ASSESSMENT OF AIR QUALITY, NOISE LEVELS AND HEAVY METAL CONCENTRATIONS DURING DRY AND RAINY SEASONS FROM INDUSTRIAL AREAS OF BLANTYRE CITY, MALAWI

MASTER OF SCENCE IN ENVIRONMENTAL PROTECTION AND MANAGEMENT DISSERTATION

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UNIVERSITY OF MALAWI
THE POLYTECHNIC

JULY, 2024

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MASTER OF SCIENCE IN ENVIRONMENTAL PROTECTION AND MANAGEMENT DISSERTATION

By

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A Dissertation Submitted to the Department of Physics and Biochemical Sciences, Faculty of Applied Sciences, in Partial Fulfilment of the Requirements for the Degree of Master of Science in Environmental Protection and Management

University of Malawi
The Polytechnic

JULY, 2024

DECLARATION

I, the undersigned, hereby declare that the work presented for the thesis entitled "Assessment of air quality, noise levels and heavy metal concentrations during dry and rainy seasons from industrial areas of Blantyre city, Malawi" is my own work and has not been submitted to any other institution for similar purposes. It has not been submitted for any degree or examination to any university or college.

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CERTIFICATE OF APPROVAL

We, the undersigned certify that we have read and hereby recommend for acceptance by the University of Malawi, The Polytechnic a thesis entitled "*Assessment of air quality, noise levels and heavy metal concentrations during dry and rainy seasons from industrial areas of Blantyre city, Malawi*."

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DEDICATION

To all those who I hold dear to my heart, thank you.

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ABSTRACT

This research investigated concentration of air quality, heavy metals and noise levels from industrial areas in Blantyre City, Malawi. Air, noise, and soil samples were collected in both dry and rainy seasons at 15 industrial sites based in Makata, Limbe, Maselema, Chirimba and Maone in Blantyre. Sampling and analysis of air, noise and soil employed the use of standardized methods detailed in the American Public Health Association (APHA), Canada Standards, English Standards as well as Malawi Standards (MS). Air was analyzed for Carbon Monoxide (CO), Total Suspended Particles (TSP), Particulate Matter 10 (PM_{10}) and Particulate Matter 2.5 ($PM_{2.5}$). Heavy metals were assessed using Atomic Absorption Spectrophotometry (AAS). Soil was analyzed for pH, electrical conductivity, Cadmium (Cd), Copper (Cu) and Zinc (Zn). Noise levels were also recorded using a noise level meter. In the rainy season, the average concentration values of CO, TSP, PM_{10}, and $PM_{2.5}$ were 0.49 ± 0.65 mg/m^3, 85.03 ± 62.18 µg/m^3, 14.65 ± 8.13 µg/m^3, and 11.52 ± 7.19 µg/m^3, respectively. Dry season average concentration values increased to 1.31 ± 0.81 mg/m^3, 99.86± 30.06 µg/m^3, 24.35 ± 9.53 µg/m^3, and 18.28 ± 7.14 µg/m^3. Noise levels remained below public MS and WHO standards (85 dB). Chirimba AP had the highest mean Zn concentrations of 822 mg/kg in the rainy season and 579 mg/kg in the dry season. Maone NM had the highest Cd concentrations, measuring 2.09 mg/kg in the rainy season and 3.06 mg/kg in the dry season. Chirimba AP also had the highest Cu concentrations with levels of 105 mg/kg in the dry season and 79 mg/kg in the rainy season. The study found that the 87 % of soil sample concentrations were in line with England's stipulated standards for heavy metal concentrations, with exceptions noted in specific instances like Chirimba AP and Makata LF, where concentrations surpassed the defined limits signifying a health concern. In the rainy season, the range of soil mean pH was 6.3 - 7.83 while in the dry season it was 6.67 - 8.15. In the rainy season, the range of soil mean electrical conductivity was 24.3±0.35 µS/cm - 265±0.42 µS/cm while in the dry season it was 43.8±0.49 µS/cm - 2353±5.508 µS/cm. Source apportionment of air quality parameters as well as heavy metals showed various factors contributing to the respective concentrations. A geo-accumulation index analysis of heavy metals in soil was done to assess potential contamination risks and Zn was shown to be a major contaminant, presenting an ecological and pollution risk. The results of the source apportionment analysis using Positive Matrix Factorization (PMF) model indicated that air and heavy metal pollution were mainly caused by (1) metal processing and manufacturing industries, (2) plastic manufacturing industries (3) cement manufacturing industries, (4) food manufacturing industries, (5) beverage manufacturing industries and (6) furniture manufacturing industries. It was recommended for periodic sampling be done to observe the seasonal pollution trends considering potential impacts on public health and environmental sustainability. Further studies should look at factors affecting the dynamics of PMF in Blantyre City. This will help in putting up measures that can help to control the release of pollutants and ensuring public health.

