ambient air sampling points of CO and $PM_{2.5}$ were also limited to five sampling sites, which depended on the security of the area and potential sources of pollution. The prevalence level of respiratory diseases was limited to the health data drawn from the community health center. Apart from air pollution, there could have been other factors that caused respiratory diseases. Despite some limitations the study determined the household and ambient $PM_{2.5}$ and CO, and incidences of respiratory diseases in Mukuru informal settlement.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Air Pollution

Air pollution is the deterioration of the air quality due to the presence of substances that are harmful to human health and environment. The environment becomes unfavorable when the concentration of air pollutants exceeds the set air quality standard values. Uncontaminated air majorly constitutes gases which include nitrogen (N_2, 78.0%), oxygen (O_2, 20.9%), rare gases such as argon (Ar, 0.9%), and carbon (IV) oxide (CO_2, 0.04%). The composition of air is very stable under normal atmospheric conditions of pressure and temperature since the three gases are non-reactive while argon is a noble gas (Vallero, 2015).

Sources of air pollution are categorized as natural and anthropogenic. Anthropogenic sources are as a result of human activities such as industrial emissions, vehicular emissions, waste disposals, open burning of wastes, agricultural activities that include use of pesticides and military sources such as nuclear weapons. Natural sources emanating from dust, volcanic eruptions that emit pollutants such as sulfur, chlorine, and ash particles, and smoke from wildfires, and volatile organic compounds (VOCs). These VOCs may react with primary pollutants such as NO_x and SO_2 to produce secondary pollutants (Vallero, 2015).

2.1.1 Indoor Air Pollution

Indoor air pollution refers to the contamination of air in an enclosed micro-environment such as households, offices, and building spaces. It is most common in Low- and Middle-Income Countries (LMICs) where 95% of the population depends on biomasses for cooking and lighting (WHO, 2016). The burning of these biomass fuels leads to the release of toxic compounds to the environment such as PM, NO_x, CO, CO_2, SO_2, BC, and VOCs (Muindi *et al*., 2016a). Carbon (IV) oxide and black carbon (BC) are released during the burning of fossil fuels that also lead to global warming (Gall *et al.,* 2013b). Smoking cigarettes is also a big contributor to household air pollution (HAP) which mostly affects children below five years of age (Naeher *et al.*, 2013).

According to research done by Naeher *et al*. (2013) in Guatemala on the effects of the use of wood and kerosene fuels in household setups, high amounts of PM, CO, hydrocarbons, and

VOCs were emitted. The 24-hour mean concentration of $PM_{2.5}$ and PM_{10} were above 100 µg/m^3 and reached up to 10,000 µg/m^3 during cooking activities. The levels exceeded the recommended WHO air quality standards of 15 and 50 µg/m^3 for $PM_{2.5}$ and PM_{10} respectively. This presents a great threat to human health when they are exposed to such levels (Naeher *et al.*, 2013.).

A case study that was also done in 13 households in Gambia that assessed the indoor air pollution due to the use of biomass through measurement of the levels of CO and $PM_{2.5}$ in relation to pneumonia and severe pneumonia in infants and children for 48 hours. This was achieved by the use of air monitors and gravimetric filter sampling which showed significantly high levels of $PM_{2.5}$. The 48-hour household monitoring for both pollutants showed an average of 3.8 ppm CO and 361 µg/m^3 $PM_{2.5}$ in the cooking area. The concentrations were at the peak during the morning hours, midday, and in the evening as a result of cooking activities (Dionisio *et al.*, 2008).

The study carried out by Were *et al.* (2020) in Athi River Township in Kenya on the correlation between $PM_{2.5}$ and PM_{10} levels with respiratory health impacts on school-going children found significantly high levels of the pollutants in the classroom environments as compared to WHO recommendations. The results reported an average of 17.7-52.4 and 28.5-75.5 µg/m^3 for the $PM_{2.5}$ and 60.8-269.1 and 52.8-232.3 µg/m^3 for PM_{10} during the dry and wet seasons, respectively. The study revealed a high-risk of PM exposure which resulted in respiratory illness. among the school-going children h (Were *et al.,* 2020a).

An investigation also conducted by Muindi *et al.* (2016) found higher levels of $PM_{2.5}$ in one of the Nairobi slums than those of the WHO air quality guideline value for $PM_{25.,.5}$. The levels of $PM_{2.5}$ were influenced majorly by the diverse types of fuels such as kerosene, cooking stoves, and charcoal that was commonly used by the household. The levels ranged from 1 to 12,369 µg/m^3 and were high during the cooking hours in the morning, afternoon, and evening(Muindi *et al.*, 2016a).

2.1.2 Outdoor Air Pollution

Fine particulate matter ($PM_{2.5}$) in the ambient air is the major environmental health concern which resulted in approximately 4.2 million premature deaths worldwide (WHO, 2016). The high percentage of these deaths, which were estimated at 91% from LMICs, South-Eastern Asia and Western Pacific regions where the effects were more pronounced due to rapid increase in industrialization in recent years (WHO, 2016). Sources of outdoor air pollution are mainly as a result of industrial emissions and unmaintained vehicle engines such as those of the heavy commercial vehicles. This results in release of CO and BC into the environment (Ndwiga *et al.,* 2014).

According to the study done by Shilenje *et al.* (2015) in Athi River Township on ambient air quality using gas analyzers and samplers mounted on a Mobile Air Monitoring Laboratory van, the concentration for the pollutants were higher than that of WHO ambient air quality standards. The study was conducted over a 24-hour period and the mean for $PM_{2.5}$ was found to be 30.74 $\mu g/m^3$ higher than that of the WHO ambient air quality of 15 $\mu g/m^3$. The BC concentration was also high. The elevated levels of these pollutants were generally attributed to the high number of cement industries in the area (Shilenje *et al.,* 2015). Ambient air pollution was also increased due to the incomplete combustion of fuels which caused the release of BC and CO from unmaintained vehicle engines.

A case study done to assess traffic impacts of $PM_{2.5}$ on ambient air quality in Nairobi city using portable air samplers revealed an elevated $PM_{2.5}$ levels on the high traffic roadways. The average$PM_{2.5}$ mean levels was 98.1 $\mu g/m^3$ on the roadsides in the central business district, This was due to the emissions from the vehicle exhausts and the dust particles, which poses a great concern on the human health and environment (Kinney, 2011).

2.2 Determination of Outdoor and Indoor Air Pollution

The determination of pollutants in the air is important in the exposure assessment and epidemiological studies. The commonly used methods are the use of optical and electrochemical sensors, active and passive air sampling. Gaseous pollutants such as CO, NOx, ozone and SO_2 are measured using continuous in-situ air monitors for hourly average concentrations. The

airborne particles are usually sampled using a fused sampling unit with defined inlets and include impactors, filter holders or substrates pumps and flow meters. The filter or substrate are used to determine the deposited mass of $PM_{2.5}$ and PM_{10} using the gravimetric method which is the gold standard for PM measurements.

2.2.1 Active Air Sampling

This is a sampling technique which incorporates sampling pump that draws air from the environment. It also integrates size selective impactor inlets for different size of PM such as $PM_{2.5}$ and PM_{10}. This method has a capability of capturing the particulate matter on a filter paper such as polytetrafluoroethylene (PTFE) filters which can further be analyzed for their composition such as heavy metals and ions. The flow rate for this method is usually in the average of millimeters per minute for gases and liters per minute for particulates. They are usually validated using a calibrator designed for the purpose. It is an effective method since large samples can be collected over a short period of time.

2.2.2 Passive Air Sampling

This method is primarily used to sample gases and vapor such as NO_2, O_3 and VOCs in the environment. It is also called diffusive sampling since it relies on the natural diffusion of air and does not require a pump to draw in the air. It is therefore suitable for long-term sampling The sample substrates, polyurethane foams (PUFs), which are often used are exposed for a certain period of time before they are analyzed. This method is only limited to gaseous pollutants and has low precision as compared to active air sampling.

2.2.3 Optical Air Sensors

This method of air sampling uses low-cost sensors in determination of PM concentrations. The sensors give the real time levels of PM over a given period of time. This method employs use of scatter light to detect the particles in the air. The intensity of the scattered light that is infrared or red light due to interaction with particles is equated to the particle concentration, which is based on the number of particles. The disadvantage of this method is that the sensors degrade with time hence less accuracy. Figure, 2.1 is the design of an optical sensor.
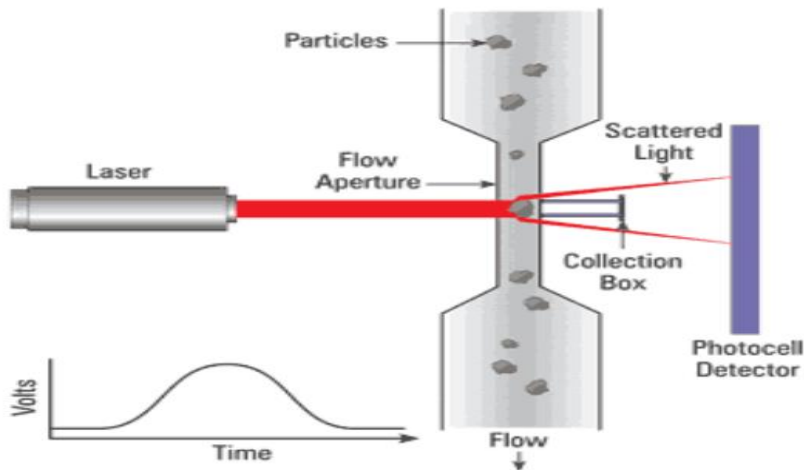
Figure 2. 1: Schematic diagram of an optical sensor for PM$_{2.5}$ sampling
Source: Badura et al., 2018

2.2.4 Electro-chemical Sensor

The electro-chemical sensor is commonly used to determine CO levels in the air for example, the portable lascar CO monitor. An electrochemical sensor schematic diagram is as shown in Figure 2.2.
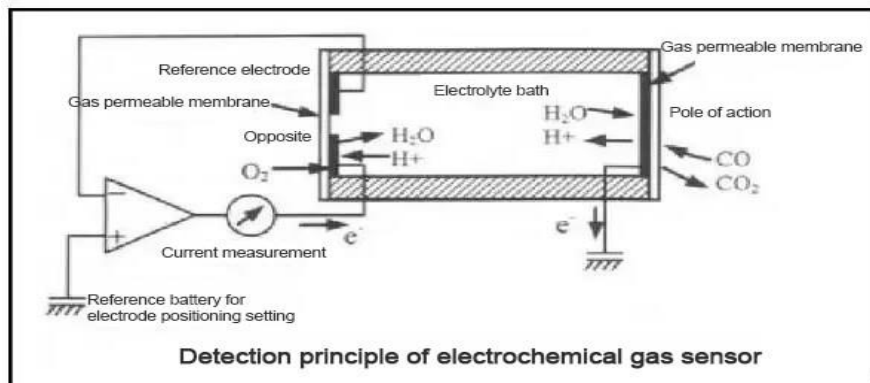
Figure 2. 2: Schematic diagram of an electrochemical CO sensor
Source: Afshar-Mohajer et al., 2018

A fixed voltage is basically applied on the negative and positive electrodes of the electrolytic cell. The reaction usually takes place on the working and the counter electrodes. These half-cell reactions on the electrodes are as follow;

Pole of action: $CO + H_2O \longrightarrow CO_2 + 2H^+ + 2e$

Opposite: $\frac{1}{2} O_2 + 2H^+ + 2e^- \longrightarrow H_2O$

Overall Reaction: $CO + \frac{1}{2} O_2 \longrightarrow CO_2$

From the overall reaction, CO is essentially oxidized to CO_2 and the electrons flow forms an external current, and the charge balance is completed by carriers flow in the electrolyte. The current produced is proportional to CO concentrations. The output signal has also a positive linear correlation with the CO concentration.

2.3 Air Pollution and Human Health

Air pollution has deleterious effects on both human health and the environment. Several studies have been conducted correlating air pollution and health effects. The health risks due to air pollution include acute respiratory infections (ARIs) as a result of frequent use of unclean cooking household fuels. Chronic obstructive pulmonary disease, pulmonary tuberculosis, lung cancer, cataracts, perinatal and infant mortality, low birth weights, nasopharyngeal and laryngeal cancer have also been reported (Sun & Zhu, 2019).

2.3.1 Respiratory Illness

There are various respiratory diseases caused by air pollution which include chronic obstructive pulmonary disease (COPD), asthma, tuberculosis, cancer and pneumonia.

2.3.1.1 Chronic Obstructive Pulmonary Disease

Chronic obstructive pulmonary disease is a prolonged inflammatory lung disease that blocks airflow in the lungs. Its symptoms include shortness of breath, chronic cough, mucus production, and wheezing. It is experienced all over the world both in high-income countries (HICs) and low-income countries (LICs). In fact, Ko & Hui (2012) had estimated that by 2020, the COPD would be ranked as a fourth or fifth burden of diseases that causes mortality. Air pollution has been considered as the main attributable factor to this burden globally. Cigarette smoking alone is estimated to cause 80% of COPD cases in the developing countries although it may not be the only contributory factor of the diseases (Bruce *et al.,* 2000). In Nepal, Pakistan and Ladakh, chronic bronchitis was more pronounced in both men and women due to smoking and frequent

use of biomass for cooking (Bruce *et al.,* 2000). A cross-sectional study done in China and the USA on passive smoking of population of over 50 years of age reported chronic bronchitis, emphysema, or COPD among the population(Lamprecht *et al.*, 2011).

2.3.1.2 Asthma and Tuberculosis

Asthma is a condition where human air tracts are inflamed, becomes narrow, and swell accompanied by the production of excess mucus leading to shortness of breath (Perez-Padilla *et al., 2008)*. There have been reports that links asthma with smoking and biomass burning that resulted in allergic conditions (Perez-Padilla *et al.,* 2008*)*. Recent studies showed that asthma is more prevalent in children below the age of 5 years (Perez-Padilla *et al.,* 2008*)*. A case study done in Turkey that used spirometry for asthmatic patients showed that coal fuel users had a high rate of coughing during day and night as compared with those who mainly used wood fuel for cooking (Perez-Padilla *et al.,* 2008*)*. A case-control study in Nairobi for school-going children found increased exposure to wood smoke in asthmatic children (Mohamed *et al.*, 1995*)*. In addition, an investigation in rural Nepal, the odds ratio of 2.3 for asthmatic people who frequently used wood fuels were found to be high compared to those who used liquefied petroleum gas (LPG) for cooking (Bruce *et al.*, 2000).

Tuberculosis coupled with air pollution have had a great impact on public health although the correlation between the two remains uncertain (Blount *et al.,* 2017). There is also evidence of the risk of active tobacco smoking and contracting TB leading to increased mortalities (WHO, 2016). A study done in California, USA, that was characterized by unhealthy ambient air showed that 25% of all TB cases usually occur in the country (Blount *et al.,* 2017). The risks associated with active TB patients and air pollution was established to be high and this was caused by the traffic air pollution and high concentration of $PM_{2.5}$ (Blount *et al.,* 2017).

2.3.1.3 Cancer

Exposure to air pollution poses a high risk of cancer and there is robust epidemiological evidence linking cancer to air pollution. The findings from several studies e showed that there is a high risk of developing cancer among the communities that frequently use biomass for cooking (Kim *et al.,* 2011). The International Agency for Research on Cancer (IARC) recently termed biomass

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smoke as a number one carcinogen. Research done in India and Mexico to investigate the health risk of cigarette non-smoking women on long-term exposure to biomass cooking smoke showed that there was the development of adenocarcinoma of the lung (Fullerton *et al.,* 2008).

Moreover, studies in the US showed a relationship between air pollution and cancer risks and mortalities. In California, a 15-year cohort study on 6,338 non-cigarette smoking adults who were exposed to air pollutants such as particulate matter, sulphur (IV) oxide, and ozone had a high risk of developing cancer although $PM_{2.5}$ levels was not included which is regarded as more harmful (Wong *et al*., 2016). A case study done in Canada to establish the relationship between the long-term exposure to ambient fine particulate matter and lung cancer for the non-cigarette smokers revealed that for every 10 ug/m^3 of the particulate increase, there was a significant rise in cancer mortality rates by about 15-27 % (Turner *et al.,* 2011).

2.3.1.4 Pneumonia

The study was done to establish the relationship between air pollution on hospitalized children suffering from pneumonia. The confidence limits were established using carbon (II) oxide, particulate matter ($PM_{2.5}$ and $PM_{10,}$) ozone, sulfur dioxide, and nitrogen dioxide. A positive association was observed between ambient air pollution and the children who had been hospitalized for Pneumonia (Nhung, 2017). Similarly, the research that was done in Utah by Pirozzi *et al.* (2018) involving the evaluation of 4,336 pneumonia cases in seven hospitals showed a consistent positive correlation between $PM_{2.5}$ levels and the elderly population of greater than 65 years. These pollutants were also high in concentrations during the cold months and the reduction of these levels greatly decreased the prevalence levels of Pneumonia (Pirozzi *et al.,* 2018).

2.3.2 Non-Respiratory Illness

Although respiratory cases due to air pollution are more common it should be pointed out that there are also cases of non-respiratory illness such as low birth weights in children as a result of air pollution. There has been reported relationship between exposure to air pollutants especially carbon (II) oxide, and low birthweights in infants. For instance, a study carried out in Guatemala showed that the weight of newborn babies was influenced by the type of household cooking fuels

that was commonly used. Infants whose mothers were using wood fuels were found to be 63 g lower than those using clean fuels such as electricity and LPG. Similar findings were also observed in Zimbabwe, Ecuador, and the Czech Republic. The health effects were even higher when mothers were exposed to high levels of $PM_{2.5}$ (Kim *et al.,* 2011).

The cohort study by Pedersen *et al.* (2013) was established on the exposure to air pollutants among 74,178 smokers and non-smokers women during pregnancy. Results showed that a large population of infants born to non-smoking mothers that were exposed to particulate matter of 5 µg/m^3 above the recommended limits had low birth weights. The health effects were more adverse for the smoking mothers than infants. Pedersen et al., (2013) further observed the reduction of $PM_{2.5}$ levels to 10 µg/m^3 resulted in a significant decrease in the number of cases of low birthweights by 22%). The same trend was reported in the 22 countries in Africa, Asia, and Latin America (Fleischer *et al.*, 2014).

CHAPTER THREE
3. MATERIALS AND METHODS

3.1 Introduction

The study commenced between May and December 2021 after obtaining the necessary authorizations of the clearance research permit from the National Commission for Science, Technology and Innovation (Appendix IX). Approvals were further obtained from the relevant Sub County authorities. The study was subsequently set to determine $PM_{2.5}$, and CO levels in the ambient and indoor air in Mukuru informal settlements. This was carried out during the dry and rainy seasons (Appendix IV) and the levels were compared with those of the control. The prevalence levels of the respiratory diseases in the communities were also evaluated during the same period.

3.2 Research Design

The study was a cross-sectional that involved a walk-through survey and mapping of the sampling sites to identify the potential sources of air pollution in Mukuru informal settlements in Nairobi County. The $PM_{2.5}$ and CO were sampled from household and ambient air in Mukuru informal settlements and the control site during the dry and rainy seasons. Prevalence levels of respiratory diseases were also determined from the Mukuru community health facilities and was compared with those from the control during the same period (Appendix I). The meteorological conditions that had influence on the $PM_{2.5}$ and, CO were further assessed.

3.3 Study Area

The study sites with diverse sources of pollution were selected within the densely populated area of Mukuru Slum (Ondayo *et al.,* 2016). The slum is geographically located at a latitude of 1.3213° S and a longitude of 36.8842° E as shown in Figure 3.1 with a population of 385,056 resulting from a population density of 110,326 per square kilometer (KNBS, 2019). It is situated in the Eastern side of Nairobi City along the largest industrial hub, Nairobi Industrial Area in Kenya. The slum is majorly subdivided into three sections (Mukuru Kwa Njenga, Mukuru Kwa Reuben and Kayaba) and consists of nine villages namely Mukuru Kwa Reuben, Sinai, Kayaba, Paradise, Kingstone Jamaica, Fuata Nyayo, and Mariguini.

The area is endowed with seasoned climate change with no myriad variations since Nairobi is close to the equator. Dry and wet seasons are largely experienced from December to March, and August to November, respectively (Kariuki, 2018), The Mukuru slum is congested with temporal housing structures that are characterized by poor sanitation and inadequate ventilation (Muindi *et al*., 2016). The road networks within the area are also poorly constructed and are mainly unpaved. In addition, there are undefined waste management systems with open burning of garbage posing threats to human health including respiratory diseases that are managed within the Community Health Centers. Majority of the people in this community have limited resources and solely depends on charcoal and kerosene as their main source of fuel hence exposing themselves to various pollutants (Muindi *et al*., 2016).
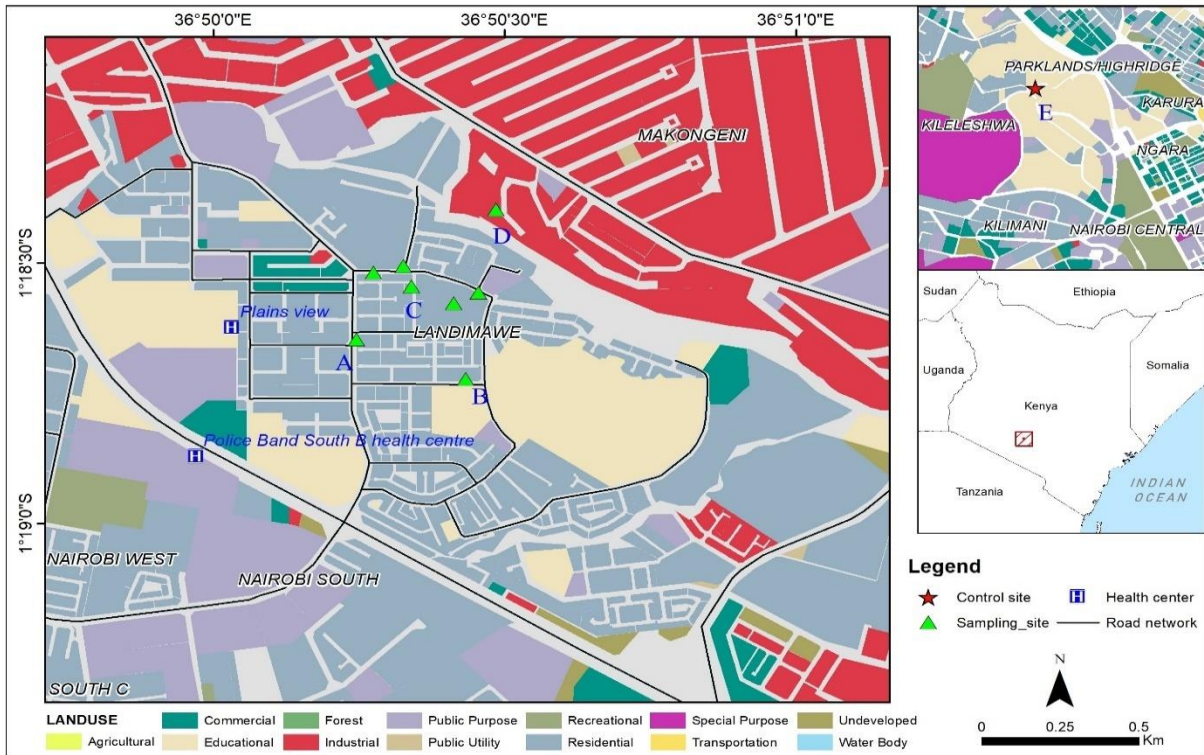
Figure 3. 1: A map of the study area of Mukuru slums and the control site
Source: Base Layer, Open Street Map, 2022

3.4 Selection of the Sampling Sites

The selection of sampling points for the indoor air pollution or household sites was mainly based on the types of cooking fuels that was used. On the other hand, the outdoor air pollution sites were chosen in the context of their close proximity to the potential sources of pollution. The

security of the sampling equipment was also put into consideration when choosing the outdoor sampling sites. These sites were: South B Total Gas Station with the latitude -1.30843° S and a longitude of 36.83881° E, South B Garage with latitude of -1.31205° S and a longitude of 36.8406° E, Mukuru Kayaba was located at a latitude of -1.30908° S and a longitude of 36.83904° E and Land Mawe Police Station with a latitude of -1.30663° S and a longitude of 36.84147° E coded as A, B, C, and D, respectively. The sampling sites together with different forms of land use are as shown in the Figure 3.1. In addition, University of Nairobi, Chiromo Campus was chosen as a control site coded E with coordinates of -1.27381° S and 36.80732° E.