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LIST OF ACRONYMS/ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
AOAC	Association of Official Analytical Chemists
APHA	American Public Health Association
AR	Analytical Reagent
BCA	Blantyre City Assembly
CEQS	Chinese Environmental Quality Standards
CMB	Chemical mass balance
CO	Carbon monoxide
DEAP	District Environmental Action Plan
DOE	Department of Environment
EC	European Commission
EIA	Environmental Impact Assessment
EOS	Earth Observing System
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
FA	Factor Analysis
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GoM	Government of Malawi
GPR	General Purpose Reagent
GPS	Geographical Positioning
HC	Hydrocarbons
HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectory
IBM SPSS	International Business Machines Statistical Package for the Social Sciences
IPCC	Intergovernmental Panel on Climate Change
LAi	A-weighted instantaneous sound pressure level
LPDM	Lagrangian Particle Dispersion model
MDGs	Millennium Development Goals
MGDS	Malawi Growth and Development Strategy

MODIS	Moderate Resolution Imaging Spectroradiometer
MSB	Malawi Standards Board
NEAP	National Environmental Action Plan
ND	Not Detected
NMVOCs	Non-Methane Volatile Organic Compounds
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrogen Oxides
O_3	Ozone
PPE	Personal Protective Equipment
PIC	Prior Informed Consent
PM	Particulate Matter
POPs	Persistent Organic Pesticides
RDP	Rural Development Project
READY	Real-time Environmental Applications and Display System
SADC	Southern African Development Community
SDGs	Sustainable Development Goals
SOER	State of Environment Report
SO_2	Sulfur Dioxide
Sox	Sulfur Oxides
SSA	sub-Saharan Africa
UN	United Nations
USA	United States of America
US-EPA	United States Environmental Protection Agency
VOCs	Volatile Organic Compounds
WHO	World Health Organization

LIST OF APPENDICES

CHAPTER ONE: INTRODUCTION AND BACKGROUND

1.1 Background of the study

Pollution is a human-induced activity that leads to the introduction of substances or energy into water, air, or soil, either directly or indirectly. These additions have harmful effects on living organisms or structures that we aim to protect, and they also diminish the overall quality of water, air, or soil for future utilization (Thulu, 2023). Currently, pollution stands as one of the most pressing challenges on a global scale, impacting not only developed nations but also extending its detrimental effects to developing countries. Both living and non-living entities are experiencing adverse consequences as a result (Prabhu, 2022) which is a deterrent to growth and prosperity of the nation. Al-Taani et al. (2018) stated that the outcome of pollution of an area is far reaching as it is cross-boundary, aids in climate change and global warming which have their roles in reducing consumable food, altering water resources, deteriorating buildings as well as leading to the rise in sea levels as well as recurrence of harsh weather conditions. Pollution stems from many sources, however, industries significantly contribute to environmental degradation which includes that of air, soil and noise quality (Manojkumar et al., 2019; Assanov et al., 2021; Hsu et al., 2021).

The issue of air pollution has escalated significantly, posing detrimental effects on both health and environmental sustainability. This problem arises from the release of harmful substances, including volatile organic compounds (VOCs), into the atmosphere through numerous industrial processes involved in manufacturing and energy generation (Al-Taani et al., 2018; Nazzal et al., 2021). Air pollution is described as a detrimental phenomenon to the ecological system and the regular conditions of human existence and development, occurring when certain substances in the atmosphere surpass a specific concentration (Bai et al., 2018). As stated by the World Bank (2019), in Malawi, air pollution is considered the second-highest risk factor which causes death and disability (after poor water and sanitation) and is ranked the fourth-highest risk factor overall [after malnutrition, unsafe sex, and poor water and sanitation]. Jhanwar (2016) described noise pollution as the presence of excessive noise that has the potential to disturb or disrupt the activities and equilibrium of human beings. Noise pollution is usually denoted by sounds which are of nuisance in nature and these do not only affect people but animals as well (Maqsood et al., 2019). Various noise sources contribute to environmental noise, with industrial activities such as machinery, heavy equipment, and transportation being the primary culprits. These sources of noise not only impact the environment but also create discomfort for the surrounding community (Osei & Effah, 2022). This is also highlighted in a study conducted in Blantyre, Malawi which showed that noise levels in most industries are above the acceptable limit level of 85 dBA (Chirwa et al., 2019).

Soil heavy metal pollution denotes the presence of heightened levels of metallic elements characterized by high atomic weights and densities. This contamination has the potential to harm organisms and plants by disrupting the metabolic functions of crucial organs and glands (Timothy & Tagui Williams, 2019). Li et al. (2020) iterated that heavy metal contamination of soil is another environmental problem with extensive consequences for biotic and abiotic resources through the accumulation of elements such as lead, cadmium, mercury, and arsenic on land mainly from industrial activities. These elements have persisted for long periods of time, threatened the processes in nature, agricultural output, as well as human health via the food web (Masindi & Muedi, 2018; Eijsackers et al., 2020). A study conducted by Malikula et al. (2022) in Blantyre City examined the presence of heavy metals and nutrient loads in water, soil, and crops irrigated with wastewater treatment plant (WWTP) effluent. The findings revealed that plants irrigated with WWTP effluent exhibited elevated levels of these metals, surpassing both Malawi Standards and the permissible limits set by the World Health Organization (WHO) which shows the persistent nature of heavy metals.