3.4.1 Description of Sampling Sites

The descriptions of both household and outdoor sampling sites coded A-D are as follows;

3.4.1.1 Site A

This site was in close proximity to the largest Industrial Area, Nairobi, neighboring residential areas and commercial centers (Figure 3.2). The common sources of ambient air pollution that were observed on the site were vehicular exhaust, loose suspended dust particles from the unpaved road and occasional open burning of wastes on the road sides.

Figure 3. 2: Outdoor Sampling Site A, the Total Petrol Station
Photo taken by Author-Vincent Kipter

The selected household sampling site A was about 100 meters adjacent to the Total Petrol Station. The house structure was small with no window to allow natural ventilation and with only one door which was closed most of the time. Due to limited space, cooking activities and sleeping area were under one room. The common source of cooking fuel was the paraffin stove (Figure 3.3).

Figure 3. 3: Household Sampling Site A (Cooking Fuel was Paraffin stove)
Photo taken by Author-Vincent Kipter

3.4.1.2 Site B

The outdoor sampling site was a Garage that was neighboring the residential areas (Figure 3,4). The major sources of air pollution observed in the area were open burning of wastes, loose suspended dust particles from unpaved road, car exhaust fumes and paint aerosols that emanated from the garage.

Figure 3. 4: Outdoor Sampling Site B in the Garage
Photo taken by Author-Vincent Kipter

The household sampling site B was about 50 meters from the outdoor sampling site B (Garage). The house had small space with only one window and a door with limited ventilation. Cooking was done in the living room using charcoal as the main source of fuel (Figure 3.5).

Figure 3. 5: Household Site B using Charcoal as the main Source of Fuel
Photo taken by Author-Vincent Kipter

3.4.1.3 Site C

The outdoor sampling site was within the Mukuru residential areas in close proximity with the Industrial Area, Nairobi. The sources of air pollution that were observed in the area were suspended dust particles from the unpaved roads, open cooking on the roadside using wood fuels, and uncontrolled open burning of wastes (Figure 3.6).

Figure 3. 6: Outdoor Sampling Site C adjacent to Industrial Area, Nairobi
Photo taken by Author-Vincent Kipter

The household sampling site C was similar to the household sampling site B that used similar fuel for cooking and same house structure (Figure 3.7).

Figure 3. 7: Household Site C using Charcoal as the main Source of Fuel
Photo taken by Author-Vincent Kipter

3.4.1.4 Site D

The outdoor sampling site D was the Police Station within the Industrial Area, Nairobi. The sources of air pollution observed were vehicular exhaust fumes, loose suspended dust particles from the unpaved road and industrial emissions (Figure 3.8).

Figure 3. 8: Outdoor Sampling Site D_ Police Station within the Industrial Area, Nairobi-Kenya;
Photo taken by Author-Vincent Kipter

The household sampling site D was situated close to the Police Station about 100 meters adjacent to the industrial area. The house structure was stone walled with only one window and cooking was done in the living room. The major sources of fuel for cooking were Liquid Petroleum Gas (LPG) and charcoal (Figure 3.9).

Figure 3. 9: Household Sampling Site D using LPG gas for Cooking
Photo taken by Author-Vincent Kipter

3.4.1.5 Control Site E

The University of Nairobi, Chiromo Campus was selected as the control sampling site (Figure 3.10). It was far from any known sources of air pollution compared to the sampling sites in Mukuru informal settlement. The outdoor sampling site E was an open space at Chiromo while the indoor was a room within the Chiromo Campus with no activities. There was however, ongoing construction of Nairobi Express Way during the sampling periods.

Figure 3. 10: Control Site E Outdoor and Indoor Set Ups
Photo by Author-Vincent Kipter

3.5 Collection of PM$_{2.5}$, Carbon (II) Oxide and Meteorological Parameters

Samples of particulate matter (PM$_{2.5}$) and CO as well as prevailing meteorological conditions were collected as follows;

3.5.1 Collection of PM$_{2.5}$

PM$_{2.5}$ was collected from the indoor and outdoor air of the Mukuru sampling sites A-D and the control site E for three consecutive days over the 24-hour period. They were collected using a Harvard Impactor sampler equipped with an inlet size-selective for PM$_{2.5}$ with an aerodynamic diameter of less or equal to 2.5 µm. This was done using pre-weighed Polytetrafluoroethylene (PTFE) with a pore size of 2 microns and a diameter of 37 mm. The filter papers were pre-conditioned for 4 weeks in the gravimetric laboratory before pre weighing at the temperature between 20 and 25 ^{o}C and percent relative humidity (RH%) ranging from 45-60 (Appendix V). This was necessary to stabilize the weights of filter papers. During collection of PM$_{2.5}$, the height

of the sampler was placed at an average human breathing zone of about 1.8 meters. The flow rate of the air sampler was maintained throughout the sampling period. After sampling, the loaded filter papers were then removed from the impactor using forceps and stored in separate petri dishes and then post conditioned for 3 days. They were then post weighed using semi micro-balance in the gravimetric laboratory.

3.5.2 Collection of Carbon (II) Oxide

The carbon (II) oxide (CO) was collected from the household and ambient air of the Mukuru sampling sites A-D and the control site E for three consecutive days over the 24-hour period. This was done using the Lascar CO portable electrochemical sensor (Figure 3.11) during the dry and the rainy seasons. The data sets were then stored automatically by the Lascar monitor.

Figure 3. 11: Lascar CO monitor.

3.5.3 Collection of Meteorological Elements

The prevailing meteorological conditions were also collected on three consecutive days for a period of 24 hours during the rainy and dry seasons. This was achieved using the mobile application for wind speed and direction as well as the onset HOBO monitor for temperature and RH (%) as shown in Figure 3.10. The data sets were automatically stored by the HOBO Monitor.

Figure 3. 12: HOBO temperature and humidity logger

3.6. Gravimetric Analysis of PM$_{2.5}$

PM$_{2.5}$ concentrations were obtained by the difference in weights of post-conditioned filters after sampling and the pre-conditioned filter papers before sampling using gravimetric methods of analysis.

3.6.1 Determination of PM$_{2.5}$ Levels

The concentration of PM$_{2.5}$ were determined using the Equations 1, 2 and 3. Equation 1 was used to determine the mass of PM$_{2.5}$ collected on PTFE filter paper in micrograms.

$M_{2.5} = (M_f-M_i) \times 10^6$…………………………………………………..Equation 1.

Where;

$M_{2.5}$ =Total mass of particulate matter (micrograms).
M_f = mass of the conditioned filter after sample collection (g).
M_i =mass of conditioned filter before sample collection (g).
10^6=Unit conversion factor for grams (g) to micrograms.

The equation 2 was used to determine the volume of the air passing through the sampler in cubic meters.

$V = Q_{avg} \times t \times 10^{-3}$ ………………………………………………….....Equation 2.

Where;

V= total sample volume per cubic meter.

Q_{avg} = average flow rate of the entire sampling period.

t= duration of the sampling period (min).

The 10^{-3}= unit conversion factor for liters into cubic meters.

PM$_{2.5}$ concentrations was therefore, reported as µg per m^{3}of air using equation 3

$PM_{2.5} = M_{2.5} /v$ …………………………………………………Equation 3

3.7 Quality Assurance and Control

Quality assurance and control during the sampling period and analysis was necessary for reliability and accuracy of the results. The following measures were therefore considered:

- Filters were conditioned before and after sampling. This was carried out in the Gravimetric Laboratory with the temperature maintained at 20-23 °C and relative humidity at 30-40% as per the United States Environmental Protection Agency guidelines (US EPA, 2016). This assisted in the weight stabilization of the filters (Appendix V).

- The flow rate of the air sampler was maintained at 1.8 ± 0.36 l/min throughout the sampling period.

- Field blank filters were used during sampling to assess any contamination of the primary filters from field conditions to minimize errors (Appendix VI).

- The equipment used during sampling were regularly maintained and calibrated to minimize related errors.

3.8 Incidences of Respiratory Diseases

The study considered the residents of Mukuru slums and those of the control site who sought outpatient services for various respiratory diseases in Mukuru and a control community health center during the dry and rainy seasons (Appendix 1). The Mukuru health facilities were: Nairobi Remand Prison, South B Police Band, Nairobi South B and St. Catherine which were coded as A, B, C and D respectively. The University of Nairobi, Chiromo Campus health center coded E was considered as a control. The respiratory health data that included asthma, upper respiratory tract infections, tuberculosis and pneumonia were then manually retrieved from the community health register (Appendix I). The prevalence levels of respiratory diseases (%) at each community health center (A-E) was expressed as the total number of outpatient cases with respiratory diseases over the total number of outpatients who visited the health facility times 100. The percentage (%) prevalence levels of respiratory diseases in Mukuru slums (A-D) and control community (E) were subsequently compared during the dry and rainy seasons.

3.9 Data Analysis

The results from this study were analyzed using Microsoft excel and Statistical Package for Social Scientists (SPSS version 26). The stored data sets of CO concentration that were taken in 5 seconds intervals over a 24-hour period for three consecutive days during the rainy and dry seasons were downloaded from the portable lascar CO monitor and analysed (Figure 3.11). The data obtained were therefore reported as mean ± standard deviation (SD) parts per million (ppm)

with their corresponding graphical CO peaks (Appendix VII and VIII). In addition, $PM_{2.5}$ concentrations were evaluated with the set WHO ambient air quality guideline of 15 µg/m^3 (WHO, 2021) while CO levels were evaluated using WHO 2010 and 2016 guidelines levels of 6.1 and 3.5 ppm for both indoor and outdoor setups, respectively. It should however be noted that there are no national air quality guidelines for indoor $PM_{2.5}$ levels. The resulting $PM_{2.5}$ and CO concentrations during the dry and rainy seasons were also compared using a t-test at a significant value of $p<0.05$. Furthermore, the 24-hour average outdoor $PM_{2.5}$ and CO concentrations were correlated with temperature and relative humidity during the dry and rainy seasons using regression analysis. The prevalence levels of respiratory diseases of Mukuru and control communities during the dry and rainy seasons were also compared.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Outdoor PM$_{2.5}$ Levels during the Dry and Rainy Seasons

Table 4.1 presents the outdoor PM$_{2.5}$ levels (μg/m^3) sampled for three consecutive days at each of the selected sites A, B, C, and D of the densely populated Mukuru slum and control site E over the 24-hour average period during the dry and rainy seasons. The possible sources of ambient PM$_{2.5}$ levels as a result of different activities within the Mukuru informal settlement and control site are also presented.

Table 4. 1 Outdoor PM$_{2.5}$ levels (µg/m^3) and their possible sources in Mukuru slum and control site sampled for three consecutive days over the 24-hr period during the dry and rainy seasons.

Sampling Sites			Possible sources of ambient PM$_{2.5}$ levels	Outdoor PM$_{2.5}$ levels (µg/m^3) during the dry season			Mean ± SD (µg/m^3)	Outdoor PM$_{2.5}$ levels (µg/m^3) during the rainy season			Mean ± SD (µg/m^3)
				Day 1	Day 2	Day 3		Day 1	Day 2	Day 3	
Mukuru Informal Settlement		A	Vehicular exhaust fumes, unpaved roads and open burning of wastes	41	33	23	32±9.0	38	28	57	41±14.7
		B	Open burning of garage waste and vehicular exhaust fumes	13	17	20	17±3.5	26	20	19	22±3.8
		C	Unpaved roads, roadside cooking and Open burning of wastes	58	40	51	50±9.1	28	39	20	29±9.5
		D	Vehicular exhausts fumes, industrial emissions and open burning of wastes	56	77	36	56±20.5	53	64	50	56±7.4
Range of PM$_{2.5}$ levels (µg/m^3)				13-77				20-64			
Overall mean ± SD PM$_{2.5}$ levels (µg/m3)				39 ± 17.7				37 ± 14.9			
Control site		E	Open field with no known activities, except for the expressway that was under construction, 100 m away from the site	20	12	30	21±9.0	15	27	21	21±6.5

±SD = standard deviation from the mean

4.1.1 Outdoor PM$_{2.5}$ Concentrations during the Dry Season

From Table 4.1, the ambient PM$_{2.5}$ levels ranged from 13 to 77 µg/m^3 with an overall mean ± standard deviation (SD) of 39 ± 17.7 µg/m^3 of the sampled sites A, B, C, and D of Mukuru informal settlement over the 24-hour average period during the dry season. On the other hand, the control site had PM$_{2.5}$ levels that ranged from 12 to 30 µg/m^3 with a lower mean value of 21 ± 9.0 µg/m^3 during the same period. However, the overall means of ambient PM$_{2.5}$ levels between Mukuru and the control sites were not statistically different (t (5) =1.592, p=0.172 >0.05). The level of PM$_{2.5}$ from the control site could have been as a result of the construction activities of the Nairobi express way and the Uhuru highway that were 100 meters away from the site during the sampling period.

The high overall mean of PM$_{2.5}$ levels that was found in Mukuru slum could be attributed to several pollution sources that included vehicular exhaust fumes, open burning of wastes, open cooking along the roadsides and industrial emissions. The findings of our study is comparable to a study conducted in a densely populated slums in India that reported a mean PM$_{2.5}$ level of 41 ± 25 µg/m^3 during the dry season (Anand & Phuleria, 2021). The elevated levels of PM$_{2.5}$ were also due to high traffic near the slums and the open burning of waste materials within these areas.

Within the Mukuru slum, site D contributed the highest mean PM$_{2.5}$ concentration of 56 ± 20.5 µg/m^3 with a range of 36 to 77 µg/m^3. The elevated levels observed in site D were probably as a result of the several sources of emissions and included the site being in close proximity to the busy traffic road that was about 30 meters away. Additionally, the site was situated within the industrial emissions zones. A study done by Huang *et al*. (2018) showed that vehicular exhaust fumes and suspended particles largely contributed to the PM$_{2.5}$ concentrations by about 9%–19%. Another study was done in Beijing, China on the spatial distribution of PM$_{2.5}$ and categorized industrial emissions as one of the critical sources that contributed to air pollution (Huang *et al.,* 2018).

For site C, which had a mean PM$_{2.5}$ concentration of 50 ± 9.1 µg/m^3 that ranged from 40 to 58 µg/m^3 had also many emission sources. The sources included, open cooking on the roadsides, open burning of household waste, and suspended dust from the unpaved roads. Similar

observations were reported by Egondi *et al.* (2016), who carried out the study in the slums of Nairobi. Site A had a mean $PM_{2.5}$ level of 32 ± 9.0 µg/m^3 in the range of 23 to 41 µg/m^3. This level is attributable to the exhaust fumes that were emanating from the vehicles that were passing through the Petrol Filing Station. In addition, the open burning of waste and tyres on the roadsides, and dust re-suspensions from unpaved roads also contributed to $PM_{2.5}$ levels that was reported. Nonetheless, site B had the lowest mean $PM_{2.5}$ level of 17 ± 3.5 µg/m^3 with a range of 13 to 20 µg/m^3. The contributory factors included minimal and occasional emission activities, such as spray painting and open burning of waste materials. The site had also a slight standard deviation implying that the emissions were consistently lower over the three days sampling period.

4.1.2 Outdoor $PM_{2.5}$ Concentration during the Rainy Season

The ambient $PM_{2.5}$ levels ranged from 20 to 64 µg/m^3 with an overall mean $\pm$ standard deviation (SD) of 37 ± 14.9 µg/m^3 from sites A, B, C and D in Mukuru informal settlement during the rainy season (Table 4.1). The same trend was observed in the Mukuru slum during the rainy season as that of dry season, where the overall mean $PM_{2.5}$ concentrations was higher than that of the control site. There was also no significant difference (t (5) =1.781, p=0.135 >0.05) between the overall mean $PM_{2.5}$ levels in Mukuru and those in the control site. These results are consistent with a study that was done in Mumbai's densely populated community, where a mean concentration of 125 ± 46 µg/m^3 was reported during the rainy season. This was majorly as a result of the heavy- vehicles and traffic congestion (Anand & Phuleria, 2021). Further, the control site had $PM_{2.5}$ levels that ranged from 15 to 27 µg/m^3 with a mean value of 21 ± 6.5 µg/m^3.

Furthermore, there were variations in the mean $PM_{2.5}$ levels across the sampling sites during the rainy season. The site A had a mean concentration of 41 ± 14.7 µg/m^3 ranging from 28 to 57 µg/m^3 whereas B had a mean of 22 ± 3.79 and a range of 19 to 26 µg/m^3, and D had a mean $\pm$ SD of 56 ± 7.4 µg/m^3 that ranged from 50 to 64 µg/m^3 during the rainy season. Nonetheless, these levels were not significantly different (p>0.05) from those of the dry season. This could be because of the same sources of pollution and sampling points during both seasons and prevailed meteorological parameters might have had little impact. For site C it had had a significantly

(p<0.05) lower $PM_{2.5}$ mean concentration of 29 ± 9.54 µg/m^3 ranging from 20 to 39 µg/m^3 during the rainy season than the mean of 50 ± 9.1 µg/m^3 during the dry season. This could have been due to site C not having cooking activities using firewood on the roadsides during the rainy season. The previous studies also revealed high levels of $PM_{2.5}$ during the dry season compared to the rainy season as a result of using firewood to cook along the roadsides (Tian *et al.,* 2021).

4.1.3 Mean Ambient $PM_{2.5}$ levels and the Set Air Quality Limit

Figure 4.1 compares the ambient mean $PM_{2.5}$ concentrations of residential areas in Mukuru slum and control sites that were derived from Table 4.1 with the WHO $PM_{2.5}$ guidelines of 15 µg/m^3 (WHO,2021). The use of WHO air quality guideline for $PM_{2.5}$ was necessitated by the lack of the national regulatory air quality limit for the ambient $PM_{2.5}$ in residential areas.
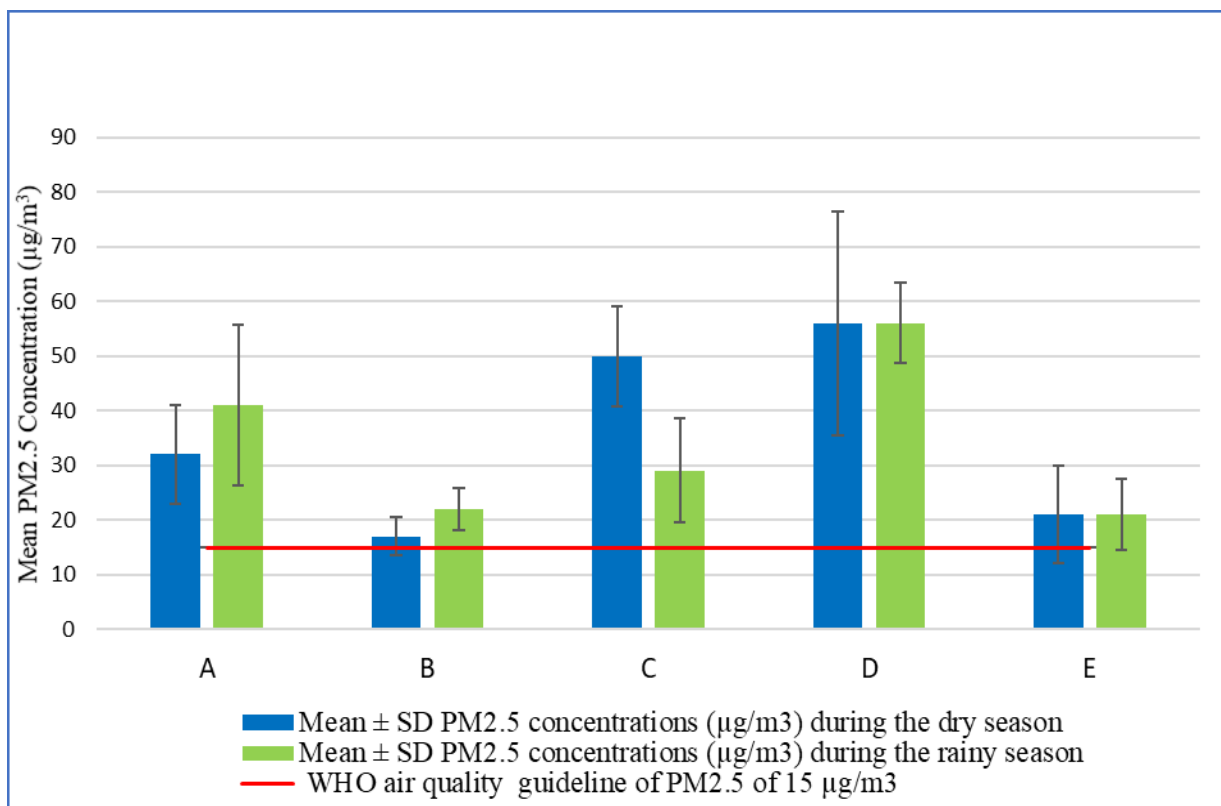

Figure 4.1: Mean $PM_{2.5}$ levels in the Mukuru sites (A-D) and control site E and the WHO air quality guideline of 15 µg/m^3 during the dry and rainy seasons.

All the sampling sites in the Mukuru slum together with those of the control site, had $PM_{2.5}$ mean levels that exceeded the WHO air quality guideline of 15 µg/m^3 over the 24-hr average during

both seasons. The results are not surprising since the exceedance values of $PM_{2.5}$ at the control site for both seasons could have been due to the ongoing construction activities of the Nairobi expressway that was about 100 meters from the site. These activities were observed to release substantial amount of dust into the environment during the sampling period.

In addition, the outdoor $PM_{2.5}$ concentrations during the rainy season were higher than those of the dry season for sites A and B, except for site C. However, the overall means of $PM_{2.5}$ levels for both seasons were not significantly different (t (8) =0.138, p>0.05). In site C, the high concentrations of $PM_{2.5}$ during the dry season could be attributed to increased contributory sources of air pollution such as a high number of open-roadside cooking, uncontrolled burning of waste materials, and resuspension of dust particles from the unpaved roads.

In general, the high values of $PM_{2.5}$ during the rainy season could be caused by the low temperatures, which increased the atmospheric pressure leading to elevated levels of particulate matter in the air. Owing to the high pressure that existed in the atmosphere, $PM_{2.5}$ levels could not be dispersed over a wide area and hence concentrated in the local vicinity, thereby resulting in high concentrations (Xu *et al.,* 2017). In contrast, when the ambient temperatures are high, $PM_{2.5}$ concentrations remain low. This shows that low atmospheric pressure exists when the temperatures are high, thus exhibiting atmospheric instability, which ultimately facilitated the pollutants to disperse widely in the region (Xu *et al.,* 2017).

Similar results were observed in a study done in two socially deprived areas in Nairobi (Korogocho and Viwandani) (Egondi *et al.*, 2016) and another done in Athi River in schools (Were *et al.*, 2020b). The results showed high $PM_{2.5}$ concentrations during the rainy season as compared to the dry season.

4.2 $PM_{2.5}$ Levels and Meteorological Parameters during the Dry and Rainy Seasons

The relationships between outdoor $PM_{2.5}$ concentrations from Table 4.1 and meteorological factors (Appendices II and III) that prevailed were correlated using Pearson Correlation Coefficients. The correlation between $PM_{2.5}$ levels with temperature and relative humidity during the dry and rainy seasons are presented in Figures 4.2-4.5.