As previously emphasized, industries play a significant role as the primary contributors to heavy metal pollution in soil, air, and noise. Therefore, a thorough examination of the various forms of pollution generated by industrial sites, including their origins and impacts, is crucial. This analysis is essential for elucidating industrial practices and implementing stringent regulations to alleviate the adverse effects of pollution resulting from industrial activities. Kuerban et al. (2020) defined Positive Matrix Factorization (PMF) as an analytical tool which has efficient capabilities in general source allocation and aids in identifying sources through multivariate factor analysis. The areas where this study was centered were namely Makata, Limbe, Maselema, Chirimba and Maone industrial sites in Blantyre district.

1.2 Problem statement

More than 80% of Malawi’s industrial sector is dominated by manufacturing, agricultural as well as structural and construction materials production (Commonwealth of Nations, 2020) which increases the likelihood of environmental pollution through release of fumes, effluent and other forms of emission emanating from line operations. There have been limited studies involving an analysis of particulate matter 2.5 ($PM_{2.5}$), particulate matter 10 (PM_{10}), total suspended particles (TSP), carbon monoxide (CO), and noise levels around the main industrial areas in Blantyre namely, Makata, Limbe, Maselema, Chirimba and Maone. Assanov et al., (2021) stated that this indicates a knowledge gap in industrial regions, considering that other countries have successfully conducted similar studies to assess the extent of pollution in these areas. This is crucial for protecting public health, preserving the environment, ensuring regulatory compliance, formulating effective policies, fostering international collaboration, gaining investor confidence, raising community awareness, and promoting long-term sustainability. Several studies have examined outdoor air pollution, including one that highlighted the impact of Blantyre City's major highway and industrial areas (Makata) on air quality. The study revealed that the presence of non-methane volatile organic compounds (NMVOCs) and carbon monoxide (CO) levels contributed to the deterioration of air quality in these locations (Mapoma & Xie, 2013). As per Malawi State of Environment and Outlook Report (GoM, 2010), a few studies, such as the one on spatial variation of volatile organic compounds and carbon monoxide in Blantyre City, Malawi (Mapoma et al., 2013), have been done specifically to analyze the levels of pollution surrounding some selected industrial areas in Malawi.

There is lack of thorough and updated assessments of heavy metal pollution related to the above mentioned industrial areas in Blantyre Malawi and most of these studies have focused on a few of the specified industrial locations (Kaonga et al., 2017).

The selection of parameters, specifically $PM_{2.5}$, PM_{10}, CO and TSP, was based on their association with decreased lung function and increased hospital admissions resulting from short-term exposure (Liu et al., 2017). Additionally, these parameters were chosen due to the availability of sampling equipment which could not accommodate other parameters such as sulfur dioxide (SO_2) and nitrogen dioxide (NO_2). Cd, Zn and Cu were selected because it was determined that in large doses these heavy metals may cause symptoms which are irreversible in people who are exposed (Brifa et al., 2020). Furthermore, these heavy metals were selected because the cathode lamps to be used for the Atomic Absorption Spectrophotometer were available unlike those for other heavy metals like chromium (Cr) and iron (Fe) which were unavailable due to lack of stock from suppliers within

Malawi. Notably, importation costs for those cathode lamps were expensive. Noise level was chosen because it was identified as injurious to the health of those exposed if levels were higher than 85dB in any one day (Government of Malawi, 2019). Furthermore, the monitoring equipment was readily available.

The importance of this research lies in its ability to monitor these industrial areas, allowing for the early identification of hazardous conditions. This, in turn, facilitates well-informed decision-making and the formulation of specific measures to decrease pollution levels, ultimately safeguarding the environment and communities.

1.3 Study objectives

1.3.1 Main objective

The main objective of this study was to assess concentration levels of air quality, heavy metals and noise levels from industrial areas in Blantyre City, Malawi.

1.3.2 Specific objectives

The specific objectives were to:

1. To determine the concentration levels of air quality (CO, TSP, $PM_{2.5}$ and PM_{10}), heavy metals (Cd, Zn, and Cu) and noise levels from sites in industrial areas (Makata, Limbe, Maselema, Chirimba and Maone).
2. To examine sources (source apportionment) of CO, TSP, $PM_{2.5}$, PM_{10}, Cd, Zn, and Cu in the industrial areas.
3. To determine the movement pattern of the air pollutants using trajectory models from National Oceanic and Atmospheric Administration (NOAA).

1.4 Significance of study

This study provides baseline information on air quality, noise levels and heavy metals in soil from the main industrial areas in Blantyre, Malawi. This is a baseline study, as there hasn't been a comprehensive evaluation, all in one study of the levels of diverse environmental pollution around the primary industrial sites in Blantyre, Malawi. The study also helps in providing information on the sources of the various pollutants and recommendations on how these can be managed.

Furthermore, in Malawi, air pollution is considered the second-highest risk factor that causes death and disability which is a problem in need of solving. Identifying noise prone sites and implementing mitigation measures helps reduce the industrial sites' ecological footprint and aids in preserving biota. Assessing heavy metals helps in identifying areas of contamination and potential environmental risks and aids in policy enforcement and/or amendment. Holistically, this study assists in improving the industrial area's environmental quality which leads to policy enforcement and decision making on positioning and management of such sites in relation to the surrounding communities as well.

1.5 Study limitations

There was limited existing data on outdoor air quality, noise levels and heavy metals from industrial sites in Blantyre District due to lack of stringent regulations or enforcement mechanisms related to industrial emissions resulting in a lower priority for monitoring activities, leading to limited available data. Another limitation was related to the inability to sample during the nighttime due to security concerns since the sampling was not done within the industrial compounds.

To mitigate the existence of limited data on outdoor air quality, noise levels and heavy metals, targeted environmental sampling was conducted, and the available limited data in literature was utilized. It was difficult to mitigate the inability to sample during the night due to logistical hindrances, however, it is recommended for future researchers to use sensors and samplers which are automated that can operate independently, collecting data during the night without the physical presence of the sampling team.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

In this chapter, research insights from previous studies have been shown. Conceptual frameworks for air, noise and soil quality have been explained from literature and their analytical aspects such as in Malawi have been underscored. More to that, air, noise, and soil pollution across the globe including Malawi have been outlined.

2.2 Environmental pollution in industrial areas

Industrial areas are characterized by various forms of pollution, including air, water, soil, and noise pollution (Prabhu, 2022). Ukaogo et al. (2020) stated that some emissions are sourced from man-made events as well as anthropogenic phenomena, however, some are from other forms of pollution. These pollutants often result from emissions, discharges, and waste generated by industrial processes. Industries emit pollutants such as particulate matter, sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and heavy metals (Zhang et al., 2020). These emissions come from processes like combustion, chemical reactions, and transportation (Khan et al., 2019; Zhao et al., 2020). Kelishadi (2012) iterated that pollution of the environment contributes significantly to long term changes in temperature and weather patterns which have deteriorating effects on people’s health such as infant death, respiratory problems, allergies, perinatal disorders, mental disorders and more. Industrial effluents contain harmful chemicals, heavy metals, and organic compounds, which can contaminate water bodies (Ukah et al., 2019). Prabhu (2022) stated that common sources of pollutants include wastewater discharges and accidental spills. Industries may release contaminants into the soil through improper disposal of hazardous waste, leakage from storage tanks, and landfills (Anwar et al., 2021). Maqsood et al. (2019) emphasized that noise pollution in industrial areas can have adverse effects on the well-being of both workers and nearby residents and is mostly generated by machinery, equipment, and transportation. Pollution can harm ecosystems, leading to biodiversity loss, disruption of natural processes, and damage to aquatic and terrestrial habitats (World Bank, 2019). Exposure to industrial pollutants can lead to a range of health issues, including respiratory diseases, cancer, neurological disorders, and reproductive problems (Laden et al., 2000; Olatunde et al., 2020). Choi et al. (2019) highlighted that industries have adopted various pollution control technologies, such as air scrubbers, wastewater treatment plants, and pollution prevention measures, to reduce their environmental footprint. Green technologies and sustainable practices, such as renewable energy adoption and circular economy principles, are gaining importance in mitigating industrial pollution (Muchaendepi et al., 2019).