4.2.1 Outdoor PM2.5 Level and Temperature during the Dry Season

Figure 4.2 is a scatter plot of the relationship between ambient $PM_{2.5}$ concentrations ($\mu g/m^3$) and temperature over a 24-hour sampling period during the dry season

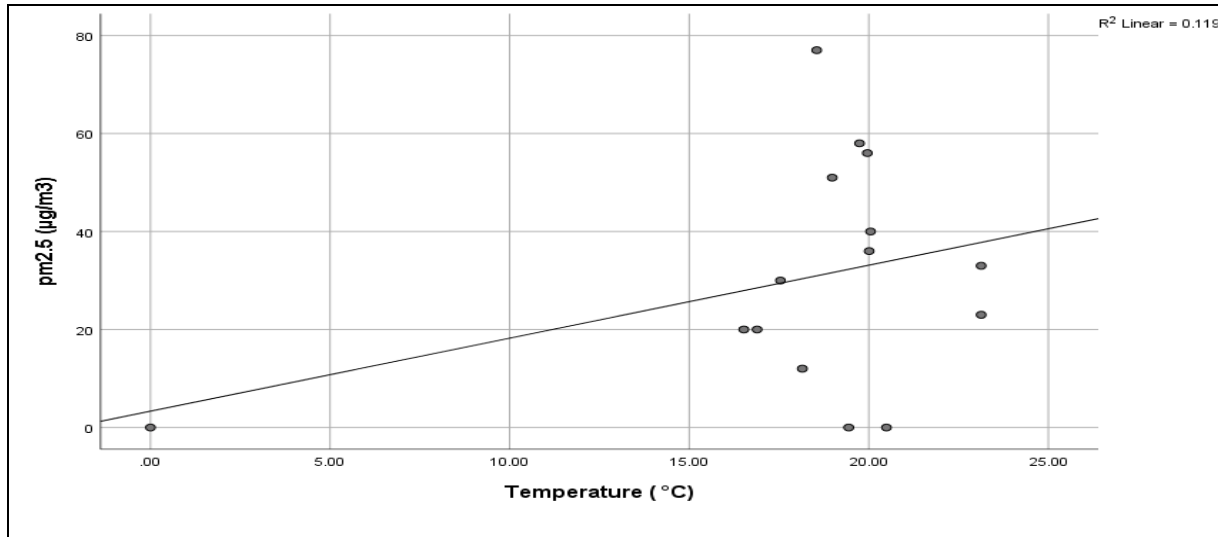Figure 4. 2: Correlation between outdoor $PM_{2.5}$ levels ($\mu g/m^3$) and temperature (°C) during the dry Season

A weak positive correlation coefficient of r=0.303 was observed between the temperature variation and ambient $PM_{2.5}$ levels over the 24-hour sampling period. The results were similar to a study that was carried out in urban areas of China where the correlation between $PM_{2.5}$ concentrations and the latter was positive but weak (Chen *et al.,* 2016).

4.2.3 Outdoor PM2.5 Concentrations and Relative Humidity

The outdoor $PM_{2.5}$ values ($\mu g/m^3$) were correlated with the relative humidity (RH%) during the dry season as shown in Figure 4.3.
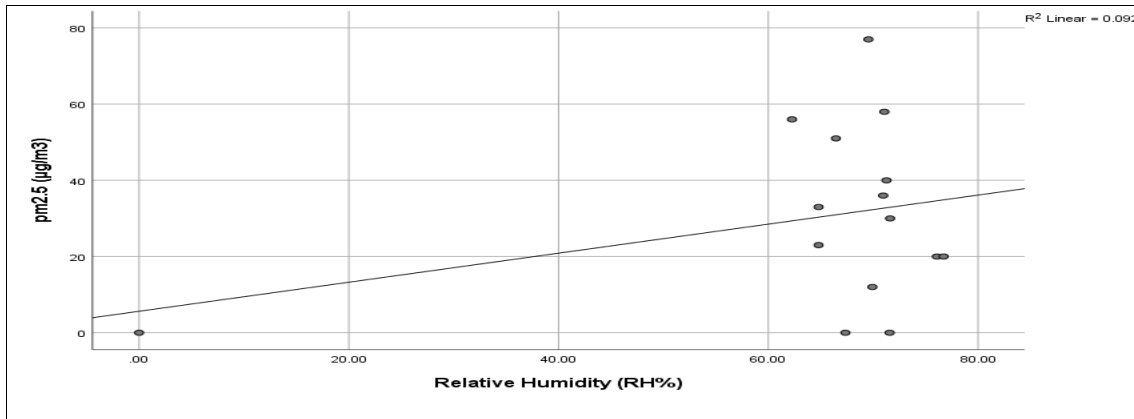
Figure 4. 3: Relationship between outdoor PM$_{2.5}$ levels (µg/m^3) and relative humidity (%) during the dry season

A weak positive correlation of r=0.345 was also observed between the outdoor PM$_{2.5}$ levels and RH %. Our result has revealed that the relative humidity was directly proportional to PM$_{2.5}$ concentrations despite the weak correlation. This suggests that an increase in relative humidity also increases the amount of PM suspended in the air. This is because of the reduced rapid air circulation in the atmosphere.

4.2.4 Outdoor PM$_{2.5}$ Concentrations and Temperature during the Rainy Season

A Pearson correlation analysis was conducted between ambient PM$_{2.5}$ concentrations and variations in temperature over a 24-hour period of sampling during the rainy season (Figure 4.4).
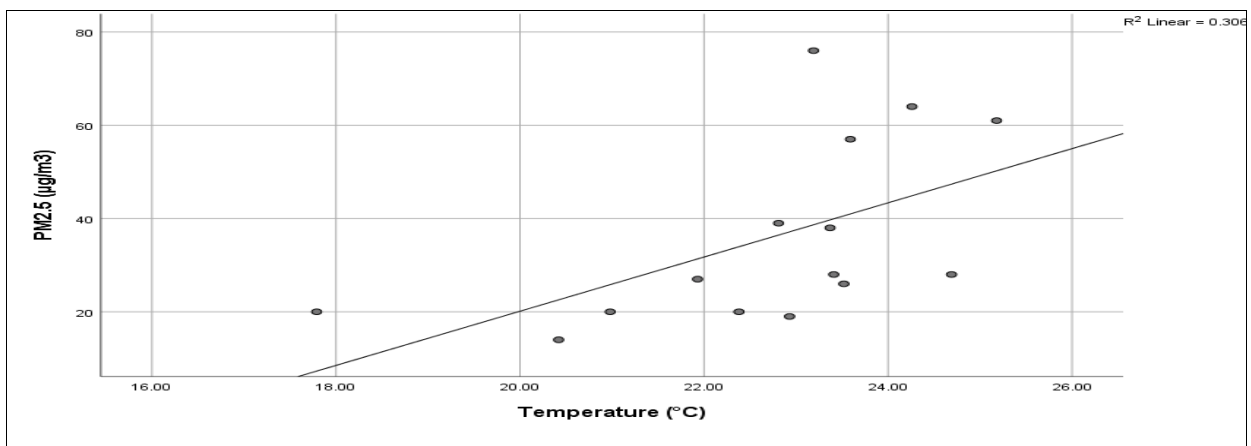

Figure 4. 4: A scatter plot of outdoor PM$_{2.5}$(µg/m^3) with temperature (°C) during the rainy season

The correlation coefficient between the outdoor $PM_{2.5}$ and temperature was positive, r= 0.554. This indicated that an increase in temperature increased $PM_{2.5}$ concentrations. Temperature increases the rate of air diffusion leading to the widespread dispersion of particulate matter (Chen *et al.*, 2020). This consequently affected the concentration of $PM_{2.5}$ in the sampling sites.

4.2.5 Outdoor PM₂.₅ Levels and Relative Humidity during the Rainy Season

Figure 4.5 is a scatter plot showing the correlation between outdoor $PM_{2.5}$ concentration and relative humidity during the rainy season
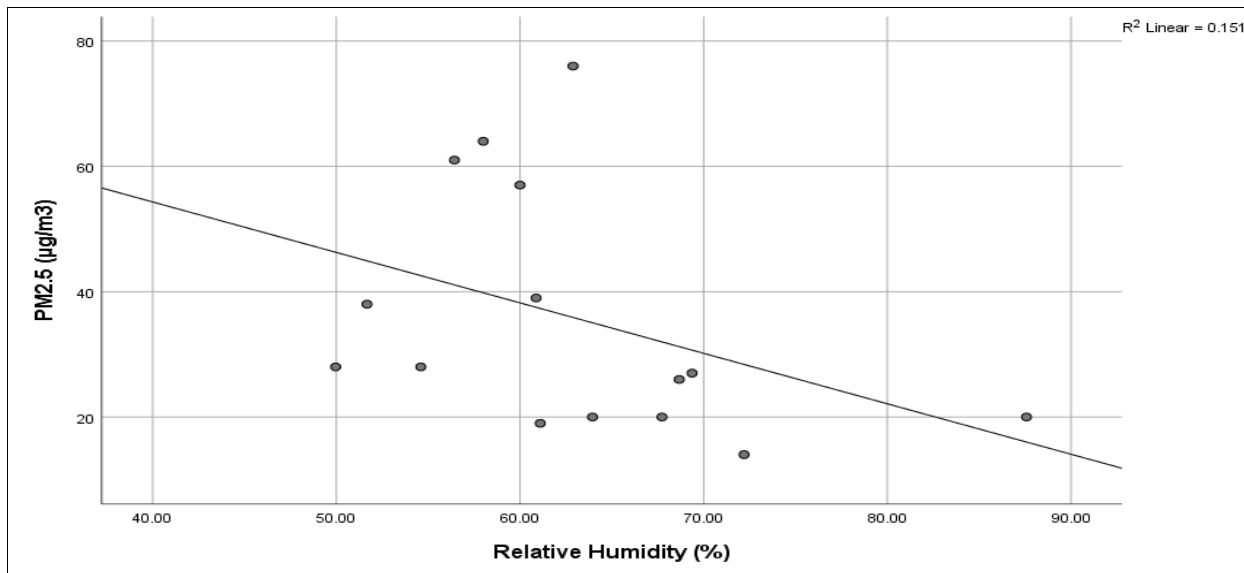

Figure 4. 5: Relationship between the outdoor $PM_{2.5}$ levels ($\mu g/m^3$) and relative humidity (%) during the rainy season

A weak negative correlation of r=-0.389 was observed between the 24-hour averaged relative humidity and outdoor $PM_{2.5}$ levels. The result is in agreement with the study that found a weak negative correlation between $PM_{2.5}$ and relative humidity. This was because of relative humidity that removed atmospheric particulates and reducing the amount of re-suspended dust by making them moist (Akyüz & Çabuk, 2009).

4.3 Indoor PM₂.₅ Concentration during the Dry and Rainy Seasons

Table 4.2 shows the indoor $PM_{2.5}$ concentrations in selected sampling sites A, B, C, and D and the control E during the dry and rainy seasons. The type of household cooking fuel that was commonly used is also presented.

Table 4. 2 PM$_{2.5}$ levels (µg/m^3) and the type of household cooking fuels used in Mukuru slum and control site for three consecutive days over the 24-hour period during the dry and rainy seasons.

Sampling Sites		Types of household fuels used	Indoor PM$_{2.5}$ level (µg/m3) during the dry season			Mean ± SD (µg/m^3)	Indoor PM$_{2.5}$ levels (µg/m^3) during the rainy season			Mean ± SD (µg/m3
			Day 1	Day 2	Day 3		Day 1	Day 2	Day 3	
Mukuru Informal Settlement	A	Kerosene Stove	54	48	48	50±3.5	214	274	149	212±62.5
	B	Charcoal	46	8	13	22±20.6	169	152	101	141±35.4
	C	Charcoal	30	62	61	51±18.3	69	107	50	75±29.0
	D	LPG and Charcoal	111	109	151	124±23.7	117	134	115	122±10.4
Range of PM$_{2.5}$ Levels (µg/m^3)			8-151				50-274			
Overall mean ± SD of PM$_{2.5}$ levels (µg/m^3)			61±43.6				137.5±56.9			
Control site	E	None	30	15	13	19±9.2	27	12	18	19±7.6

± SD= standard deviation from the mean

4.3.1 Indoor PM$_{2.5}$ Concentration during the Dry Season

The overall mean ± SD of indoor PM$_{2.5}$ level was 61 ± 43.6 µg/m^3 and ranged from 8 µg/m^3 to 151 µg/m^3 in Mukuru slum. The elevated concentrations could be attributed to the different types of household cooking fuels. These fuels included charcoal, kerosene stoves, and liquefied petroleum gas (LPG). Studies have categorized efficiencies of these fuels as 20% for charcoal, 30% for wood, 50% for paraffin, and 70% for LPG. The rating of their efficiencies is also inversely related to pollution and health effects (Were *et al.,* 2020). Furthermore, the cooking activities were usually carried out in limited and poorly ventilated areas. This explain clearly why PM$_{2.5}$ levels were significantly (p<0.05) higher in the household compared to the outdoors, which had several sources of pollution. In addition, outdoor infiltration through the wall crevices and openings could have increased the indoor PM$_{2.5}$ concentrations (Hossain *et al.,* 2021). There were lower mean concentrations of 19±9.3 µg/m^3 with a range of 13 to 30 µg/m^3 at the control site compared to the Mukuru sites because there was no activity in the latter site during the sampling period. The former site had a mean concentration that was significantly lower (t (5) =1.619, p=0.016 <0.05) than that of the latter sites.

Similar studies have been done on indoor levels of PM$_{2.5}$, which agrees with the results of our study. The study done by Li *et al.* (2016), found a mean indoor levels of 125 ± 51 and 119 ± 64 µg/m^3 in the kitchen area and the bedroom, respectively, during the dry season. This was as a result of using coal, and LPG for cooking. There was also infiltration of pollutants from outside, which contributed to household air pollution (Li *et al.,* 2016).

The highest levels were recorded in site D with a mean ± SD concentration of 124 ± 23.7 µg/m^3 and a range of 109 to 151 µg/m^3. The concentration from site D could be due to the household using charcoal stove at most times of the day, although LPG was also used. Although the ventilation was natural, the house was a single roomed with only one small window and a door. This hindered the circulation of air, thereby increasing PM$_{2.5}$ concentrations in the limited space over the 24-hour sampling period.

Site C household recorded a mean ± SD concentration of 51±18.3 with a range of 30 to 61 µg/m^3. This was as a result of using charcoal most of the time for cooking in a single unit with

one window. There was hence reduced rate of air circulation within the space, which therefore explains the high levels of $PM_{2.5}$ that were measured. On the other hand, site A recorded a three-day mean $\pm$ SD concentration of 50 ± 3.5 µg/m^3 ranging from 48 to 54 µg/m^3. The household was using a kerosine stove for cooking at least twice a day, and the house structure was similar to that of site C, with no windows but with a small opening on the roof. The concentrations of $PM_{2.5}$ were further higher in site C compared to A possibly because of the different fuels used. Charcoal usage seemed to have high emissions of PM than kerosine stoves. The results were consistent with the study done by Ubuoh and Nwajiobi in Nigeria, where they found that charcoal emitted high levels of $PM_{2.5}$ compared to kerosene stoves (Ubuoh & Nwajiobi, 2018).

The lowest levels of $PM_{2.5}$ were recorded in site B with mean $\pm$ SD of 22 ± 20.6 µg/m^3 and a range of 8 to 46 µg/m^3. On the contrary, lower levels were observed despite the household using charcoal in less ventilated house with similar structure as that of site C. The household was using charcoal less frequently over the period of 24 hours of sampling. The frequency of fuel use seamed to influence the amount of PM released in the house.

4.3.2 Indoor PM$_{2.5}$ Concentration during the Rainy Season
The overall mean $\pm$ SD indoor $PM_{2.5}$ level in Mukuru sites was found to be 137.5 ± 56.89 µg/m^3 with a range of 50 µg/m^3 to 274 µg/m^3. On the other hand, the control site E had a lower $PM_{2.5}$ mean concentration of 19 ± 7.55 µg/m^3 and a range of 12 to 27 µg/m^3. The Mukuru informal household had a higher $PM_{2.5}$ concentrations that was significant (t (5) =3.5, p=0.017 <0.05) than that of the control site. The high indoor $PM_{2.5}$ concentrations in the Mukuru informal settlement households were attributed to the different sources of dirty fuels used in the households and the housing structures that lacked proper ventilation. This resulted in poor circulation of air leading to elevated levels of $PM_{2.5}$. In addition, the infiltration from the outdoor air pollutants, which is a result of the re-suspended dust particles from the unpaved roads, roadside cooking, the uncontrolled waste burning of kitchen waste materials, and vehicular exhaust fumes from the nearby busy roads also played a role in indoor pollution (Pokhrel *et al.*, 2015).

A study done in Nepal to compare the levels of $PM_{2.5}$ emitted by different sources of fuels in household kitchens had a similar trend as that of our study, reporting a high $PM_{2.5}$ concentrations

that was influenced by the type of fuel used. They reported a mean household $PM_{2.5}$ concentrations of 656 ± 924 µg/m^3 from biomass, 169 ± 207 µg/m^3 from kerosene, 101 ± 130 µg/m^3 from LPG, and 80 ± 103 µg/m^3 from electric stoves. The charcoal contributed the highest concentration of $PM_{2.5,}$ followed by a kerosine stove and the least was from LPG. The results had high standard deviation resulting from the spikes of $PM_{2.5}$ concentration during cooking periods as compared to other periods (Pokhrel *et al.*, 2015; Li *et al.,* 2016).

The highest $PM_{2.5}$ concentrations were found in site A with a mean of 212 ± 62.5 µg/m^3 that ranged from 149 to 274 µg/m^3. The household used a kerosine stove regularly for cooking and heating that contributed to the elevated levels of $PM_{2.5}$. The second highest concentration was recorded in site B with mean of 141 ± 35.4 µg/m^3 that ranged from 101 to 169 µg/m^3. The household had a similar house structure and fuel source as site A. The mean concentration of $PM_{2.5}$ at site D was 122 ± 10.44 µg/m^3 that ranged from 115 to 134 µg/m^3. The charcoal was used most frequently in addition to LPG, hence high concentrations of $PM_{2.5}$. Lastly. site C had the lowest $PM_{2.5}$ concentration among the Mukuru sites, with a mean of 75 ± 29.0 µg/m^3 in the range of 50 to 107 µg/m^3. The household used charcoal as a fuel source less frequently thus leading to low emission of $PM_{2.5}$.

4.3.3 Indoor PM₂.₅ concentration during the Dry and Rainy Seasons

The indoor $PM_{2.5}$ concentrations were compared during the dry and rainy seasons as shown in Figure 4.6.
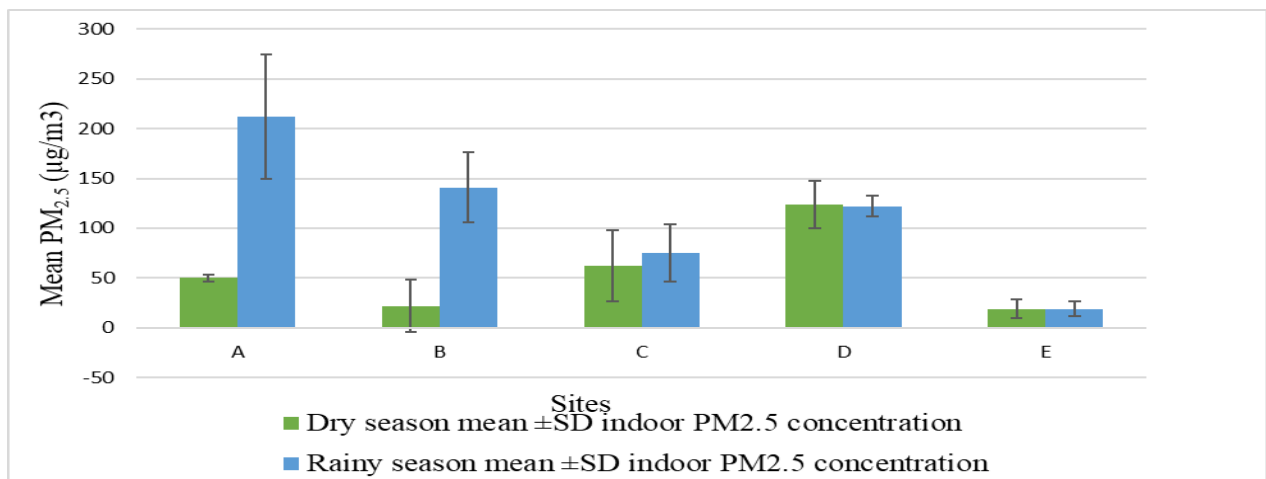

Figure 4. 6: Indoor mean $PM_{2.5}$ concentration for Mukuru sites (site A-D) and control site E for the dry and rainy seasons

The indoor $PM_{2.5}$ concentrations during the rainy season were higher than those of the dry season except for site D (Figure 4.6). However, there was no significant difference (t (8) = 1.616, p>0.05) in their overall means for both seasons. High levels of $PM_{2,5}$ during the rainy season could be attributed to the high frequency of fuel usage and burning of wet biomass (charcoal) compared to the dry season. However, the control site $PM_{2.5}$ concentrations did not differ significantly (p>0.05) during both seasons.

4.4 Outdoor Carbon (II) Oxide Levels during the Dry and Rainy Seasons

Table 4.3 shows the summarized 24-hour mean ± SD CO concentrations sampled for three consecutive days during the dry and rainy seasons.

Table 4. 3: The 24-hour mean outdoor CO concentrations (ppm) sampled in selected sites for three consecutive days including, their potential sources, during the dry and rainy seasons

Sampling Sites		Possible sources of air pollution for outdoor sampling sites	Outdoor CO levels (ppm) during the dry season			Mean ± SD (ppm)	Outdoor CO levels (ppm) during the rainy season			Mean ± SD (ppm)
			Day 1	Day 2	Day 3		Day 1	Day 2	Day 3	
Mukuru Informal Settlement	A	Vehicular exhaust fumes, unpaved roads, open burning of wastes	0.73	1.49	0.06	0.76±0.72	0.05	0.43	0.08	0.18 ± 0.21
	B	Open burning of garage waste and vehicular exhaust fumes	0.28	0.68	0.06	0.34±0.32	0.94	0.79	1.02	0.92 ± 0.11
	C	Unpaved roads, open cooking on the roadsides Open burning of wastes	0.07	0.04	0.08	0.06±0.02	0.001	0.54	0.001	0.18 ± 0.31
	D	Vehicular exhausts fumes, industrial emissions, open burning of wastes	0.43	0.18	0.15	0.25±0.15	0.59	0.27	0.81	0.55 ± 0.27
Range of CO Levels (ppm)			0.04 - 1.49				0.001 - 1.02			
Overall mean ± SD of CO levels (ppm)			0.35±0.29				0.46±0.35			
Control site	E	Open field with no activities but the expressway about 100 m away from the site was under construction	<0.001	<0.001	<0.001	<0.001	0.10	0.10	0.002	0.07 ± 0.05

NOTE: ±SD= Mean Standard Deviation

4.4.1 Outdoor CO Concentrations during the Dry Season

From Table 4.3, the overall CO mean ± SD level in parts per million (ppm) from all the Mukuru informal settlement sites was 0.35 ± 0.29 ppm with a range of 0.04 to 1.49 ppm. These concentrations were much higher than that of the control site which were all less than 0.001 ppm. The levels in the Mukuru informal settlement sites varied and depended on the sources of air pollution such as the burning of garage wastes, vehicular exhaust fumes, uncontrolled burning of wastes within the slum and along the roads, open-air cooking in the streets, and industrial emissions. The maximum values of CO were also observed when various activities were carried out. For instance, high traffic during peak hours was clearly observed on the CO peak charts. The results obtained from our study are supported by a similar investigation done in Pakistan near busy roads that found the 24-hour mean CO concentrations ranging from 1.5 to 6.1 ppm (Ali & Athar, 2007).

The highest CO concentrations were observed in site A with a mean of 0.76 ± 0.72 ppm that ranged from 0.06 to 1.49 ppm. The concentrations had high deviation as a result of variations in CO concentrations during the peak and off-peak hours. The high CO level could have been due to the exhaust fume emissions from the vehicles passing through the nearby busy road that was approximately 30 meters away from the sampling points, coupled with the occasional burning of tyres and waste materials. Site B reported high mean CO levels of 0.34 ± 0.32 ppm than site D, that had a mean of 0.25 ± 0.15 ppm. The high CO concentrations in site B could have been due to a contribution that involved the burning of waste materials from the garage, and vehicle exhaust fumes. The levels of CO from Site D could probably be as a result of the heavy commercial vehicle exhaust fumes, which was 20 meters away from site D, together with the smoke released from the nearby industries. The lowest CO mean level of 0.06 ± 0.02 ppm, which ranged from 0.04 to 0.08 ppm, was observed in site C and could be attributed to the cooking activities on the roadsides and the occasional burning of household wastes. In addition, site C was far away from the busy roads and industries as compared to sites A and D.

4.4.1.1 The Outdoor CO Peaks during the Dry Season

The 24-hour CO levels peaks showed different spikes throughout the sampling period (Figures 4.7 and 4.8). These peaks varied greatly and were strongly influenced by the CO levels that were

emitted from each of the sites. The highest concentrations were reported in ite A and were more pronounced in the morning and evening hours (Figure 4.7). This points out the high traffic that was more experienced during peak hours, mainly in the morning and afternoon.
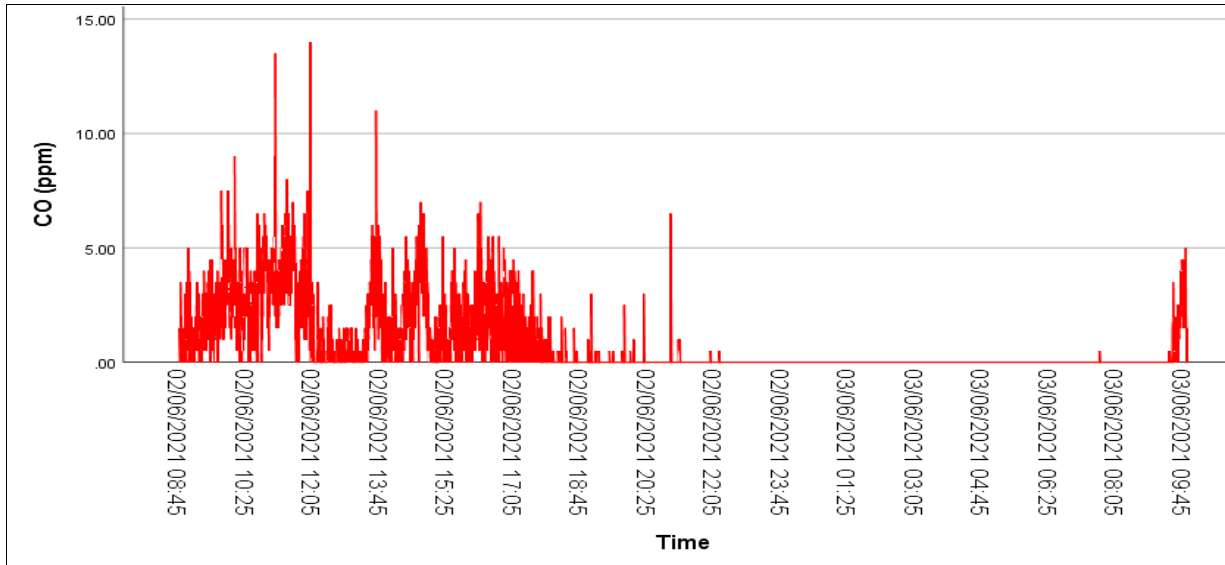

Figure 4. 7: Site A: Outdoor CO chart over 24-hour period during the dry season

On the contrary, site C had a minimal number of CO spikes that were prominent during mid-morning and afternoon hours. It should also be noted that the roadside cooking activities could have caused more pronounced spikes during lunch hour periods (Figure 4.8).
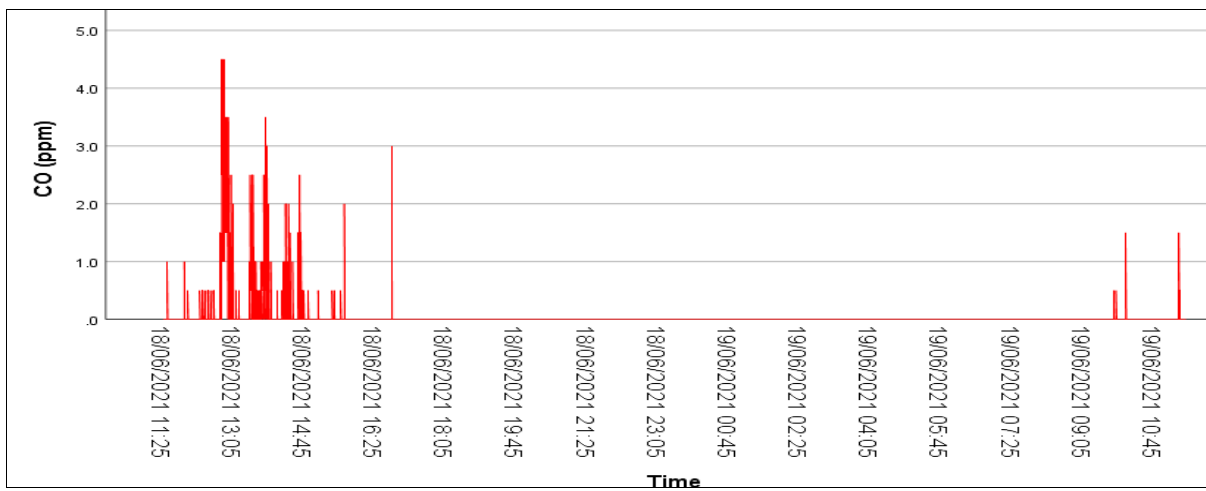
Figure 4. 8: Site C Outdoor CO chart over 24-hour period during the dry season

4.4.2 Outdoor CO Concentrations during the Rainy Season

The overall 24-hour CO concentration mean ± SD for the Mukuru informal settlement sites was 0.46 ± 0.35 ppm and ranged from 0.001 to 1.02 ppm. The mean value for CO in Mukuru slum was significantly higher (t (3.204) =2.164, $p < 0.05$) than the control site E with a mean value of 0.07±0.05. This is because few activities were carried out at the control site with less emission of CO. On the contrary, Mukuru sites had elevated CO levels that were dominantly influenced by the diverse sources of air pollution that was similar to those of the dry season. The CO emissions patterns were also similar with those of the dry season, whereby maximum values were experienced near the roads during peak hour. Our study results were in tandem with the study done in Imo state, Nigeria that found the vehicular exhaust fumes coupled with the power generators contributed to the elevated levels of CO. The mean values were above their national CO standards level of 10 ppm (Njoku *et al.*, 2016).

The highest concentration was observed in site B with a mean level of 0.92 ± 0.11 and the key contributors were emission from the burning of garage waste. The levels varied greatly on the three sampling days and ranged from 0.79 to 1.02 ppm. These levels were influenced by the number of vehicles that were being repaired on-site and the burning of garage waste. Site D had the second-highest mean concentrations of 0.55 ± 0.27 ppm with a range of 0.27 to 0.81 ppm. This could have been due to emissions of exhaust fumes from the heavy commercial vehicles powered by diesel engines that passed through the busy industrial area road that was about 30 meters away from the sampling site. The incomplete combustion of fuels and emission from the nearby industries also led to the release of black smoke into the environment (Reşitoğlu *et al.*, 2015).

In addition, site C and A had a mean ± SD value of 0.18 ± 0.31 and 0.18 ± 0.21 ppm ranging from 0.001 to 0.54 ppm and 0.05 to 0.43 ppm, respectively with a high standard deviation from the mean like that of the dry season. In addition, site C had minimal cooking activities on the roadside; hence there was low concentrations of CO reported when compared to sites B and D. However, for site A, the low levels of CO reported when compared to that of site B and D and could be attributed to minimal traffic flow in site A during the sampling period. This suggests that low traffic flow results in low volumes of exhaust fumes released into the environment.

4.4.2.1 The Outdoor CO Peaks during the Rainy Season

The CO concentration peaks were generated for different sites that were influenced by various sources of air pollution over the period of 24 hours (Figures 4.9-12). The CO charts showed high concentrations of CO for sites A and D during morning and evening hours. This is attributable to the high vehicle exhaust fumes emissions during the peak hours A similar study that was done on major traffic routes in Nigeria also revealed high concentrations of CO during morning and evening peak hours (Effiong, 2016).
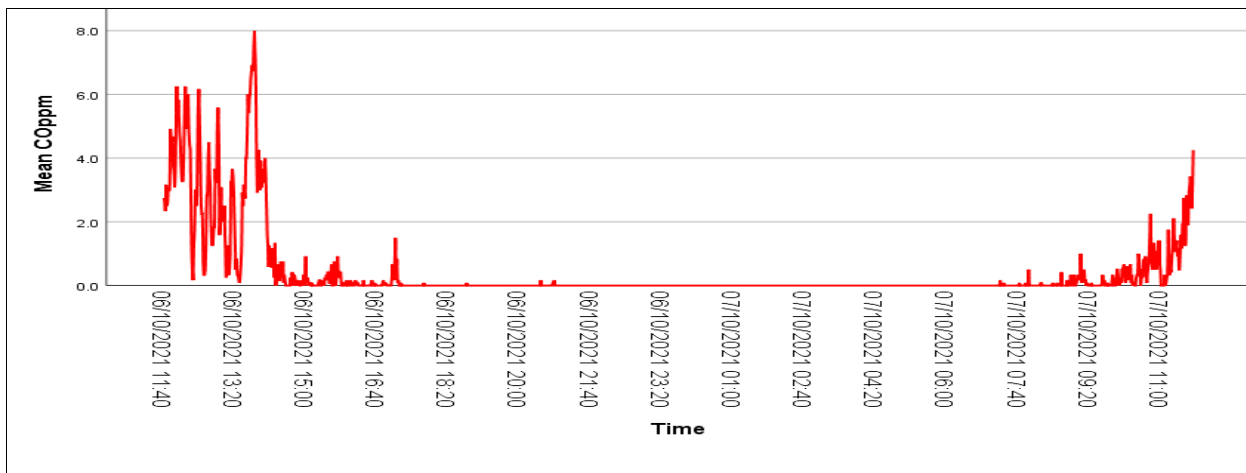
Figure 4. 9: Site A (Total petrol station) CO chart over 24-hour period
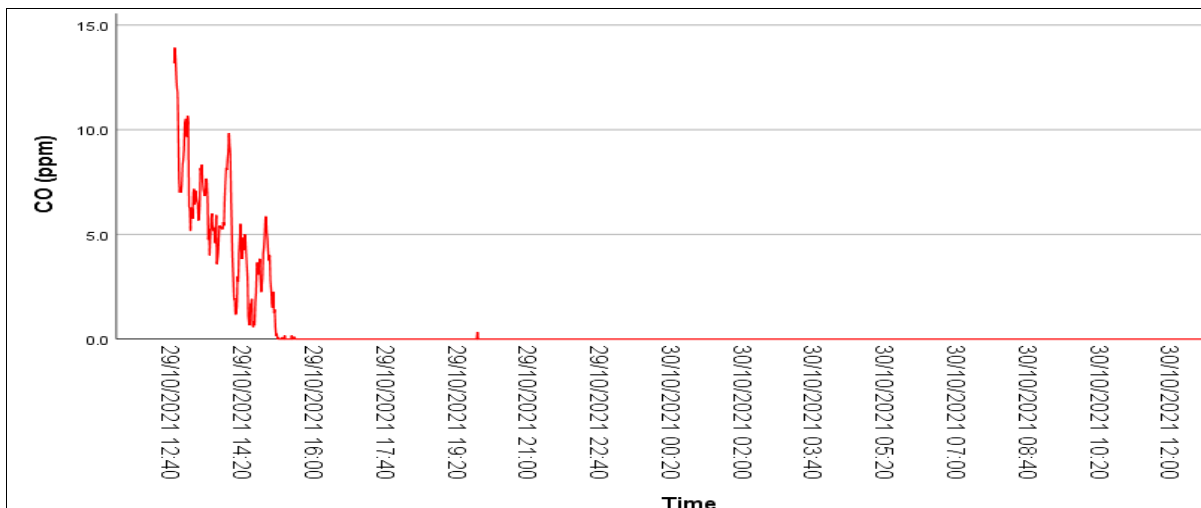
Figure 4. 10: Site D (Industrial area) CO chart over the 24-hour period

The CO peaks were only high in the afternoon and relatively low for the rest of the hours in site C, (Figure 4.11) while in site B, at the garage station, the CO concentrations were high in the afternoon and evening hours (Figure 4.12). This could probably be due to the burning of garage wastes which were observed during the sampling period.
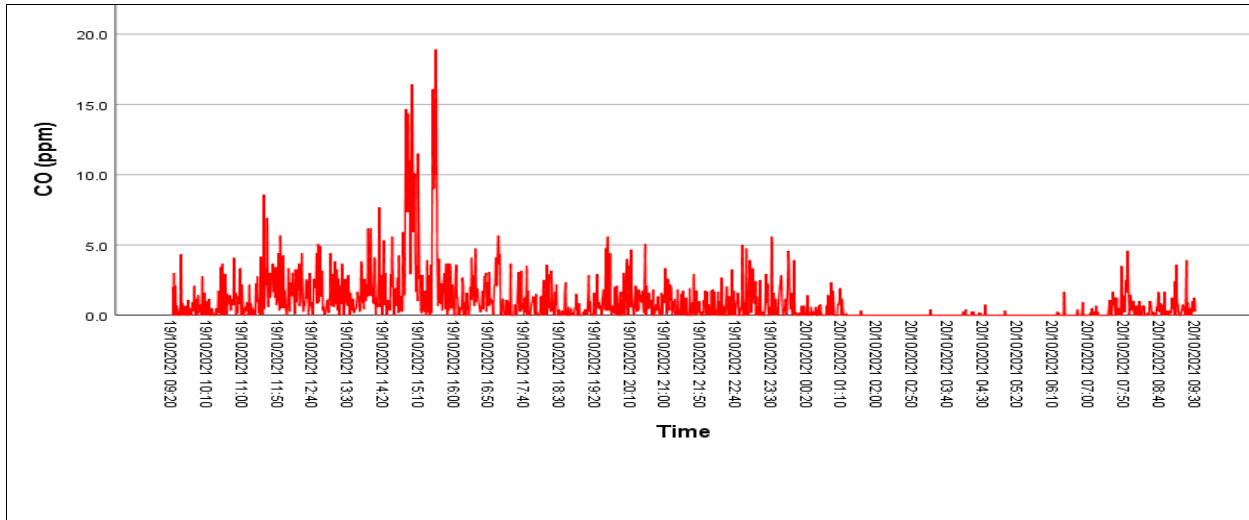
Figure 4. 11: South B, Garage CO chart over the 24-hour period
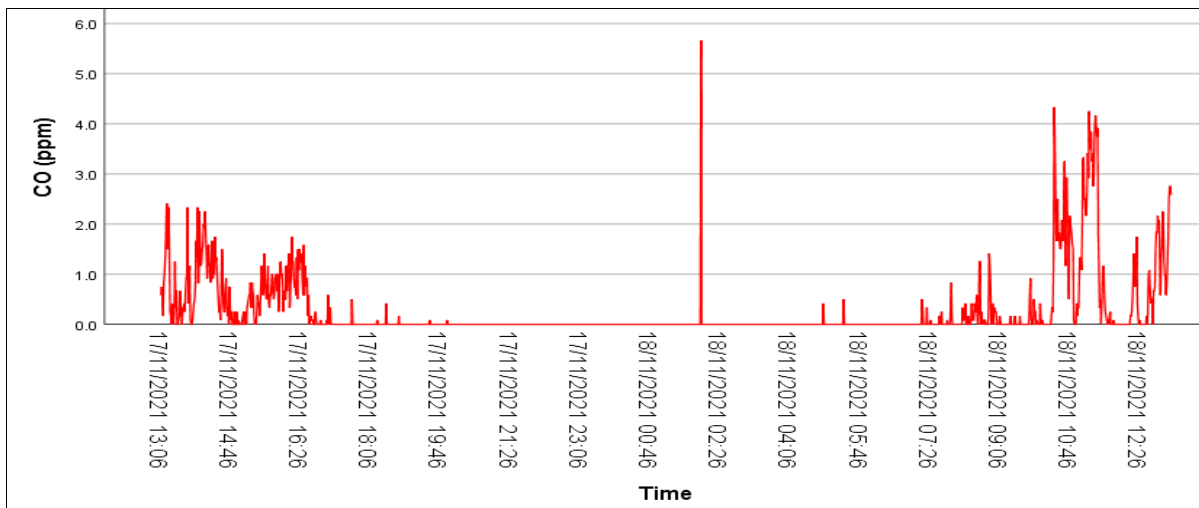
Figure 4. 12: Site C CO chart over the 24-hour period

4.4.3 Ambient CO and the Established Air Quality Limit

From Table 4.3, the mean ambient CO concentrations (ppm) during the dry and the rainy seasons were compared with the set WHO limit of 3.5 CO ppm (WHO, 2021), (Figure 4.13).
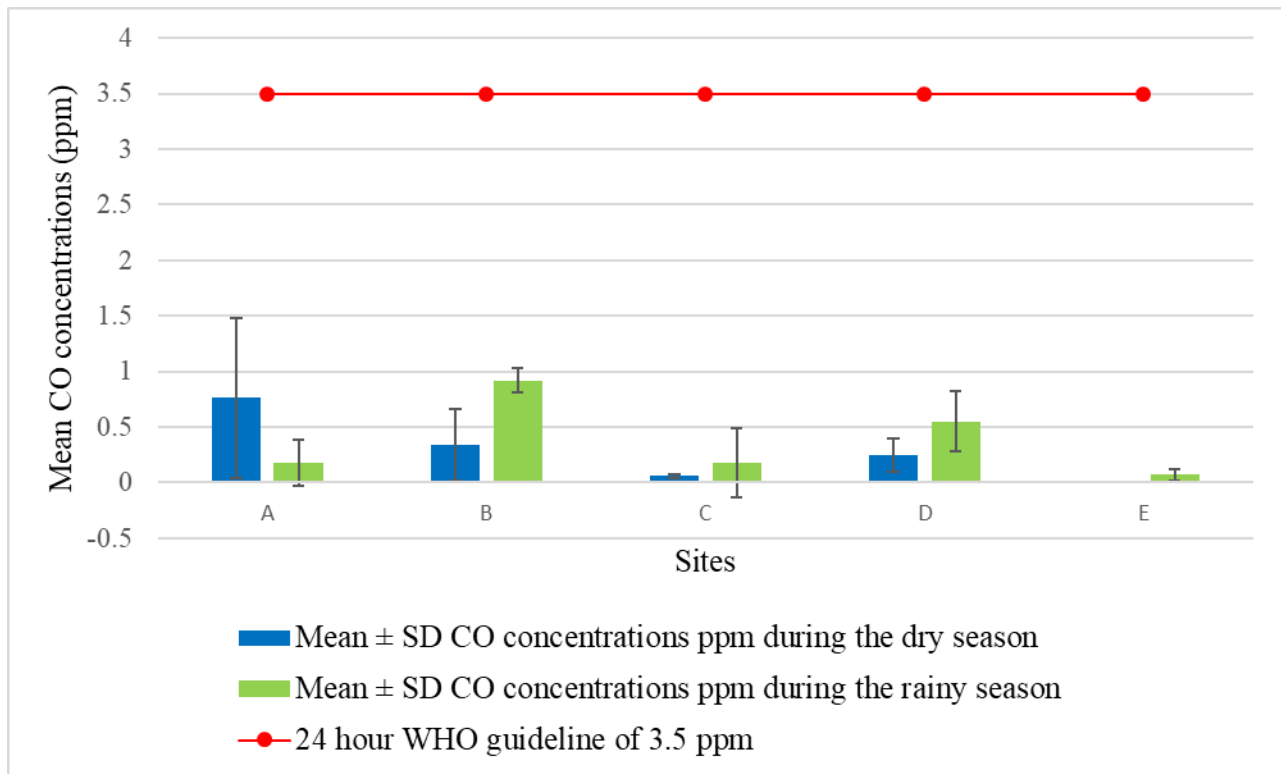
Figure 4. 13: The outdoor 24-hour CO concentrations from Mukuru sites A-D and the control site E, and the set WHO guideline of 3.5 ppm during the dry and rainy seasons.

The CO concentrations for both the control and Mukuru sites did not exceed the WHO limit over the 24-hour sampling period during both seasons (WHO, 2021). During the peak hours, the maximum values for CO were much higher, approximately ten times more than that of WHO air quality limit of 3.5 ppm. The sites were closer to the busy traffic roads that experienced vehicular emissions caused by incomplete combustions of fuels. The high CO concentrations during the rainy season could be attributed to the high atmospheric pressure due to low ambient temperatures leading to low air dispersion in a given site. Human activities like burning of rubbish, tyres and vehicular exhaust fumes on the sites could have also contributed to the varying levels of CO. On the contrary, site A had high CO concentrations during the dry season and this could be attributed to the number of vehicles passing and increased burning of tyres near the site during the dry season. In general, our study results were consistent with a study done in Dhaka Megacity, where major pollutants, including CO, were reported to be high during the rainy season (Hoque *et al.,* 2020).

4.5 Ambient CO Levels and Meteorological Parameters during the Dry and Rainy Seasons

The relationships between outdoor CO concentrations (ppm) (Table 4.3) with meteorological factors (Appendices II and III), such as temperature and relative humidity, were correlated using Pearson correlation during the sampling periods, as shown in Figures 4.14 to 4.17).

4.5.1 Outdoor CO Levels and Temperature during the Dry Season

The relationship between outdoor CO levels and temperature during the dry season is shown in Figure 4.14.
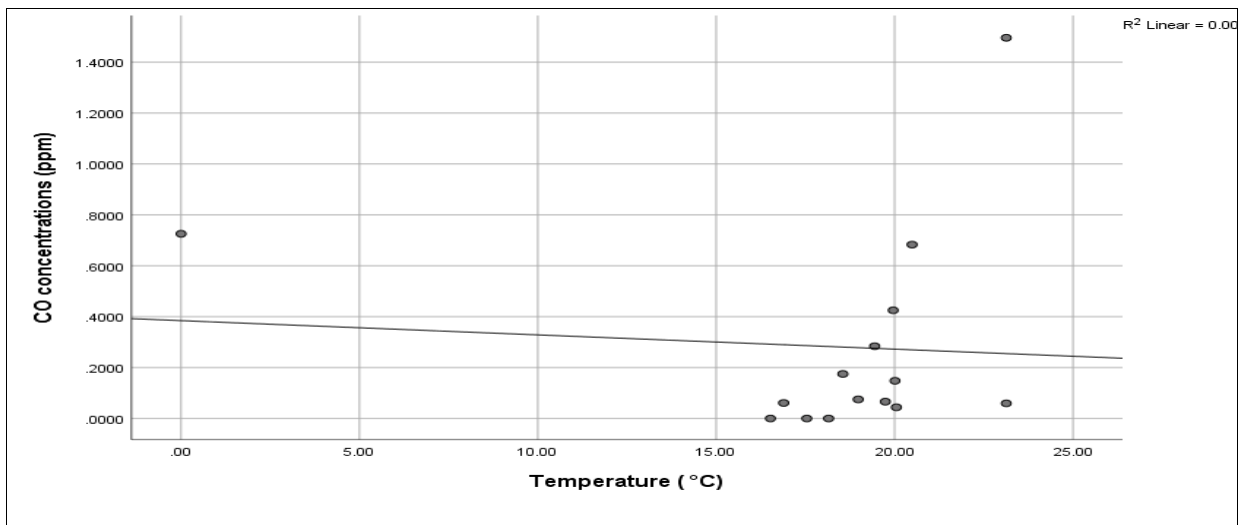
Figure 4. 14: A scatter plot of outdoor CO (ppm) with temperature (°C) during the dry season

A weak negative correlation of r=-0.073 was observed between the ambient 24-hour temperature and outdoor CO concentrations. The relationship was not statistically significant (p>0.05). The findings were in agreement with a study done in Romania by Bodor *et al.* (2020) on major air pollutants with temperature and a negative relationship between the ambient CO levels with temperature during summer was reported.