2.3 Air pollution in industrial areas

Air pollution is described as a detrimental phenomenon to the ecological system and the regular conditions of human existence and development, occurring when certain substances in the atmosphere surpass a specific concentration (Bai et al., 2018). Industries are the main sources of air quality pollution and the developing countries are at high risk from the health effects related to this (Assanov et al., 2021). As such, this places a requirement to study trends in industrial emissions. Saleh et al. (2021) conducted a study in Malawi on monitoring of individual air quality which revealed that particulate levels often surpassed the upper limits recommended by the WHO, even when no identifiable sources of biomass burning were present. Freijer and Bloemen. (2000) stated that atmospheric pollution from the immediate surrounding environment serves as a main source of pollutants which are in gaseous form. The outcome of pollution of an area is far reaching as it is cross-boundary, aids in climate change and global warming which have their roles in reducing consumable food, altering water resources, deteriorating buildings as well as leading to the rise in sea levels as well as recurrence of harsh weather conditions (Al-Taani et al., 2018). Every country is showcasing an incline in greenhouse gas emissions from the industrial sector. This is evidenced by the carbon dioxide emissions from fossil fuel usage and associated industrial activities which have contributed approximately 78 % of the total GHG emission increase from 1970 to 2010, which was similar to the values found in the year 2000 to 2010 (IPCC, 2014). Many studies relate assessment of air quality in urban areas to growth of cities and increase in population with its associated effects on over-usage of fuel for domestic, transportation and industrial processes (Vargas, 2003; Wong et al., 2008). Zhu et al. (2023) stated that industrial facilities such as factories, power plants, chemical plants, and refineries emit a variety of pollutants, including particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), carbon monoxide (CO), and heavy metals like mercury and lead. Some well-known types of air pollutants found in urban areas are carbon monoxide (CO) and volatile organic compounds (VOCs) which are mostly sourced from fossil fuel use such as coal and gasoline (Ho et al., 2003; Anderson et al., 2010; Chen et al., 2011; Sun et al., 2020). In relation to transportation, industrial areas often have high traffic volumes, contributing to air pollution through vehicle emissions of pollutants like NO_x and particulates (Wang et al., 2019). Every country is showcasing an incline in greenhouse gas emissions from the industrial sector. In a study area in Portugal, the usual meteorological aspects related to emissions from the locality, mostly industrial work, and movement of vehicles are the main sources of air quality depletion (Figueiredo et al., 2013; Clark et al., 2020). Pollution of the environment which has contributed significantly to long term changes in temperature, growth of cities, population rise, and use of vehicles as well as the boom in industrialization has greatly influenced the rise in air pollution (Akimoto, 2003). Engines which run on diesel, that are part of mobile sources, emit considerably reduced levels of CO and hydrocarbons (HC) than those which run on petrol (Bendelius, 1996; Anyanwu et al., 2018; Shrivastava et al., 2018). Furthermore, the diesel operating engines release an elevated portion of NO_x and SO_x in comparison with petrol running engines (Chan et al., 1997; Olatunde et al., 2020). Laumbach (2010) stated that the effect of air pollutants on people relies on period of exposure and how sensitive the individuals are to the specific constituent(s) in the polluted air. The growth of cities and increase in population size has directly led to the incline on emission from mobile and stationary fuel sources. Motor vehicles, motorcycles and locomotives are examples of mobile sources which make up a good portion of overall emissions in main cities (Mejia-Velazquez & Rodriguez-Gallegos, 1997; Holloway & Ii, 2000; Makra et al., 2010; Wang et al., 2019). Construction and demolition projects generate dust and emissions which contribute to localized air pollution. Ukaogo et al. (2020) further emphasized that, incineration, landfill sites, and waste treatment facilities release pollutants into the air, including methane (a potent greenhouse gas). Many studies have conducted, scrutinized as well as reported these harmful effects and impacts which may be minor or major diseases such as asthma, leukemia, lung cancer, stroke, premature births, death, and more which means that long-term exposure to certain industrial pollutants, such as benzene or formaldehyde, may increase the risk of cancer (Laden et al., 2000; Pope III et al., 2002; Akinsanmi et al., 2019; Aguilar-Gomez et al., 2022). Alam et al. (2018) stated that exposure to air which is polluted has shown to be the source of grave human diseases, especially in highly polluted localities including industrial areas. Weather patterns also have deteriorating effects on people's health such as infant death, respiratory problems, allergies, perinatal disorders, mental disorders and more (Kelishadi, 2012; Thomson, 2019). Wong et al. (2008) iterated that in the current times, many studies have been conducted to relate pollution of the air to people's health and state of ecology. It has been stated that a significant portion of the disease burden is attached to hazards from the environment of which air pollution takes the lead (WHO, 2006; Tong, 2019).

It is very essential to have clean air to be assured of quality health because a deviation in this would lead to deleterious effects on health of organisms as well as sustainability in the environment at large (Desauziers, 2004; Ali & Athar, 2008; Rafaj et al., 2018). "The nature and significance of air quality issues depend on many factors. Such factors include size of a city, physical and chemical industrial processes, meteorological processes, geographical features, and social factors" (Pires et al., 2008; Zhu et al., 2023). Sun et al. (2020) stated that air quality monitoring is essential for identifying pollutant sources, assessing pollutant levels, and ensuring compliance with air quality standards. Assanov et al. (2021) clarified that monitoring stations, networks, and sensors are used to measure concentrations of various pollutants in real-time. The pollutants which are highly responsible for such unfavorable impacts constitute particulate matter (PM), CO, SO_2, NO_x and O_3 (Hopke et al., 2008; Anwar et al., 2021). Liu et al. (2017) highlighted that particulate matter is divided according to the diameter of the particulates as some are less than 10 $\mu g/m^3$ (PM_{10}) while others are smaller than 2.5 $\mu g/m^3$ ($PM_{2.5}$). Due to this characteristic, they can go inside the cells of the body, such as the lungs, and may cause undesirable effects on the person exposed. The sources of such particulates are smoke from cars, burning of wood and forest, dust blown by wind from loose soil, seas spray evaporation and other activities from construction works such as grinding and demolition (Al-Saadi et al., 2005; Shrivastava et al., 2018).

Azid et al. (2015) iterated that one of the most apparent problems globally is the issue of managing sources of pollutants in the air. The Malaysian Department of Environment (DOE) has efficiently monitored the quality of air in Malaysia so that its status is compiled with the aim of informing individuals on updated levels of pollution. If the levels are beyond the limits set by the standards, then mitigation measures are implemented accordingly. Multivariate techniques were used to determine the sources of pollution as they also detect probable sources that relate to the fluctuation and changes in air quality. As such, multivariate techniques offer an efficient tool in air quality monitoring. Thurston et al. (2011) further explained that multivariate techniques were used to measure the main $PM_{2.5}$ sources in the U.S. Novel of the work as detailed: "(1) the application of factor analysis (FA) to multi-city daily data, drawing upon both spatial and temporal variations of chemical species; and, (2) the exclusion of secondary components (sulfates, nitrates and organic carbon) from the source identification FA to more clearly discern and apportion the $PM_{2.5}$ mass to primary emission source categories" .