4.5.2 Outdoor CO Levels and Relative Humidity (%) during the Dry Season

The relationship between the outdoor CO concentrations (ppm) and relative humidity is given in Figure 4.15.
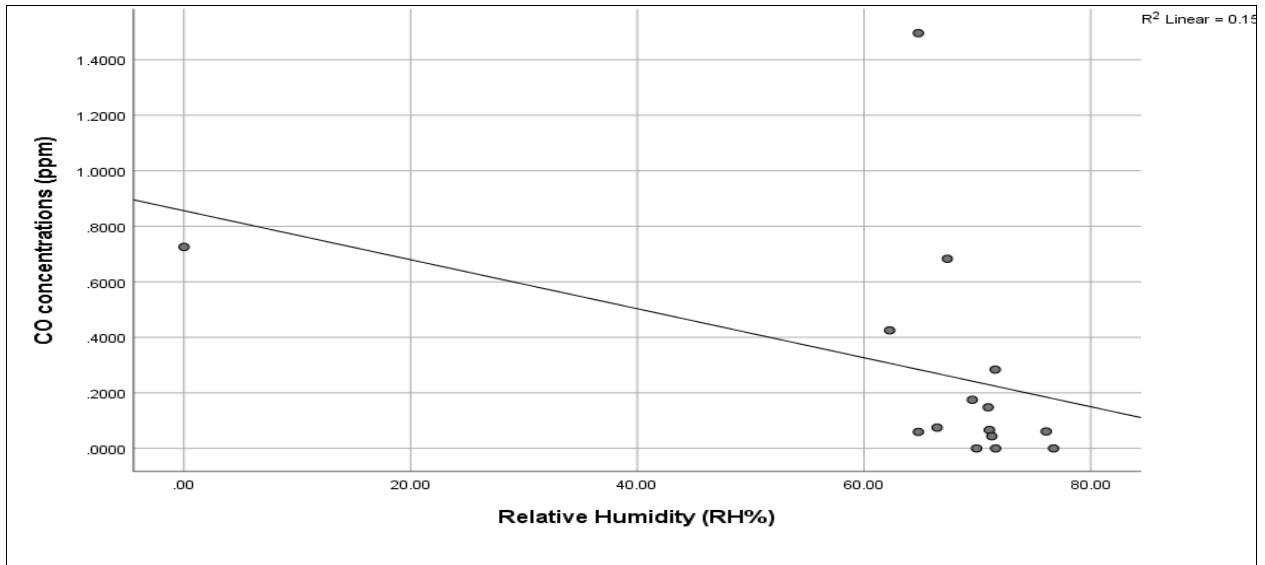
Figure 4. 15: Relationship between levels outdoor CO (ppm) and relative humidity (%) during the dry season

A weak negative correlation coefficient of r=-0.395 was obtained between the relative humidity and the CO concentrations. This implies that an increase in relative humidity decreases the CO concentrations in the environment.

4.5.3 Outdoor CO Levels and Temperature during the Rainy Season

Correlation between outdoor CO levels and temperature was established using Pearson Correlation Coefficient during the rainy season (Figure 4.16). A positive correlation of r=0.315 was obtained.
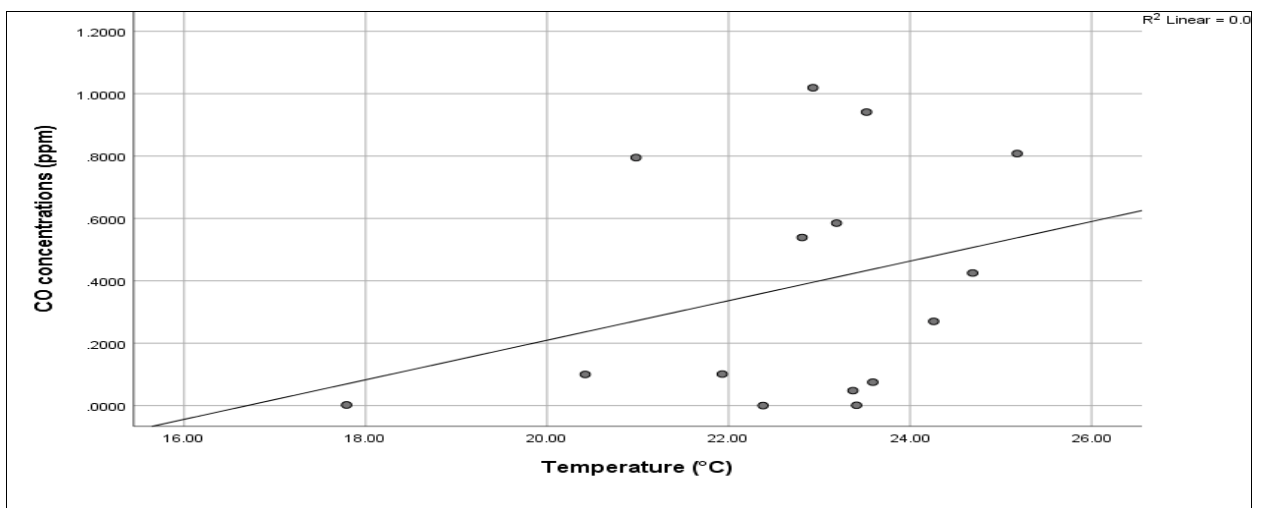
Figure 4. 16: Relationship between outdoor CO (ppm) and temperature (°C) during the rainy season

4.5.4 Outdoor CO Levels and Relative Humidity during the Rainy Season

The outdoor CO concentrations were correlated with relative humidity during the rainy season, as shown in Figure 4.17.
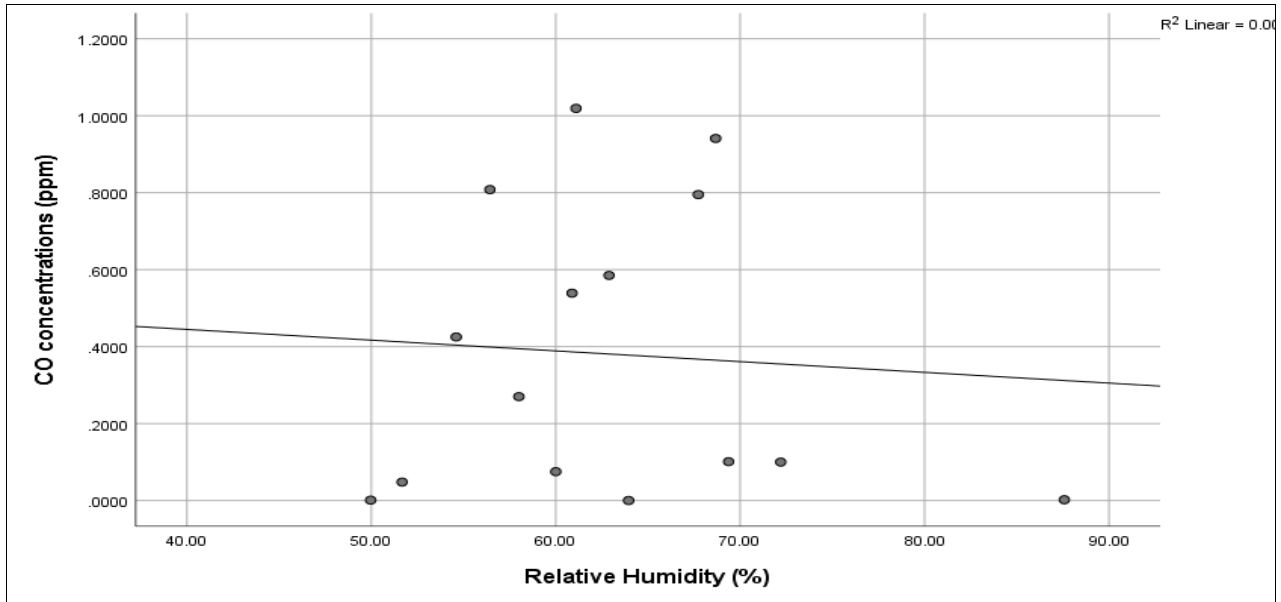
Figure 4. 17: Correlation between outdoor CO (ppm) and relative humidity (%) during the rainy season

A very weak negative correlation of r=-0.07was observed between CO concentration and relative humidity (%).

4.6 The Indoor CO Concentration during the Dry and Rainy Seasons

The 24 hours indoor CO mean ± SD concentrations (ppm) were sampled for three consecutive days during both climatic seasons and summarized in Table 4.4. In addition, the household fuel that was frequently used is also presented.

Table 4. 4: The 24-hour mean indoor CO concentrations (ppm) sampled in selected sites for three consecutive days including, the type of household fuels used, during the dry and rainy seasons

Sampling Sites		Types of household fuels used	Indoor CO levels (ppm) during the dry season			Mean ± SD (ppm)	Indoor CO levels (ppm) during the rainy season			Mean ± SD (ppm)
			Day 1	Day 2	Day 3		Day 1	Day 2	Day 3	
Mukuru Informal Settlement	A	Kerosene Stove	0.45	3.14	0.47	1.36±1.55	1.72	0.95	1.20	1.29±0.39
	B	Charcoal	9.05	13.42	5.96	9.48±3.75	16.79	18.69	14.64	16.71±2.02
	C	Charcoal	2.59	4.79	4.55	3.98±1.21	9.32	4.29	4.91	6.17±2.74
	D	LPG and Charcoal	2.70	1.93	4.73	3.12±1.44	30.31	11.30	32.47	24.69±11.65
Range of CO Levels (ppm)			0.45 - 13.42				0.95 - 32.47			
Overall mean ± SD of CO levels (ppm)			4.48±3.50				12.22±10.52			
Control site	E	None	0.10	0.10	0.002	0.07 ± 0.05	<0.001	<0.001	<0.001	<0.001

NOTE: ±SD= Mean Standard Deviation

4.6.1 Indoor CO levels during the Dry Season

From the results presented in Table 4.4, the overall CO mean ± standard deviation (SD) level (ppm) in Mukuru household was 4.48 ± 3.50 ppm, and ranged from 0.45 - 13.42 ppm The high standard deviation from the mean was as a result of high concentrations of CO during cooking hours as compared to when there is no cooking activity. The CO levels in the control site were however less than 0.001 ppm. This is because there was no known source of air pollution, and no cooking activities were observed during the sampling period. The households in Mukuru sites had diverse sources of fuel such as kerosene stoves, charcoal, and LPG that were commonly used for cooking and lighting.

The fuels emitted different levels of CO, with the charcoal emitting the highest levels, followed by the combination of LPG and charcoal, and the least emitter was from the kerosine stove. The rate of CO emission was also influenced by the frequency at which the fuel was used. In addition, Mukuru informal settlements had similar housing structures comprising of one room with one window and a door with limited space, which reduced the air circulation, hence increasing CO levels. Our findings are consistent with a study that was conducted by Bartington et al. (2017) in 12 households using biomass fuels for cooking and lighting, which reported a 48-hour mean CO concentration of 5.4 ± 4.3 ppm.

The highest mean CO level of 9.48±3.75 ppm ranging from 5.96 to 13.42 ppm was observed in household B. This household was mainly using charcoal as a source of fuel for cooking. Furthermore, the house had only one window and a door, limiting natural air circulation. The investigation in rural Southwestern Uganda had similarly high CO levels in the kitchen that frequently used charcoal for cooking in a limited space (Nakora *et al.*, 2020). In household C, the mean CO concentration was 3.98 ± 1.21 ppm and ranged from 2.59 to 4.55 ppm. The house structure and the primary fuel for cooking were similar to those of household B. However, high concentrations were observed during cooking hours, and the values were much higher than those of household B. Comparable observations were made in Bangladesh, that had high spikes of CO that were mainly experienced during cooking hours involving use of biomasses as household fuel(Khalequzzaman *et al.*, 2010).

The mean CO level of 3.12 ± 1.44 ppm with a range of 1.93 to 4.73 ppm was reported in household D. The commonly used fuel was LPG and charcoal, and the housing structure was stonewalled with only one small window and door. High CO concentration was reported due to limited ventilation. The highest CO levels were experienced during the cooking mainly in the morning, afternoon, and evening hours. The lowest concentrations of CO were found in house A, that mainly used a kerosene stove for cooking. The house structure was similar to that of household B and level of CO ranged from 0.45 to 3.14 ppm with an overall mean of 1.36 ± 1.55 ppm.

4.6.1.1 Carbon Monoxide Peaks during the Dry Season

Figures 4.18-4.20 present CO peaks for households A, B, and D that used different types of fuels for cooking. The concentrations of CO varied during the 24-hour sampling period. The highest concentrations were reported during cooking, which included morning, afternoon, and evening for all types of fuels.(Siddiqui *et al.*, 2009).
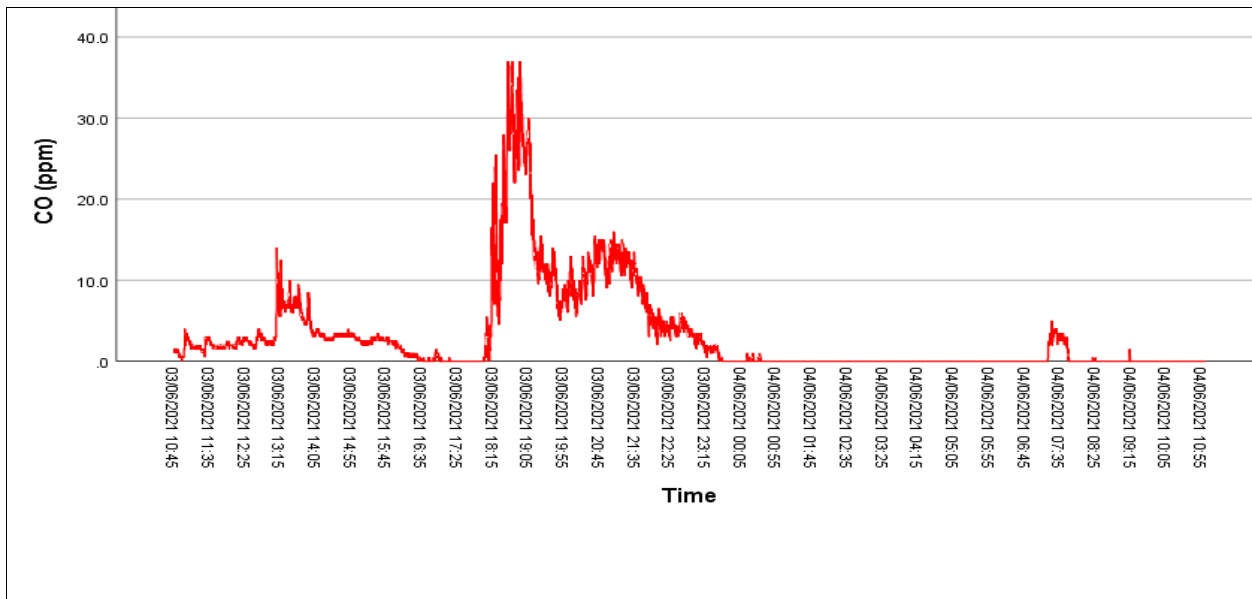
Figure 4. 18: Household A, Kerosene stove CO concentration chart for 24-hour period
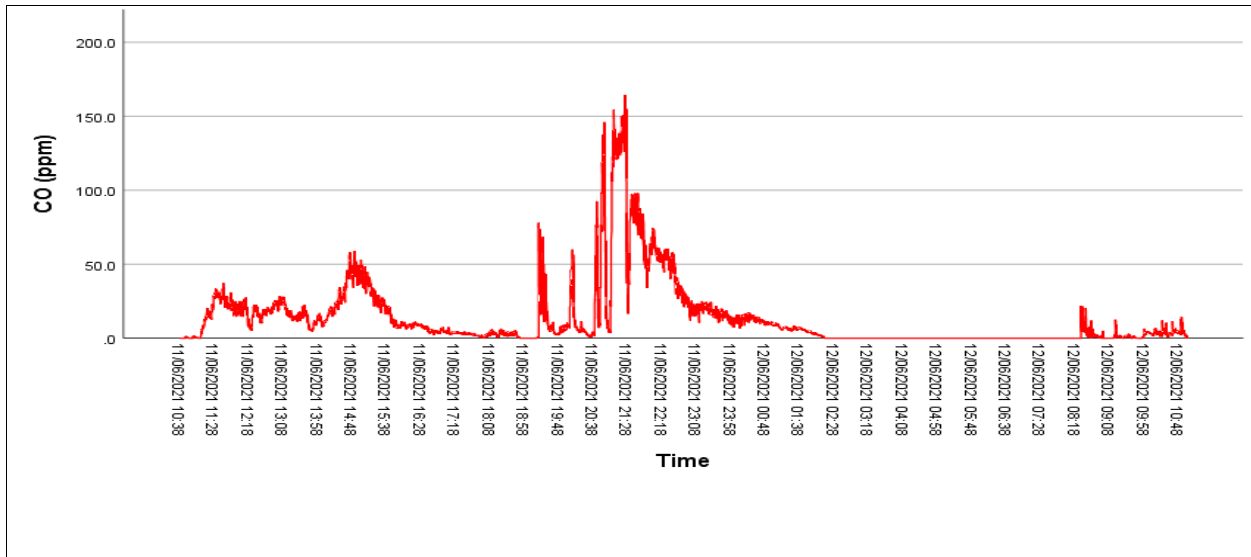
Figure 4. 19: Household B, Charcoal stove CO chart over 24-hour period
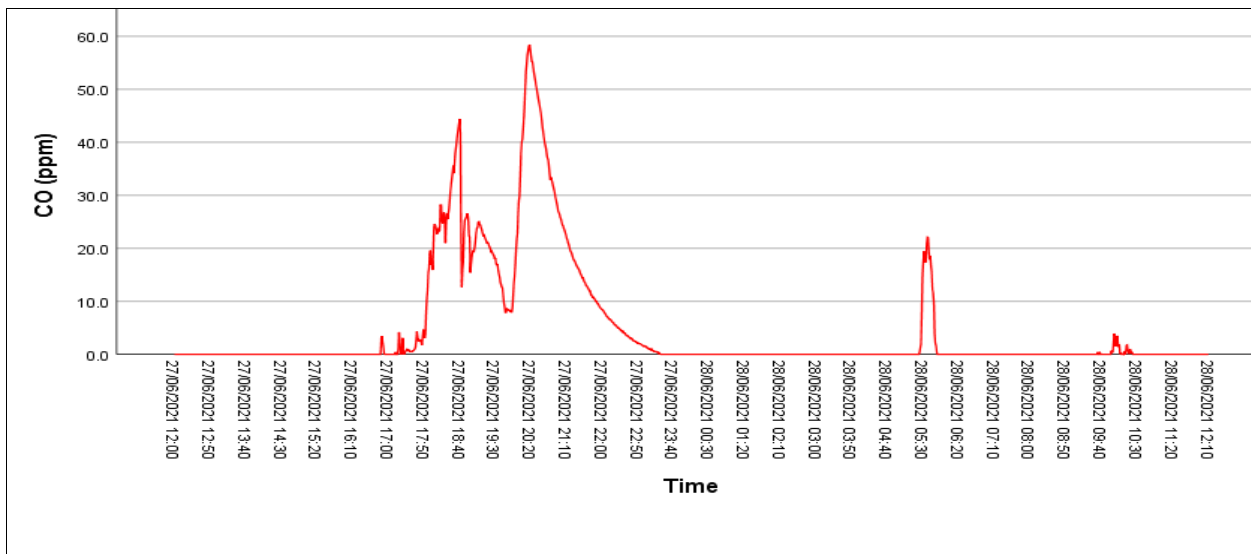
Figure 4. 20: Household D, Liquid petroleum gas CO chart over 24-hour period

The CO concentration spikes are consistent with a study done in Nepal on households that used varying types of fuels. The cooking stoves had relatively high concentrations that ranged from 21.1 to 22.6 ppm over the 24 hour period (Chen *et al.,* 2016).

4.6.2 Indoor CO Concentrations during the Rainy Season

The mean level of CO in Mukuru households was 12.23 ± 10.52 ppm and ranged from 0.95 to 32.47 ppm. These levels varied just like during the dry season and were influenced by the type of fuels that were mostly used for cooking and heating similar to that of the dry season Nonetheless,

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the CO concentrations in the control sites were less than 0.001 ppm. As mentioned earlier, all the houses had a similar structural design with one window and one door that limited the ventilation. Our findings are supported by a study done in Bangladesh that largely used biomass and fossil fuel and had high CO concentrations of over 7.6 ppm. It was attributed to the poor ventilation of the household and the use of less dried biomass for cooking (Khalequzzaman *et al.*, 2010).

The highest CO concentration was observed in household D that had a mean of 24.69 ± 11.65 ppm, ranging from 11.30 to 32.47 ppm. The commonly used fuels for cooking were LPG and charcoal. The elevated level of CO was expected especially since charcoal was used for an extended period of time in a poorly ventilated-house, despite the additional use of LPG, which is presumably cleaner fuel than the biomass (Li et al., 2016). Household B had the second highest mean level of 16.71 ± 2.02 ppm CO, with the values ranging from 14.64 to 16.69 ppm. The household mainly used a kerosine stove for cooking. The 24-hour CO emission patterns were comparable to those of household D. In addition, the housing structure had only one door and a window. As a result, air circulation was reduced due to poor ventilation thereby increasing the CO levels.

Site C had a mean value of 6.17 ± 2.74 with a range of 4.29 to 9.32 ppm. Charcoal was the most common type of fuel that was used however the means values of CO were slightly lower than those of D and B. Even if the house structure was the similar, B had a larger space that was well ventilated. As expected, the lowest CO concentration was from A that had a mean of 1.29 ± 0.39 that ranged from 0.95 to 1.72 ppm.

4.6.2.1 The CO Concentrations Peaks during the rainy season
The 24 hours mean CO concentration was influenced by the type of fuels that were frequently used. The CO concentrations were also more pronounced during cooking hours in all households in the morning, afternoon, and evening as summarized in Figures 4.21 to 4.23. This agrees with a study on biomass fuels in Nepal, where high CO levels were reported during cooking (Chen *et al.,* 2016). The charcoal stove produced high CO concentrations, and the least was emitted from the kerosene stove.
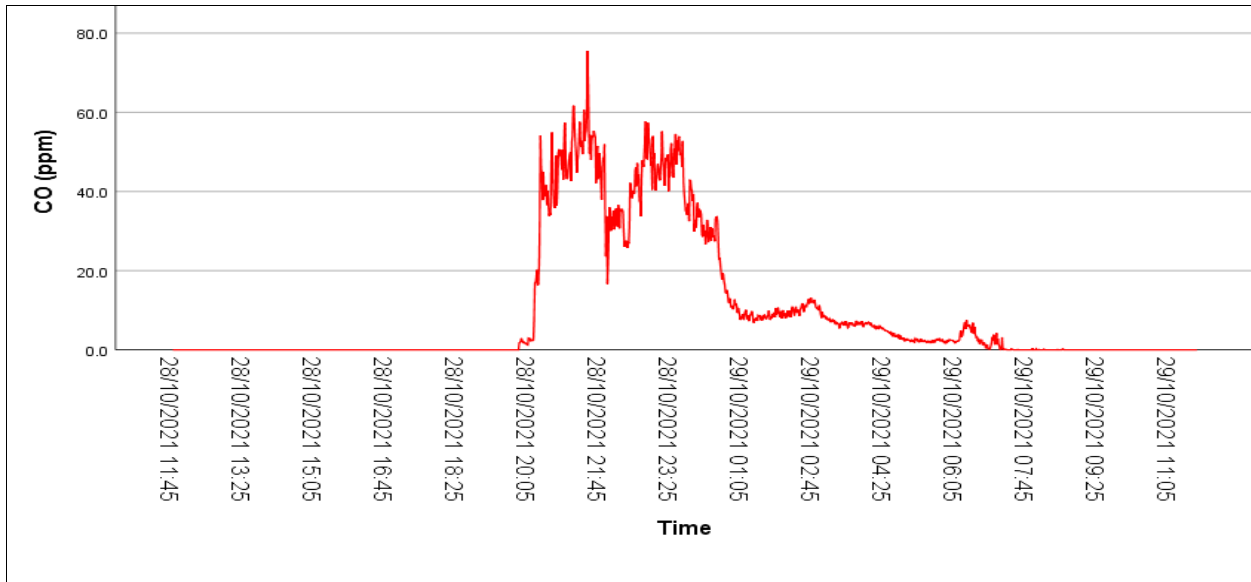
Figure 4. 21: Household C, Charcoal stove fuel CO chart over the 24 hour period
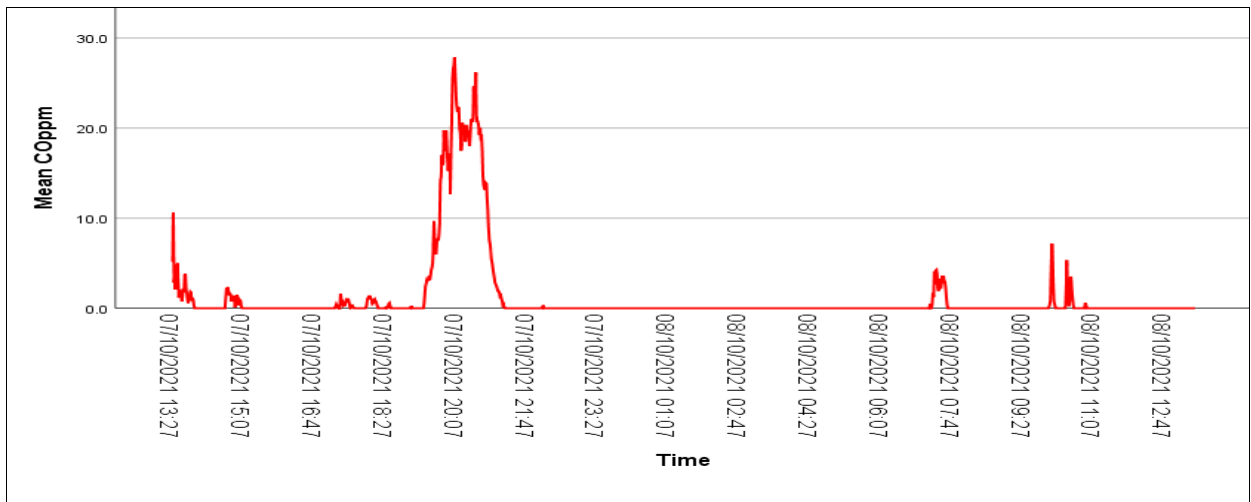

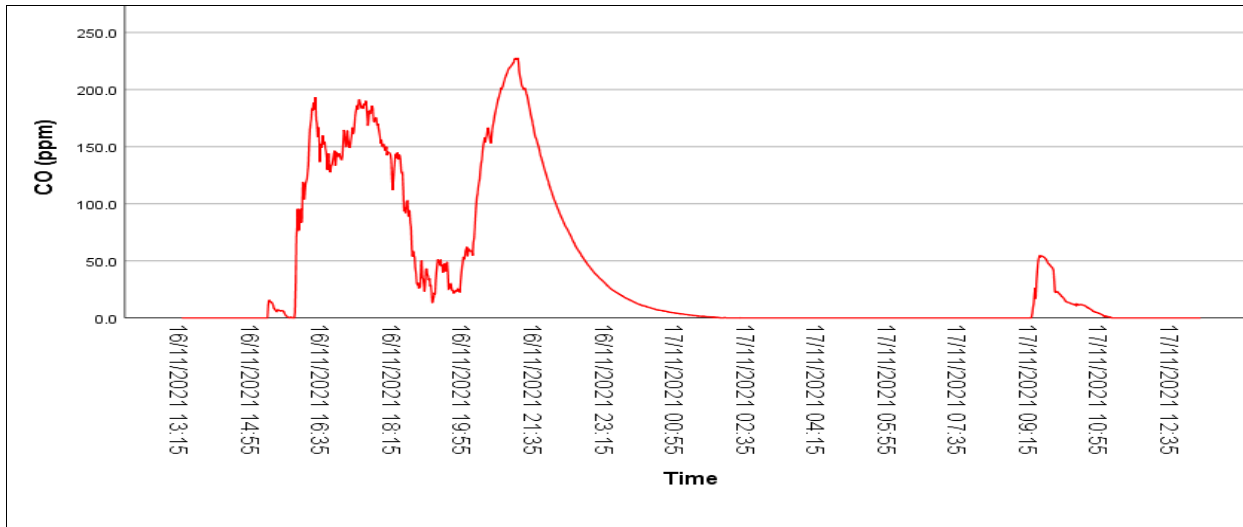Figure 4. 22: Household A, Kerosene stove fuel CO chart over the 24-hour period

Figure 4. 23: Household D, Charcoal stove and LPG fuel CO chart over 24-hour period
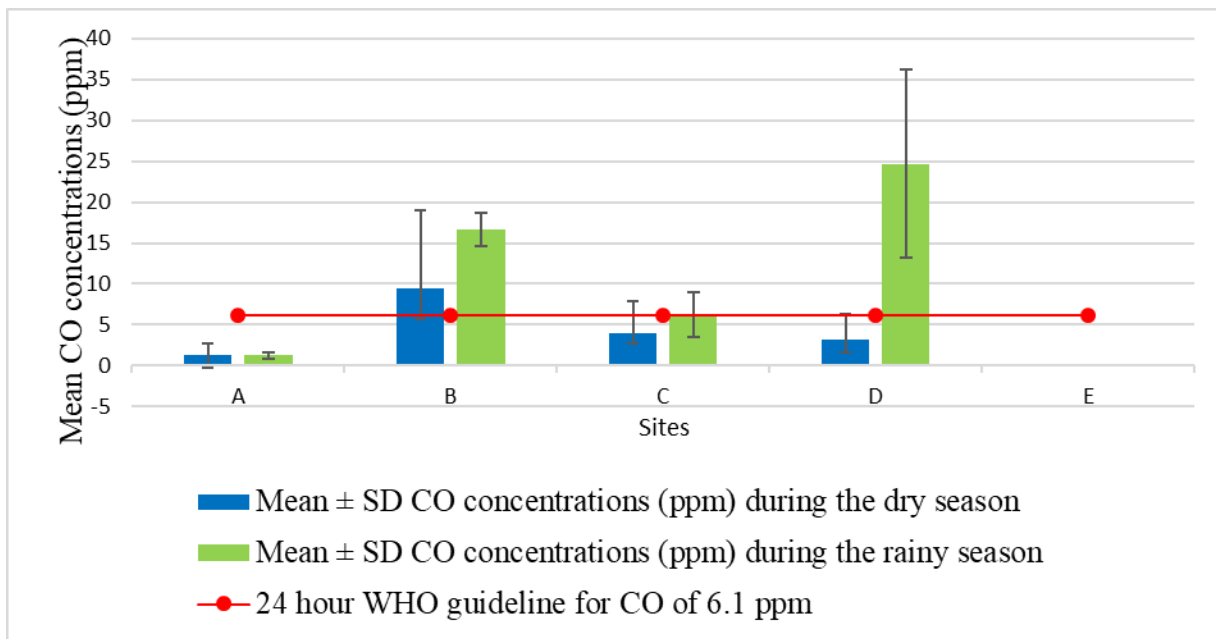
4.6.3 Indoor CO Concentration Air Quality Limit

Figure 4. 24: The comparison between the indoor 24-hour CO concentrations in site A-D and the control site E with the set WHO guideline for CO of 6.1 ppm during the dry and rainy seasons

Figure 4.2.4, presents the CO levels during both seasons compared with the established air quality limit for CO of 6.1 ppm (WHO, 2010). All the Mukuru sites had CO levels that fell within the set limit during the dry season, except for site B that had a mean value of 9.48 ± 3.75 ppm. On the contrary, during the rainy season, all the Mukuru sites had CO that exceeded the limit except for site A that had a mean value of 1.29 ± 0.39 ppm. This is attributable to extended

use of fuel for warming and heating during the cold period. For example, in site A, kerosine stove could not have been used for warming the house during the cold weather. Sites B, C, and D had much higher CO concentration during the rainy season than in the dry season. This is as a result of frequent use charcoal and the closure of doors and windows more often during the cold period. The CO concentration for the charcoal users was significantly higher than those of the LPG and kerosene stove. This was also evident in a study done by Chen and co-workers in Southern Nepal on the investigation of indoor air pollution and the cooking stove intervention trials (Chen et al., 2016).

4.7 Prevalence Levels of Respiratory Diseases during the Dry and Rainy Seasons

Table 4.5 is a summary of the data on the total number of patients including those with respiratory diseases (RD) who visited the outpatient health facilities A. B. C and D in Mukuru and the control health facility E during the rainy and dry periods. The incidences of respiratory diseases (%) from those health facilities are also given. The corresponding raw data is presented in appendix I.

Table 4.5: The prevalence levels of respiratory illness in the Mukuru community (A- D) and the control community E during the dry and rainy seasons

Communities Health centres		Incidences of respiratory diseases during the dry Season			Incidences of respiratory diseases during the rainy season		
		No. of patients with the respiratory diseases (RD) (A)	No. of outpatient cases (B)	Incidence of Respiratory Diseases (%) (A/A+B) *100	No of Respiratory Diseases (RD) (A)	No. of outpatient cases (B)	No. of outpatients with RD (%) (A/A+B) *100
Mukuru Community Health Centers	A	1334	3304	40.4	1084	3001	36.1
	B	320	681	47.0	419	957	43.8
	C	420	1138	36.9	422	1107	38.1
	D	179	431	41.5	847	2772	30.6
Control Health Center	E	87	342	25.4	1075	3342	32.2

RD: Respiratory Diseases

The prevalence levels of respiratory diseases reported in the Mukuru community health facilities A to D ranged from 36.9 to 47.0 % and 30.6 to 43.8 % during the dry and rainy seasons, respectively. In addition, the control health facility registered 25.4 and 32.2 % of patients that had various respiratory diseases during the same period. The common respiratory diseases that were noted during both seasons included pneumonia, asthma, upper respiratory tract infections, and TB. This could be attributed to the high levels of $PM_{2.5}$ for both ambient and household which was likely to cause the observed respiratory diseases. The prolonged use of unclean fuels such as charcoal and kerosene for cooking and heating releases pollutants such as $PM_{2.5}$ and CO that exceeded the WHO air quality limits, therefore, pausing a threat to human health. Moreover, exposure to different ambient sources of air pollution, such as open burning of garbage, vehicular exhaust fumes, loose suspended dust particles from unpaved roads, and industrial emissions, also possess a significant risk to respiratory health (Feng *et al.,* 2016).

A study done in Sub-Saharan African cities showed that air pollution significantly impacted human respiratory health. However, there is insufficient data to strongly correlate PM and related diseases (Cai *et al.,*2021). A similar study done in China over the years showed the impact of PM and CO on health. Several cases of cardiovascular and respiratory diseases were reported to be attributed to $PM_{2.5}$ levels in the environment (Liu *et al.,* 2019).

Furthermore, in a study done by Owili et al. (2017) on the impact of $PM_{2.5}$ to human health and the corresponding mortalities in Eastern Africa was found to be high. The results indicated that the increased levels of PM in the environment led to high mortalities, especially among children, due to the susceptibility of their lung penetration by pollutants like $PM_{2.5}$ (Owili *et al.,* 2017). Other studies have also been done showing high impacts of air pollution on human health (Feng *et al.,* 2016; Liu *et al.*, 2019).

4.7.1 Comparison of the Prevalence Levels of the Respiratory Diseases during the Dry and the Rainy Season

The prevalence levels (%) of respiratory diseases during the dry and rainy season as presented in Table 4.5 were compared, as shown in Figure 4.25.
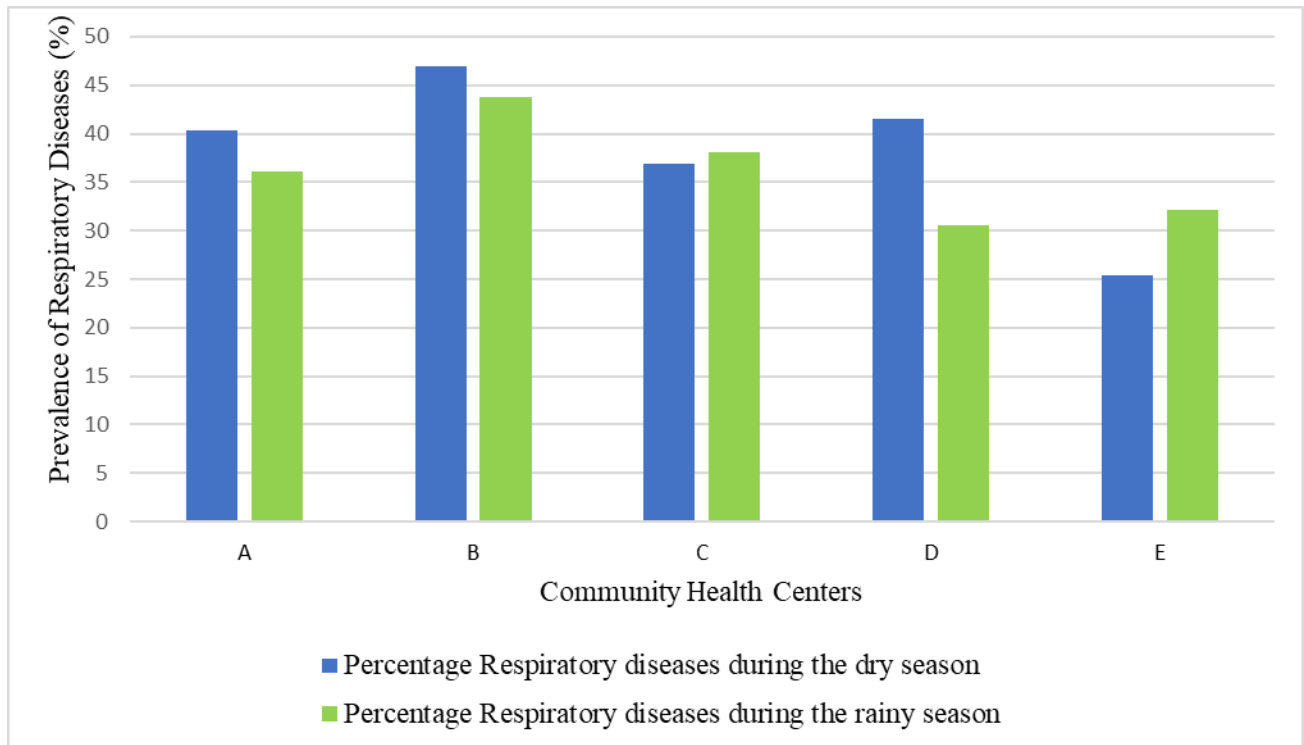
Figure 4. 25: Comparison between prevalence of respiratory illnesses in community health centers A-E during the dry and rainy season

The prevalence levels of the respiratory diseases in all the community health centers A- E did not have any significant difference ($p<0.05$) during the dry and rainy seasons. However, community health center A, B and D showed high prevalence during the dry season than the rainy season except for C and E. Both seasons exhibited high percentage prevalence levels which could have been attributable to air pollution resulting from both indoor and ambient sources.

CHAPTER FIVE
5. CONCLUSIONS AND RECOMMEDATIONS

5.1 Conclusion

The study assessed PM$_{2.5}$ and CO in Mukuru informal settlement and the control site during the dry and rainy season. Prevalence levels of respiratory diseases was also evaluated during the same period. Ambient mean PM$_{2.5}$ levels exceeded the WHO air quality guideline of 15 ug/m^3 in all the sites over the 24-hr period during the dry and rainy seasons. The contributory sources of the ambient PM$_{2.5}$ levels were the open burning of wastes, unpaved roads, cooking on the roadsides, and vehicular exhaust fumes whereas for the control site the contributory source was the construction activities of the expressway that was going on during the sampling period. The dominant sources of PM$_{2.5}$ in the Mukuru households were mainly use of kerosene stove, charcoal and liquid petroleum gas. Temperature and relative humidity influenced the ambient PM$_{2.5}$ concentrations, as depicted by the positive and negative correlations, although the correlations were weak.

The 24-hour mean CO concentrations from most households did not exceed that of the WHO household air quality standard of 6.1 ppm during the dry season except one household that used charcoal for cooking. However, during the rainy season, all the Mukuru sites had mean CO levels that were higher than the WHO air quality limit except for the household site one household that used kerosene stove for cooking. The household and ambient CO levels had prominent peaks which coincided with the cooking hours and busy traffic, respectively and these levels were much higher than the 24-hour WHO air quality limit for CO.

The study also established a high-level prevalence of respiratory diseases in Mukuru community health facilities compared to the control communities during the two seasons.

5.2 Recommendations

5.2.1 recommendations from the study

Recommendations arising from the study are as follows:

i. Establishment of the national regulatory of ambient air quality for $PM_{2.5}$ in the residential areas.

ii. Continuous monitoring of CO and PM2.5 and enforcement of existing regulatory framework.

iii. Sustainable waste management should be Universal health data management policies should be established for ease of good data management.

iv. Establishment of policies and programs to promote use of clean fuel such as improved cooking stove with reduced emissions.

v. Hazardous sites such as industrial areas should be zoned to minimize the air pollution.

5.2.2 Recommendations for Further Study

The following are recommendation for further study:

I. Monitoring of PM2.5 should be carried using personal air samplers to link $PM_{2.5}$ to individual health.

II. Assessment of levels of other pollutants like polycyclic aromatic hydrocarbons in the biological samples such as urine and blood and gaseous compounds such as NOx, SO_2 and CO_2.

III. Extensive research on the composition of $PM_{2.5}$ should be carried out.

IV. Comprehensive research on the relationship between air pollution and meteorological factors.

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APPENDICES

APPENDIX I: The Total Number of Patients Inclusive of those with Respiratory Diseases who Visited the Mukuru Community Health Centers and the Control during the Dry and Rainy seasons

Community Health Centers	Respiratory Disease	Dry season			Rainy season		
		April	May	Jun	Oct	Nov	Dec
A	URTI	244	318	421	87	280	403
	Asthma	5	6	9	2	5	6
	Tuberculosis	2	0	0	6	10	5
	Pneumonia	41	56	63	49	48	69
	OD RD	0	0	0	114	0	0
	Respiratory cases (N)	293	380	493	258	343	483
	Patients who visited the hospital inclusive of the respiratory cases (N)	**689**	**1024**	**1200**	**793**	**1102**	**1106**
B	URTI	38	41	115	96	98	132
	Asthma	1	0	27	3	0	0
	Tuberculosis	0	0	0	0	0	0
	Pneumonia	7	7	1	0	3	5
	OD RD	21	43	0	39	23	20
	Respiratory cases (N)	67	91	143	138	124	157
	Patients who visited the hospital inclusive of the respiratory cases (N)	**173**	**229**	**230**	**335**	**309**	**313**

Community Health Centers	Respiratory Disease	Dry season			Rainy Season		
		April	May	Jun	Oct	Nov	Dec
C	URTI	73	89	107	56	86	124
	Asthma	1	2	5	3	2	3
	Tuberculosis	2	1	1	0	0	1
	Pneumonia	21	20	29	22	44	37
	OD RD	18	10	14	15	12	17
	Respiratory cases (N)	**115**	**122**	**156**	**96**	**144**	**179**
	Patients who visited the hospital inclusive of the respiratory cases (N)	**305**	**389**	**362**	**276**	**406**	**425**
D	URTI	39	44	46	297	228	252
	Asthma	2	0	4	5	3	2
	Tuberculosis	1	0	1	5	8	11
	Pneumonia	5	3	6	3	1	4
	OD RD	7	14	8	1	10	17
	Respiratory cases (N)	53	61	65	311	250	286
	Patients who visited the hospital inclusive of the respiratory cases (N)	**124**	**132**	**175**	**861**	**914**	**997**

Control E	URTI	49	22		172	290	549
	Asthma	1	0		0	6	6
	Tuberculosis	0	0		1	0	8
	Pneumonia	5	0		5	16	19
	OD RD	15	0		0	2	1
	Respiratory cases (N)	70	22		178	314	583
	Patients who visited the hospital inclusive of the respiratory cases (N)	**241**	**101**		**861**	**938**	**1543**

ODRD: Other Diseases of Respiratory Diseases (common cold and Flu).

APPENDIX II: The Outdoor Meteorological Factors (Temperature and Relative Humidity) during the Dry and Rainy seasons

Site	Parameter	The Outdoor Temperature and Humidity (RH%) during the Dry season (April to June 2021)					The Outdoor Temperature and Humidity (RH%) during the Rainy season (October to December 2021)				
		Day 1	Day 2	Day 3	Average	Wind direction	Day 1	Day 2	Day 3	Average	Wind direction
A – Petrol Station	Temperature (°C)	22.93	23.13	23.13	**23.13±1.21**	SE	23.37	24.69	23.54	**23.87±0.72**	S
	Humidity (RH%)	61.45	64.79	64.79	**64.79±0.23**		51.67	54.60	60.00	**55.42±4.23**	
B – Garage	Temperature (°C)	19.44	20.49	16.89	**18.94±1.85**	E	23.52	20.98	22.93	**22.48±1.33**	SE
	Humidity (RH%)	71.57	67.35	76.07	**71.66±6.16**		68.67	67.73	61.10	**65.83±4.13**	
C – Mukuru	Temperature (°C)	19.74	20.05	18.98	**19.59±0.55**	SW	23.41	22.81	22.38	**22.87±0.52**	E
	Humidity (RH%)	71.06	71.27	66.45	**69.59±3.41**		49.96	60.88	63.95	**58.26±7.35**	
D – Land Mawe P. S	Temperature (°C)	19.96	18.55	20.01	**19.51±0.83**	S	23.19	24.26	25.18	**24.21±1.79**	E
	Humidity (RH%)	62.26	69.55	70.95	**67.59±0.99**		62.89	58.00	56.43	**59.10±3.37**	
E – Chiromo	Temperature (°C)	16.52	18.15	17.54	**17.40±0.82**	S	20.42	21.93	17.79	**20.05±2.09**	N
	Humidity	76.72	69.93	71.61	**72.76±1.19**		72.20	69.37	87.58	**76.38±9.80**	

APPENDIX III: The Indoor Meteorological Factors (Temperature and Relative Humidity) during the Dry and Rainy seasons

The Indoor Temperature and Relative Humidity during the Dry Season (April to June 2021)					The Indoor Temperature and Relative Humidity during the Rainy Season (October to December 2021)				
Site	Parameter	Day 1	Day 2	Day 3	Average	Day 1	Day 2	Day 3	Average
A - Petrol	Temperature (°C)	19.99	21.08	19.47	**20.28±1.14**	23.13	24.61	23.79	**23.84±0.74**
	Humidity (RH%)	67.22	69.76	77.55	**71.51±5.51**	60.15	59.66	63.65	**61.15±2.18**
B - Garage	Temperature (°C)	23.56	23.42	21.61	**22.86±1.09**	24.18	23.82	23.86	**23.95±0.20**
	Humidity (RH%)	59.5	59.57	69.87	**62.98±7.29**	61.57	65.78	58.64	**62.00±3.59**
C - Mukuru	Temperature (°C)	21.27	21.64	20.68	**21.20±0.48**	24.20	24.86	23.38	**24.14±0.74**
	Humidity (RH%)	63.82	62.8	64.1	**63.87±1.55**	46.46	57.98	65.63	**56.69±9.65**
D – Land Mawe P. S	Temperature (°C)	20.48	20.93	21.01	**20.81±0.28**	25.14	25.31	25.25	**25.23±0.08**
	Humidity (RH%)	90.04	87.92	90.06	**89.35±1.51**	76.86	76.82	74.17	**75.95±1.54**
E – Chiromo Campus	Temperature (°C)	18.41	19.31	19.17	**18.96±0.49**	22.16	22.34	21.66	**22.05±0.35**
	Humidity	68.32	70.01	67.76	**68.70±1.59**	62.56	59.62	65.28	**62.49±2.83**