Air quality predictions which are precise can be advantageous to the society and the economy through planning activities in advance (Chang et al., 2020). This means that people can reform the activities that are done outdoors to prevent excessive exposure to air quality which is poor thus ensuring their sound health. However, forecasting air quality is not easy. Jin et al., (2020) stated that on top of the complexity in predicting weather patterns, forecasting of air quality needs prior knowledge in levels of pollutants and what is being emitted from near to far regions, circulation pattern, chemical changes and sources of the pollutants are also vital to analyze. Chu et al. (2003) stated that in September 2003, personnel from the NASA, National Oceanic and Atmospheric Administration (NOAA), and EPA researchers showcased a first version technology for utilizing satellite constituent findings in air quality predictions compiled daily which was called IDEA. Observations from the air using the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor found on the NASA Earth Observing System (EOS) Terra satellite were merged with other near-real-time datasets. This was done along with surface measurements and locations that had wildfires which were recorded on an hourly and 30-minute intervals respectively (Chu et al., 2003). This was aimed at improving knowledge for the forecaster on the movement dynamic on pollutants throughout North America. Air mass trajectories have been used for a long time as a mechanism for finding sources of pollutants which have been identified in an area in many forms of studies for significant and insignificant events with various data sets (Sharma et al., 2006; Li et al., 2020). Stohl (1998) stated that the accuracy of single trajectories is not broad, more-so when looking into long range movement of air pollutants and when the analysis is done in an unstable boundary layer. In a study by Ji et al. (2012) matrix trajectories were utilized to indicate the air pollution trends in China. Matrix trajectories are a precise and efficient tool for analyzing the movement pattern of air mass in a region even though it has not been put to work when analyzing transportation of pollutants which are more widely distributed in an area. The calculations made use of the Web version of the Hybrid Single Particle Lagrangian Integrated Trajectory model which is found on the website of the National Oceanic and Atmospheric Administration (NOAA)'s Air Resources Laboratory. During the time of the study, these matrix trajectories indeed showcased the particulate matter spatial and temporal distributions in the northern part of China (Ji et al., 2012), showing how efficient the tool is. A study by Lv et al. (2015), analyzed $PM_{2.5}$ as well as backward air mass trajectories with a model by HYSPLIT-4 which characterized the way movements of air caused shifts in pollution concentrations in four big cities of China. The Air Resources Laboratory's Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model is a holistic system for developing simple air mass trajectories as well as complex dispersion and deposition trials (Loughner et al., 2021). Figueiredo et al. (2013) explained that the method for calculating the model is a hybrid between the Lagrangian approach, which utilizes an active frame of reference as the air masses migrate from their original point, and the Eulerian system, which uses a rigid three-dimensional grid as a frame of reference. "In the model, advection and diffusion calculations are made in a Lagrangian framework following the transport of the air parcel, while pollutant concentrations are calculated on a fixed grid".

Govekar et al. (2022) stated that NOAA and the Australia's Bureau of Meteorology ensured that the model uses advection algorithms, improved the stability and dispersion equations, upgraded the graphical user interface, and the choice to add modules for chemical transformations. Lv et al. (2015) revealed that a strategy to determine the immediate and surrounding sources contributing to $PM_{2.5}$ were then established which showed that the high $PM_{2.5}$ levels in Beijing and Shanghai were influenced by south-eastern and northern air mass movements respectively. Another study used the Lagrangian particle dispersion model (LPDM) for the statistical analysis regarding the areas identified as the sources of air pollution (Hirdman et al., 2010). This is because it was seen as more efficient than trajectories which do not include atmospheric turbulence and convection (Stohl et al., 2002). Furthermore, backward trajectories were used in another research to showcase a link between effects of health and air pollution exposure by checking levels of pollution and finding their sources. Park et al. (2007) showcased that the cardiac autonomic function was used to observe the effects from the indicators. Using a mix of aerosol and gas-phase methods for monitoring the environment, a study was done to determine the most apparent localized sources of air pollution in gaseous and particulate form in the city of Lund, Sweden (Swietlicki et al., 1996).

Many studies on air pollution in urban regions have been undertaken in areas outside Malawi and the effect on human health as well as biotic relationships were highlighted (Lu et al., 2004; Fowler et al., 2009; Makra et al., 2010). Rylance et al. (2019) revealed that Malawian adults exhibit a significant prevalence of chronic respiratory symptoms, spirometric abnormalities, and exposure to air pollution. Air pollution in industrial areas can have detrimental effects on the environment, including damage to vegetation and crops through the deposition of pollutants on leaves as well as acid rain formation. This harms aquatic ecosystems, corrodes buildings, damaged infrastructure and contaminates soil as well as groundwater with hazardous chemicals from air deposition and runoff (Kaonga et al., 2017; Ukah et al., 2019). Tilley et al. (2023) conducted a study at Queens Elizabeth Central Hospital in Blantyre which showed that air quality thresholds considered safe had consistently surpassed across various locations and time periods. The most concerning air quality issues were found in the vicinity of the shelter for caregivers and individuals undergoing HIV/AIDS treatment. Additionally, the inadequate air quality significantly affected both staff and visitors to the premises, yet they expressed a sense of powerlessness to initiate changes or address their concerns. Saleh (2022) who conducted a study in Mpemba-Malawi showed that village residents experienced elevated levels of personal exposure to airborne particulate matter and carbon monoxide, primarily attributed to cooking activities as the predominant source of exposure. Governments establish air quality standards, emission limits, and regulations to control industrial air pollution (Mapoma & Xie, 2013; MSB, 2021a). Malawi as a nation has the Malawi Standards which were formulated and published through the Malawi Standards Board (MSB, 2021a). The permissible levels of air quality are in Table 1.