APPENDIX IV: Atmospheric and Deposition Laboratory Conditions During Condition and Post Conditioning of Filter papers
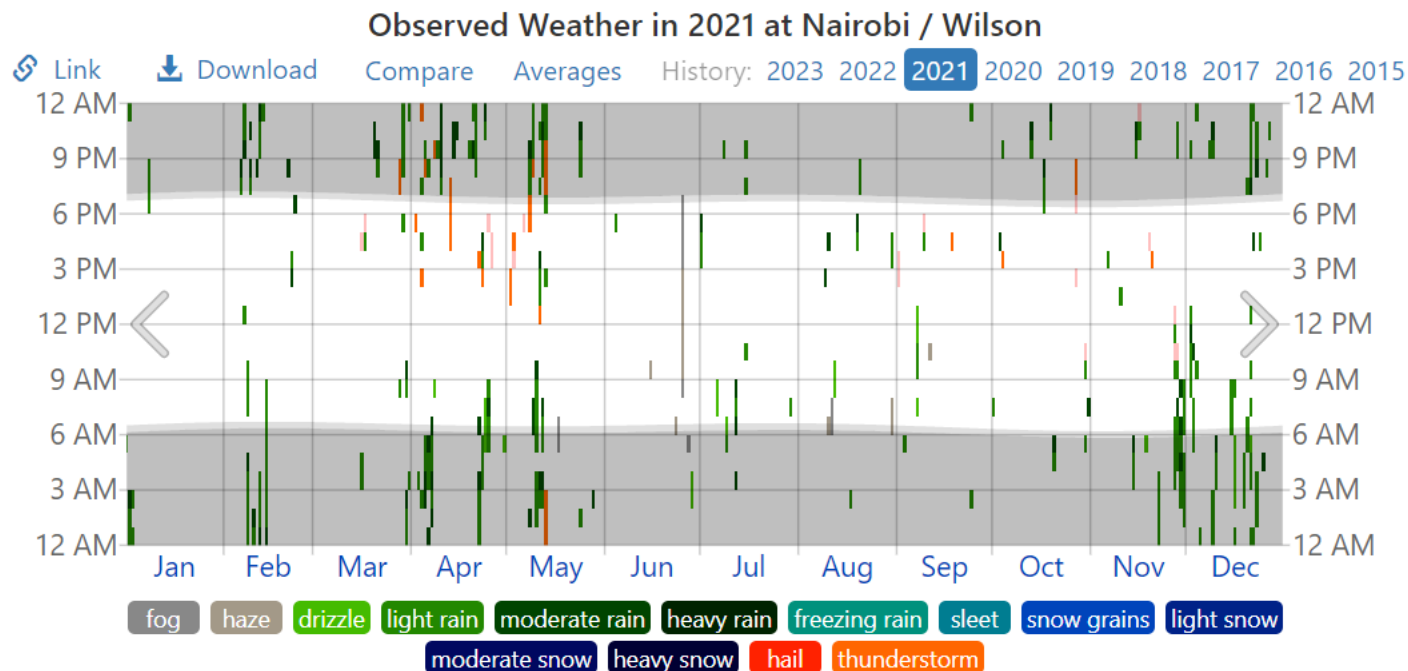
APPENDIX V: Atmospheric and Deposition Laboratory Conditions During Condition and Post Conditioning of Filter papers
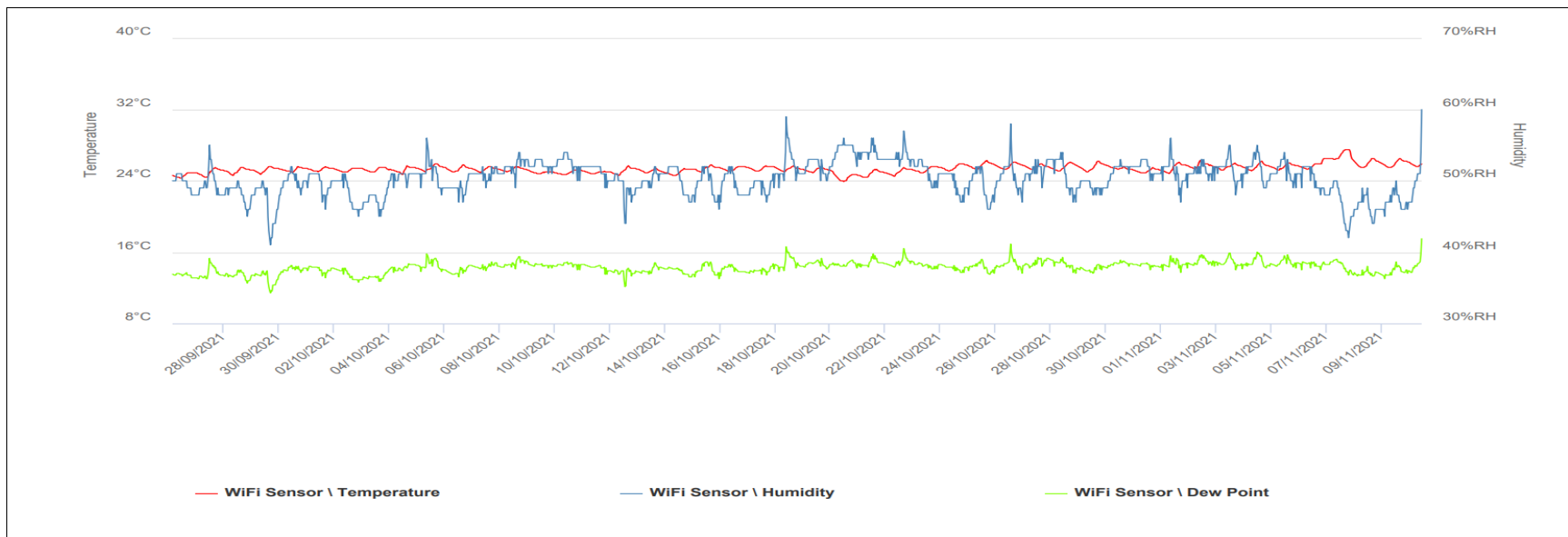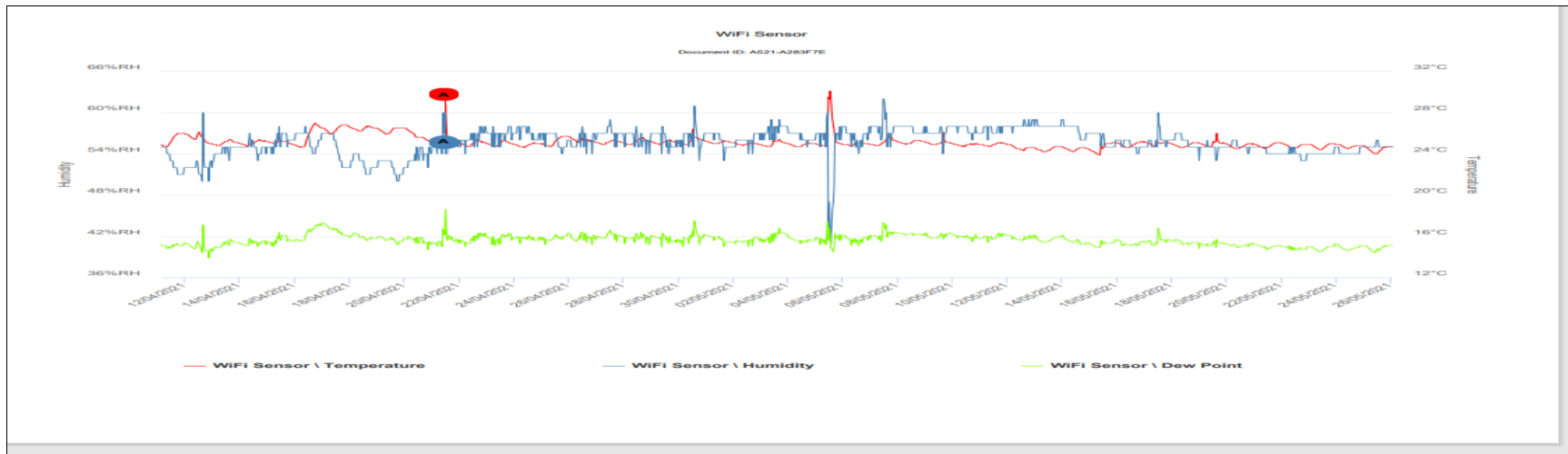
APPENDIX VI: Field Blanks and Labs Blanks Quality Control Charts (Pre-weigh and Post-weigh Difference plots).

Field Blank Quality Control Chart

Field blank mass difference (g) by post weigh date
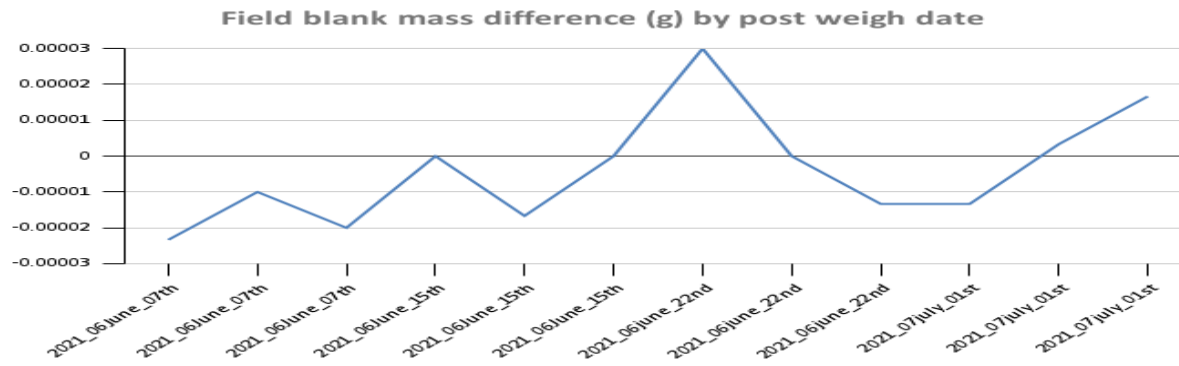
Lab Blanks Quality Control Chart
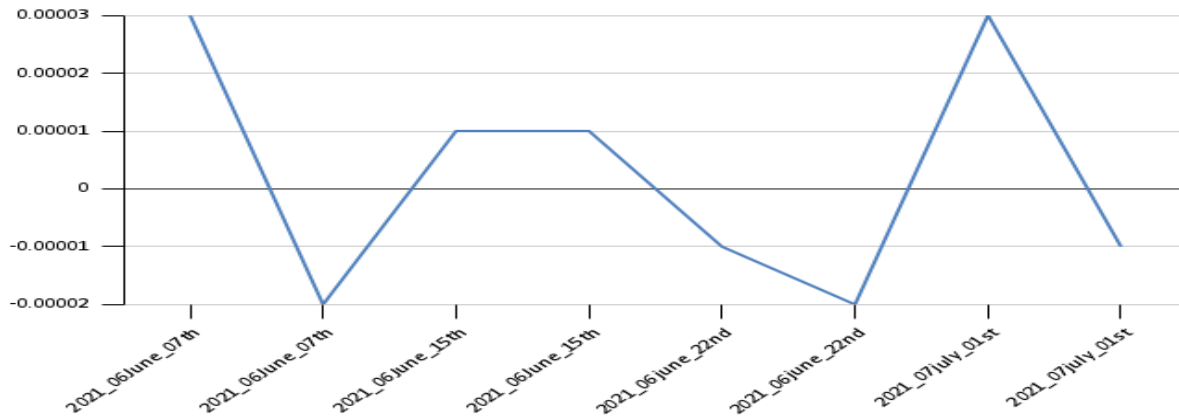
APPENDIX VII: Site A-D Indoor and Outdoor CO Concentration Peaks over Time during the Dry Season

Site A

Indoor CO concentrations Peaks
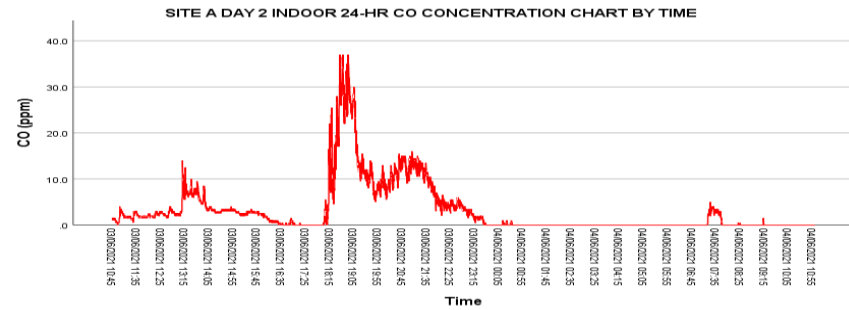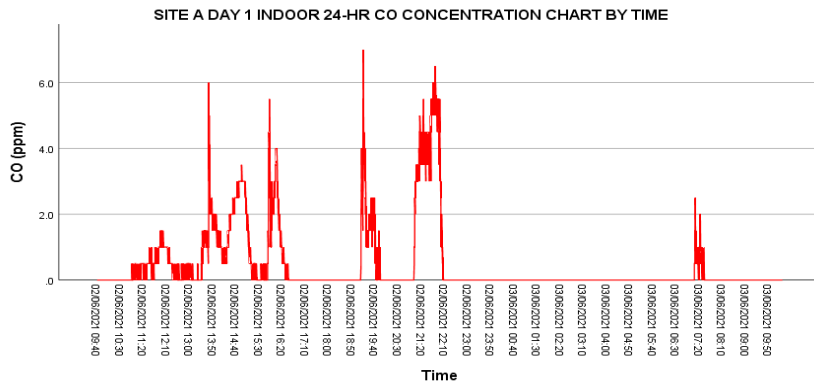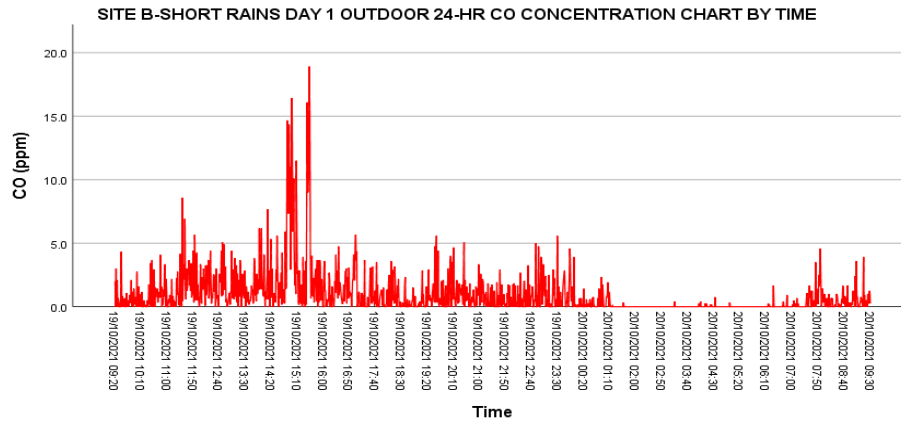

Site A Day 1 Indoor CO concentration Chart

Site A Day 2 Indoor CO concentration Chart
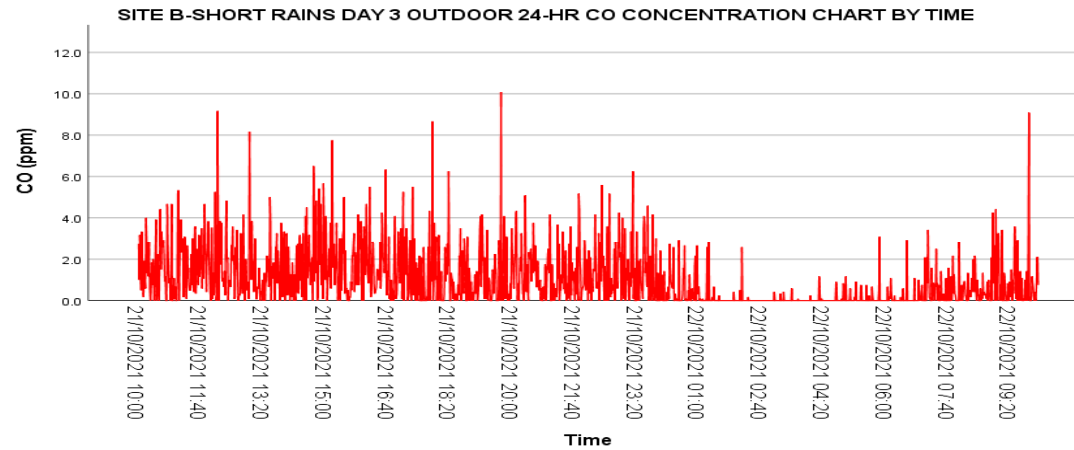

Site A Day 3 Indoor CO concentration Chart

Outdoor CO concentrations Peaks
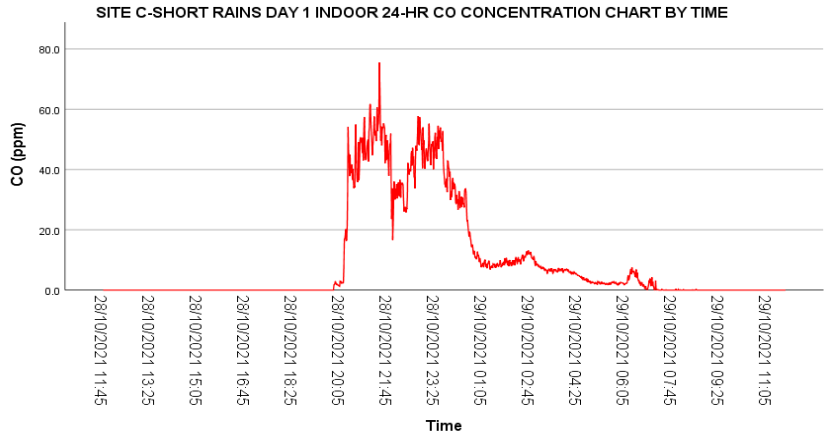

Site A Day 1 Outdoor CO concentration Chart
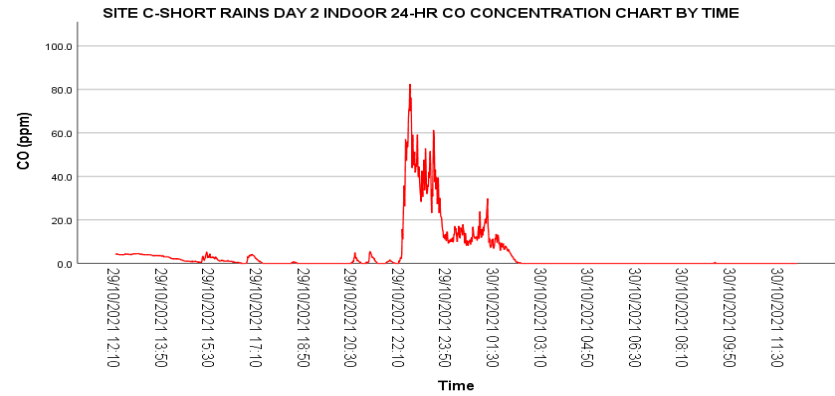

Site A Day 2 Outdoor CO concentration Chart
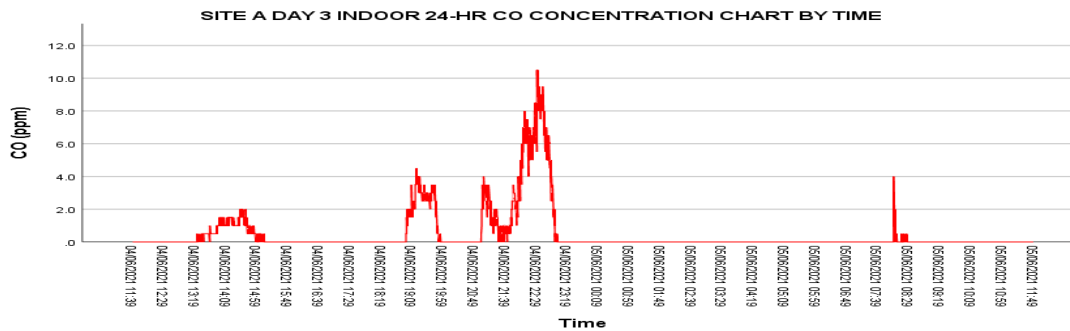
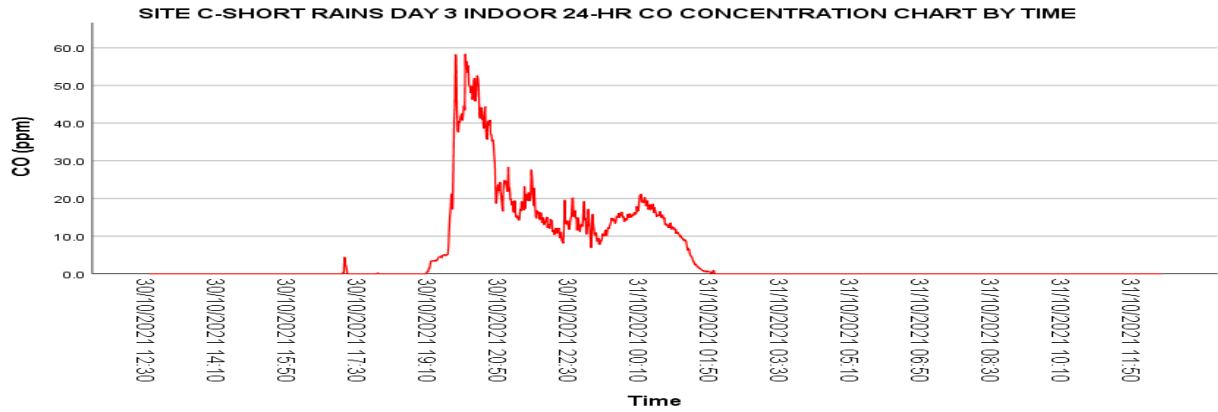**Site A Day 3 Outdoor CO concentration Chart**

Site B

Indoor CO concentrations Peaks
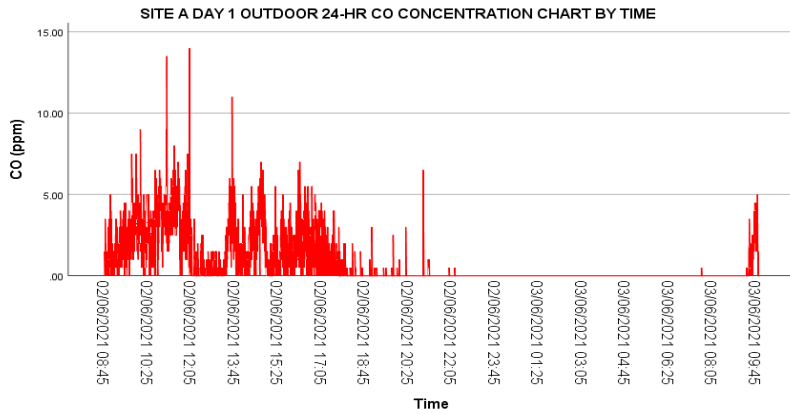
SITE B DAY 1 INDOOR 24-HR CO CONCENTRATION CHART BY TIME
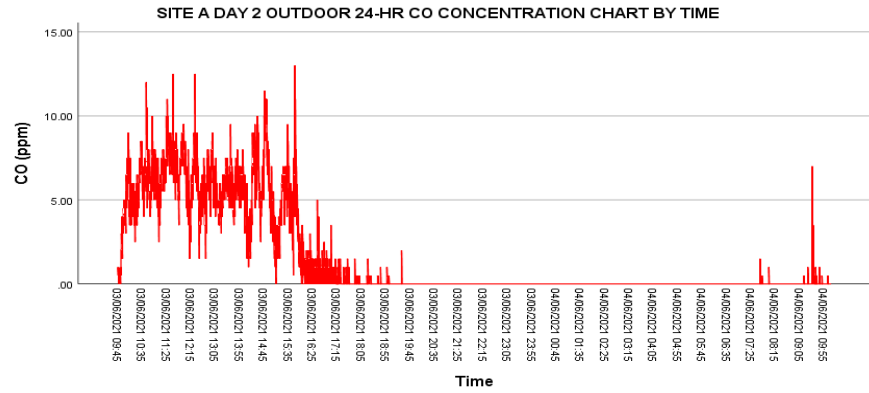
Site B Day 1 Indoor CO concentration Chart
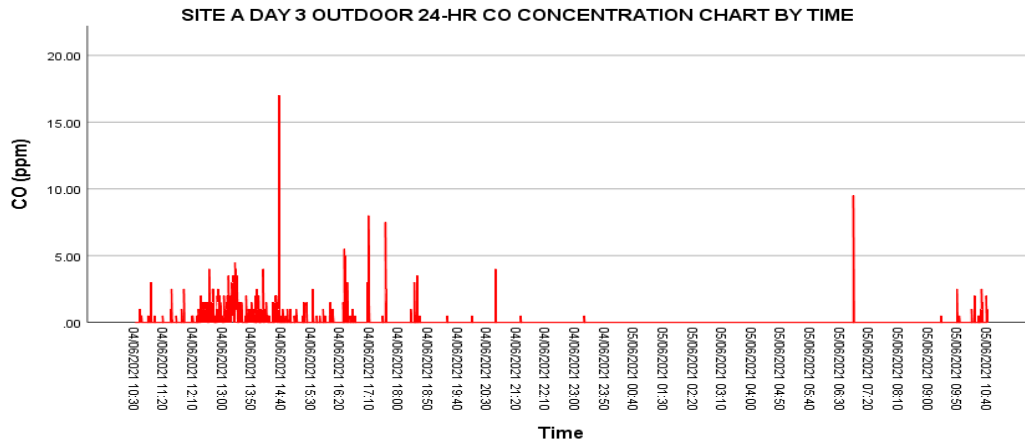
SITE B DAY 2 INDOOR 24-HR CO CONCENTRATION CHART BY TIME
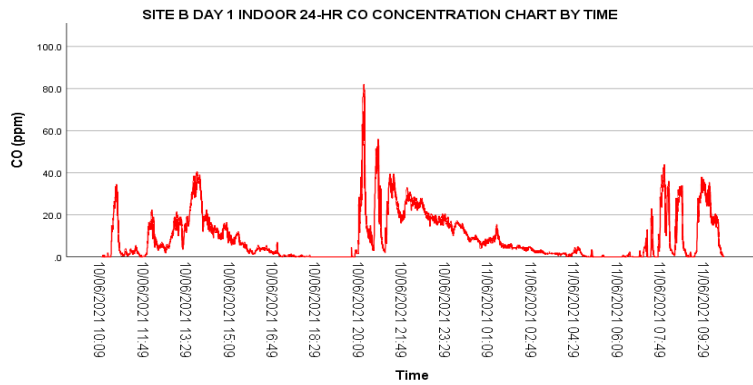
Site B Day 2 Indoor CO concentration Chart
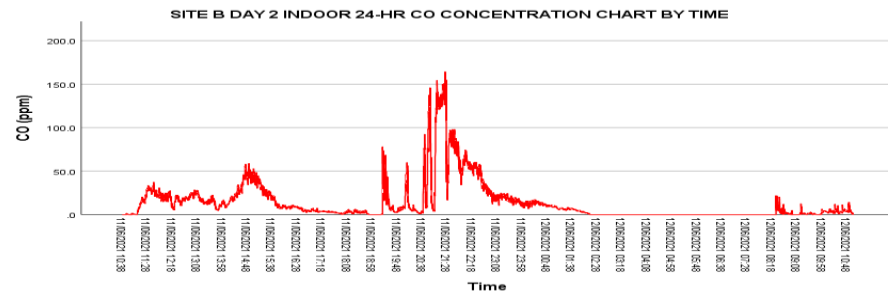
SITE B DAY 3 INDOOR 24-HR CO CONCENTRATION CHART BY TIME
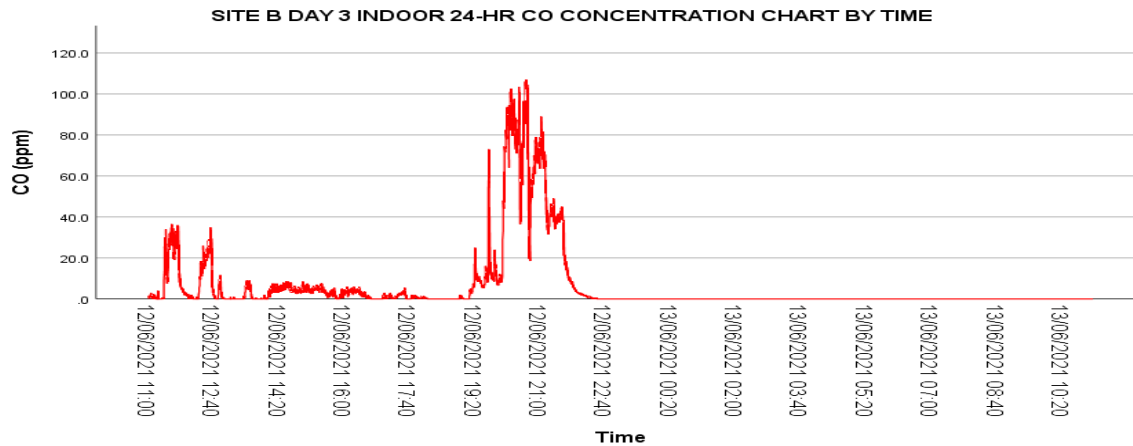
Site B Day 3 Indoor CO concentration Chart

Site B Outdoor CO concentrations Peaks

SITE B DAY 1 OUTDOOR 24-HR CO CONCENTRATION CHART BY TIME

Site B Day 1 Outdoor CO concentration Chart

SITE B DAY 2 OUTDOOR 24-HR CO CONCENTRATION CHART BY TIME

Site B Day 2 Outdoor CO concentration Chart

SITE B DAY 3 OUTDOOR 24-HR CO CONCENTRATION CHART BY TIME

Site B Day 3 Outdoor CO concentration Chart

Site C

Indoor CO concentrations Peaks

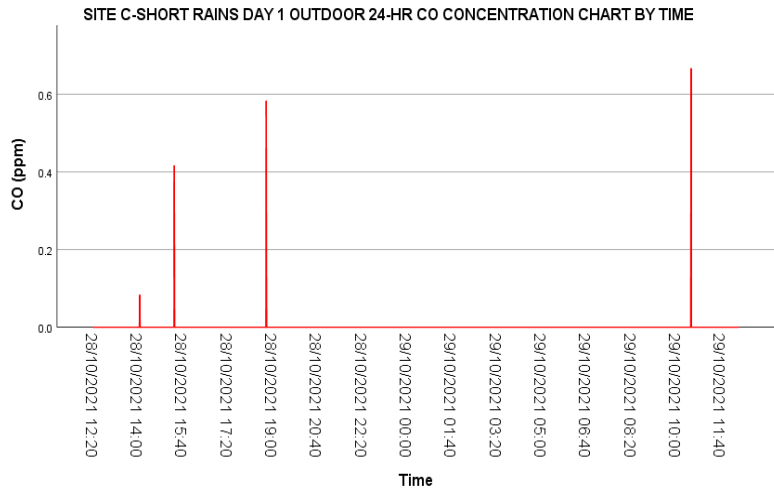**Site C Day 1 Indoor CO concentration Chart**

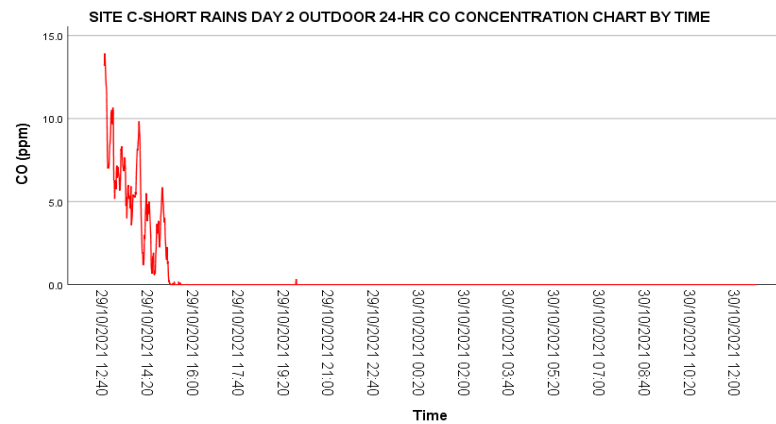**Site C Day 2 Indoor CO concentration Chart**

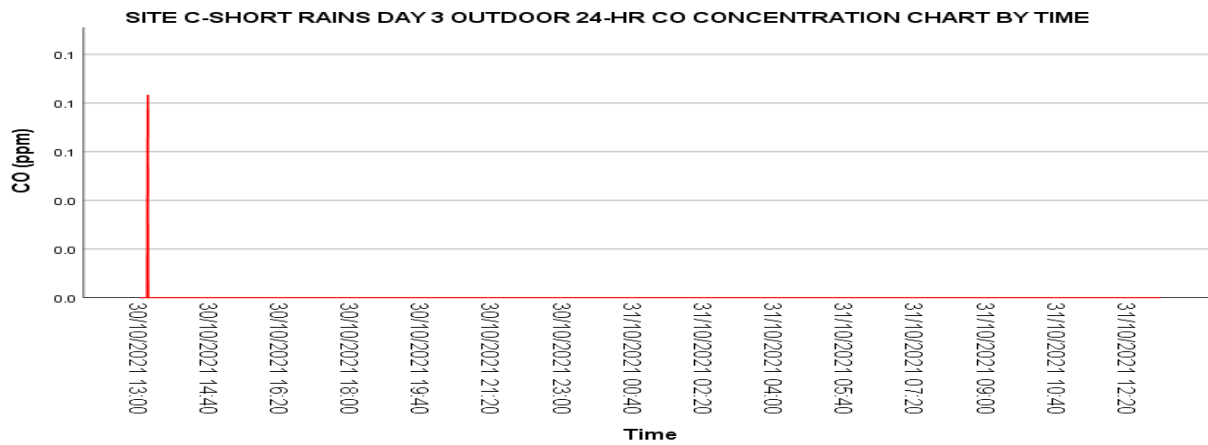**Site C Day 3 Indoor CO concentration Chart**

Outdoor CO concentrations Peaks

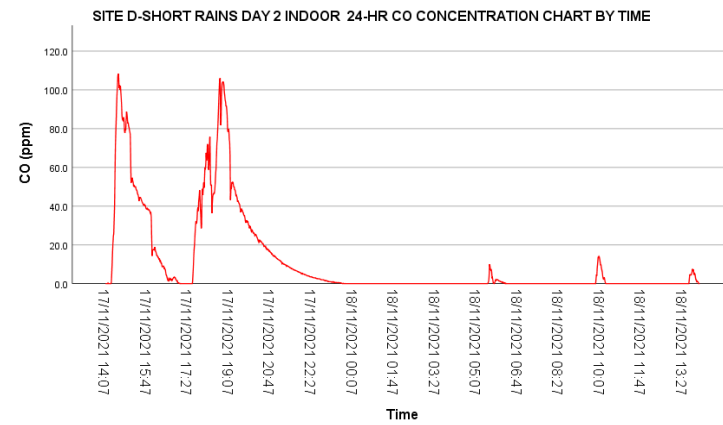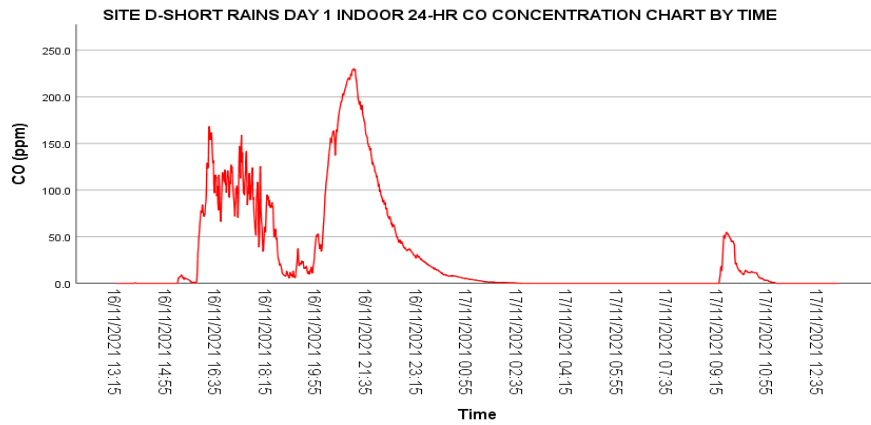Site C Day 1 Outdoor CO concentration Chart

Site C Day 2 Outdoor CO concentration Chart
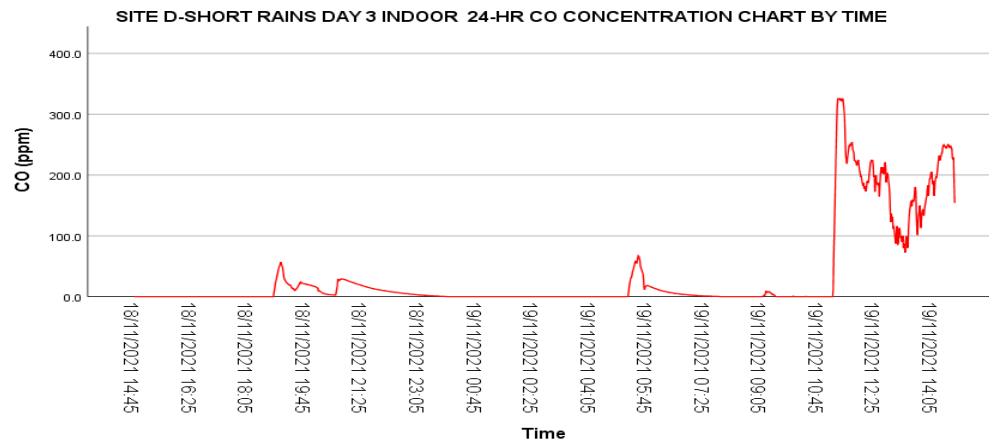

Site C Day 3 Outdoor CO concentration Chart

Site D

Indoor CO concentrations Peaks

Site D Day 1 Indoor CO concentration Chart

Site D Day 2 Indoor CO concentration Chart

Site D Day 3 Indoor CO concentration Chart

Outdoor CO concentrations Peaks

Site D Day 1 Outdoor CO concentration Chart

Site D Day 2 Outdoor CO concentration Chart

Site D Day 3 Outdoor CO concentration Chart

APPENDIX VIII: Site A- E Indoor and Outdoor CO concentration Peaks over Time during the Rainy Season

Site A
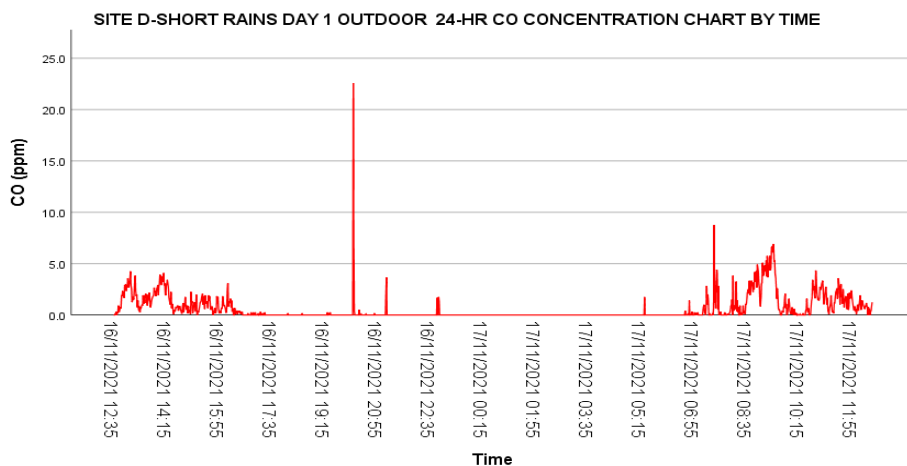
Indoor CO concentrations Peaks

Site A Day 1 Indoor CO concentration Chart

Site A Day 2 Indoor CO concentration Chart
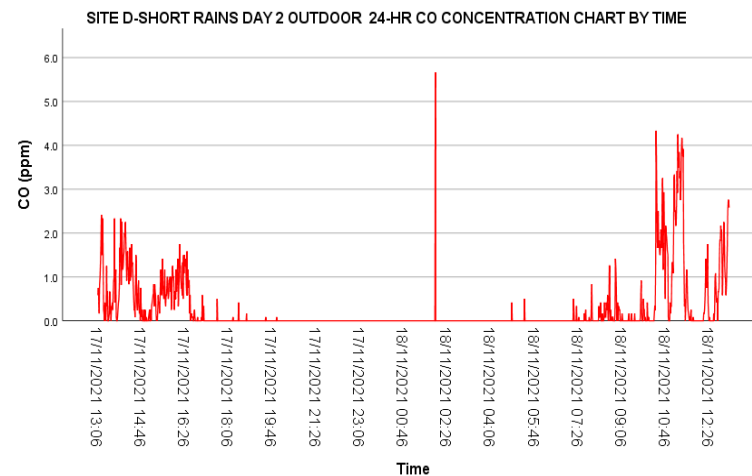

Site A Day 3 Indoor CO concentration Chart

Outdoor CO concentrations Peaks

Site A Day 1 Outdoor CO concentration Chart

Site A Day 2 Outdoor CO concentration Chart

Site A Day 3 Outdoor CO concentration Chart

Site B

Indoor CO concentrations Peaks

Site B Day 1 Indoor CO concentration Chart

Site B Day 2 Indoor CO concentration Chart

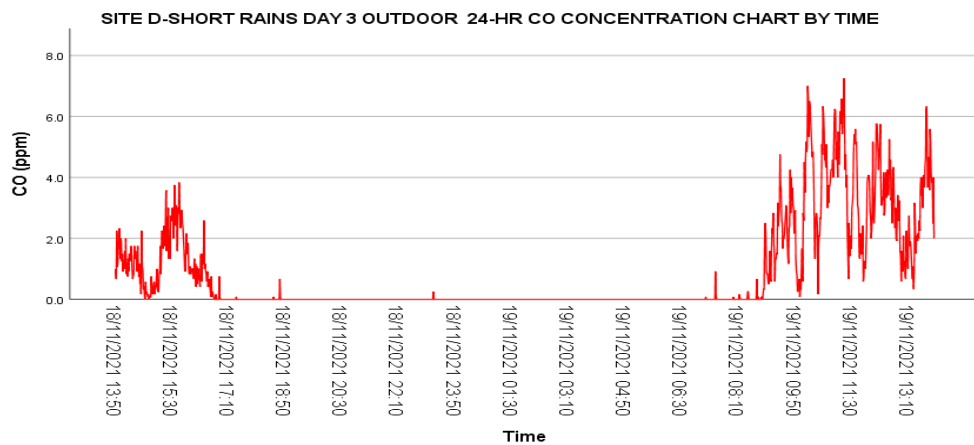**Site B Day 3 Indoor CO concentration Chart**

Outdoor CO concentrations Peaks

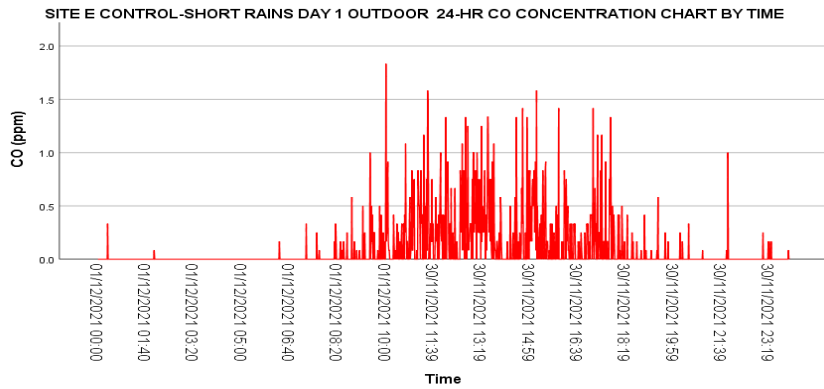
Site B Day 1 Outdoor CO concentration Chart

Site B Day 2 Outdoor CO concentration Chart

Site B Day 3 Outdoor CO concentration Chart

Site C

Indoor CO concentrations Peaks

Site C Day 1 Indoor CO concentration Chart

Site C Day 2 Indoor CO concentration Chart

Site C Day 3 Indoor CO concentration Chart

Outdoor CO concentrations Peaks

Site C Day 1 Outdoor CO concentration Chart
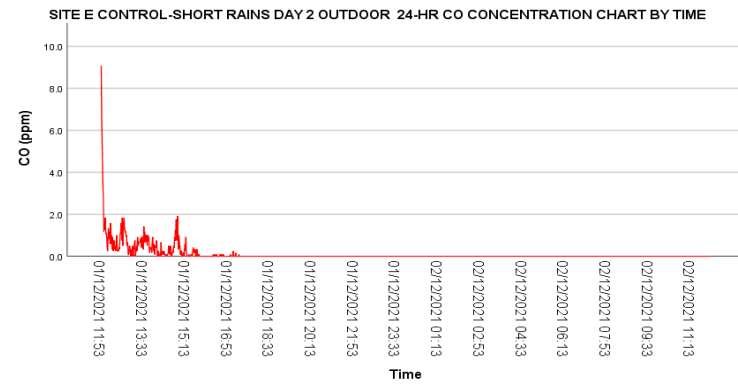

Site C Day 2 Outdoor CO concentration Chart
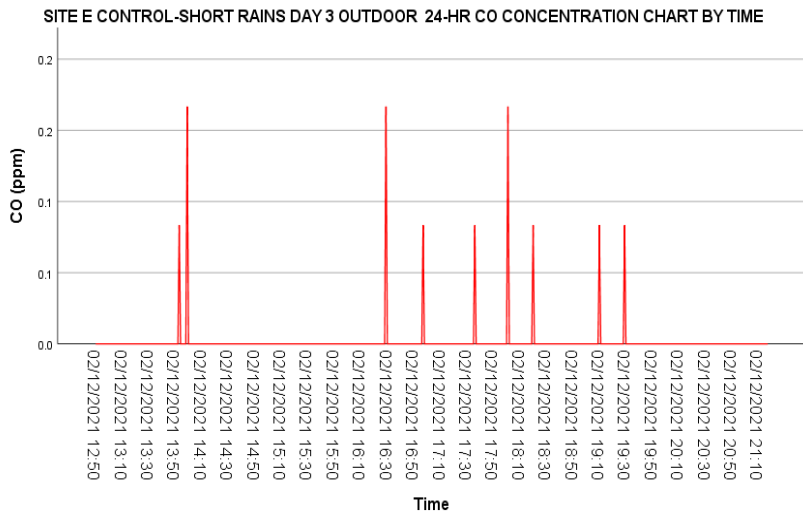

Site C Day 3 Outdoor CO concentration Chart

Site D

Indoor CO concentrations Peaks

Site D Day 1 Indoor CO concentration Chart

Site D Day 2 Indoor CO concentration Chart

Site D Day 3 Indoor CO concentration Chart

Outdoor CO concentrations Peaks

Site D Day 1 Outdoor CO concentration Chart

Site D Day 2 Outdoor CO concentration Chart

Site D Day 3 Outdoor CO concentration Chart

SITE E

Outdoor CO concentrations Peaks

Site E Day 1 Outdoor Site E CO concentration Chart

Site E Day 2 Outdoor CO concentration Chart

Site E Day 3 Outdoor CO concentration Chart

APPENDIX IX: National Commission for Science, Technology and Innovation (NACOSTI) permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: 241511

Date of Issue: 02/March/2021

RESEARCH LICENSE

This is to Certify that Mr.. VINCENT KIPYATOR KIPTER of University of Nairobi, has been licensed to conduct research in Nairobi on the topic: Assessment of Air Pollution and Related Health Effects in Densely Populated communities in Nairobi County, Kenya for the period ending : 02/March/2022.

License No: NACOSTI/P/21/9220

241511

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY &
INNOVATION

Recommended

COUNTY COMMISSIONER
NAIROBI COUNTY
P. O. Box 30124-00100, NBI
TEL: 341666

RECEIVED
ASSISTANT COUNTY COMMISSIONER
SOUTH - B DIVISION

Recommended

DEPUTY COUNTY COMMISSIONER
STAREHE SUB-COUNTY
P. O. Box 30124-00100,
NAIROBI