Table 1: Ambient air quality standards limit for Malawi (MSB, 2021a).

Pollutant	**Maximum Concentration in Ambient Air**	**Average Period**
Suspended Particulate Matter	0.5	1 Year
PM$_{10}$, µg/m^{3}	25	1 Day
PM$_{2.5}$, µg/m^{3}	8	1 Year
Carbon Monoxide, mg m^{-3}	10.31	8 Hours
	40.1	1 Hour
	0.52	1 Hour
Sulfur dioxide, mg m^{-3}	0.21	1 Day
	0.05	1 Year
	0.23	1 Hour
Nitrogen dioxide, mg m^{-3}	0.06	1 Year
Ozone, mg/m^{3}	0.14	1 Hour
Lead, µg/m^{3}	0.5	1 Year
	0.26	1 Hour
Photochemical oxidants (as ozone, mg m^{-3})	0.08	4 Hours

Source: Malawi Standard MS 737:2021 “Industrial emissions from mobile and stationary sources-Specifications”

Even though Malawi has air quality standards, the monitoring of pollution levels is not done with a standard strategy and/or on a continuous basis. It is important to forecast air quality in the short term, monitor air pollution and establish trends so that corrective and preventive actions are formulated if the air pollution levels are above the limits set in the standards (Makra et al., 2010). Many developing nations including Malawi have encountered the increasing pattern in growth of cities and extreme population increase one year after the other. Baldasano et al. (2003) stated that this is seen through many cities in developing nations which have doubled from the numbers recorded for over 50 years back. Compliance with these regulations often requires industrial facilities to adopt pollution control technologies and practices. Regulatory agencies may conduct inspections and enforce penalties for non-compliance. Industrial facilities employ various pollution control technologies, such as particulate matter control through the use of Electrostatic precipitators, fabric filters, and cyclone separators; gas treatment using scrubbers, catalytic converters, and flue gas desulfurization systems (Wang & Yang, 2018). Kambale (2021) revealed the use of emission reduction strategies such as process optimization, cleaner production techniques, and the use of alternative fuels for pollution abatement. Exposure to air which is polluted has been highlighted to be the source of grave human diseases, especially in highly polluted localities. (National Statistical Office (2019) stated that this is mostly attributed to the population growth and urbanization of Malawi over the past few years which are major contributors to air pollution in both developing and developed nations. Makata, Limbe, Maselema, Chirimba and Maone industrial areas are located in Blantyre city and are some of the heavy industrial areas possessing more than thirty companies (Kuyeli et al., 2009) which reinforces the need for this study to analyze pollutants like CO, TSP, PM_{10} and $PM_{2.5}$. Many researchers in the previous years have been undertaking studies in quality of air in urban regions and these have been documented accordingly (Brajer et al., 2006; Agbo et al., 2021). This has influenced some developing nations to introduce stringent regulation in pollution abatement even though there have been small improvements in improving the quality of air after this was put in force (Mao & Zhang, 2003; Zhang et al., 2020).

Deng et al. (2020) stated that HYSPLIT can be used proactively on ARLs READY (Real-time Environmental Applications and Display System) web site, or it can be utilized on a laptop and run through a graphically designed user platform. As such the HYSPLIT model was used because Malawi is affected by national and global air masses, and it gives details on the dispersion of pollutants and their potential effects on the health of the public. This in turn assists in the development of specified interventions to health risks reduction. Researchers use the HYSPLIT model to know the source and transport pathways of air masses impacting the nation, including pollutants or other suspended particles. This model offers either of two assumptions for computing air concentrations. The first one is that numerous particles are released throughout the release duration. Additionally, each particle moves in an advective manner and undergoes random motion affected by turbulence from the atmosphere, causing them to disperse in space and time (Draxler & Hess,1998; Salmabadi & Saeedi, 2019). Air quality dispersion models are utilized to determine the level of pollution in the air from many processes. The applications mostly used provide a simulation of emissions in gas form and particulate matter from combustion processes (MSB, 2021a). Mircea et al. (2020) clarified that to conduct a source apportionment, a receptor model of the compiled multivariate set of data was created. It was stated that it is paramount to know the contributory nature of sources found in the immediate and surrounding environment when it comes to urban air quality so that likely health risks are determined and if necessary, stiff measures to be implemented in the areas with more polluted air (Swietlicki et al., 1996; Tong, 2019).

United Nations Statistics Division (2013) elaborated that Malawi has taken part in working towards implementing strategies to having air quality levels which are sustainable for a greener environment, sound health of individuals and boosting of the economy mainly through the Millennium Development Goal number 7 along with the indicators to ensure success in implementation. With the aim of ensuring a preserved and sound environment, the Government of Malawi, ventured into developing and following an environmental management plan as an outcome of the Rio Conference 1992's Agenda 21 which was implemented in 1994 as the National Environmental Action Plan (NEAP). This plan highlighted 9 vital environmental problems to deal with and these were categorized in terms of severity. In this ranking air pollution was position on the 8th place right before issues related to climate change. Chemical mass balance (CMB) methods are often used for source apportionment to quantify the contributions from all sources which are independent using mass-balance equations that include all chemical compositions in the samples at hand (Karagulian & Belis, 2012; Chen et al., 2015; Huang et al., 2018).

2.4 Noise pollution in industrial areas

Jhanwar (2016) defined noise pollution is the presence of excessive noise that has the potential to disturb or disrupt the activities and equilibrium of human beings. Noise pollution in industrial areas is a significant concern due to the presence of various machinery, equipment, and industrial processes that generate high levels of noise (Orikpete & Ewim, 2023). Kumar and Naik. (2022) stated that there are various sources of noise pollution in industrial areas such as machinery and equipment like compressors, generators, and manufacturing equipment, which can produce loud and continuous noise. Construction activities, repairs, and maintenance work in industrial zones can involve the use of power tools and heavy equipment, and as such contribute to noise pollution (Wokekoro, 2020a). Jandacka et al. (2022) explained that industrial areas may have a high volume of truck traffic for transporting raw materials, goods, and products adding to the noise levels mainly from vehicle engines, brakes, and horns. Installed alarm systems such as sirens, or warning signals which generate loud noise during emergencies or testing are another source of noise pollution. Ventilation and cooling systems also produce noise when in operation (Mohamed et al., 2020). Adza et al. (2022) highlighted that prolonged exposure to high levels of industrial noise can lead to many health impacts such as hearing loss, stress-related health problems, sleep disturbances, and an increased risk of cardiovascular diseases among workers and nearby residents. Secondly excessive noise can impair worker concentration and communication, leading to reduced productivity and potential safety risks (Kumar & Naik, 2022). This in turn reduces the quality of life due to constant noise disruptions, making it challenging to relax, concentrate, or enjoy one's surroundings.

Reiminger et al. (2020) explained that to address noise pollution in industrial areas, various measures can be implemented such as installation of noise barriers like walls or soundproofing materials which can help block or absorb noise generated by industrial processes and machinery. Orikpete and Ewim. (2023) iterated that the use of engineering solutions related to employing quieter machinery and equipment, regularly maintaining equipment to reduce noise emissions, and optimizing industrial processes for noise control can be effective. Furthermore, governments and local authorities can implement and enforce noise regulations specific to industrial areas, setting noise limits and requiring businesses to comply with noise control measures (Mohamed et al., 2020). Butorina et al. (2020) stated that careful planning and zoning can help separate industrial activities from residential or sensitive areas to minimize noise impact on communities. Noise barriers are not often utilized in urban regions, mostly because of as lack of limited land for their installation, problems in visibility connected to traffic safety, building construction issues, as well as the point that they showcase a hindrance for those who walk on foot and use bicycles for movement from one point to the next (Jandacka et al., 2022). It was further stated that the utilization of pavements which emit less noise are not used frequently in urban environments because of increased cost in producing and maintaining these covers. Furthermore, they are prone to more damage during cold seasons and efficacy is low in urban regions then other sites. The authors also stated that through the comparison of real time measurements and the outcome of their assumed readings by using 3D models in the CadnaA program, the selection of specified factors related to reconstruction of roundabouts by urban intersections which were not signaled would reduce the noise levels caused by traffic by up to 8 dB.

A study on diagnosing hearing loss in Malawi revealed that ambient noise levels surpassed the permissible maximum at lower frequencies more frequently which has a negative impact on those exposed (Bright et al., 2019). Bright et al. (2020) emphasized the same in another study in Malawi which stated that elevated ambient noise levels can increase hearing thresholds. In Malawi, The Environmental Affairs Department (EAD) has collaborated with the Malawi Bureau of Standards to establish environmental standards for water, air, soil, and noise. In cases where Malawian standards are unavailable, internationally accepted standards, such as those from the World Bank and World Health Organization, are referenced (Spong & Walmsley, 2001). OMS (2020) revealed that providing education and training to workers on noise hazards and the use of personal protective equipment (PPE), such as earplugs or earmuffs, can help reduce the risk of hearing damage. Efforts to reduce noise pollution in industrial areas are essential to protect the well-being of workers, nearby residents, and the environment, while also promoting sustainable and responsible industrial practices. Chirwa et al. (2019) however highlighted that it is not possible to fully control noise pollution, but it is possible to reduce the levels to the most practicable values using the available technologies at efficient costs.

2.5 Heavy metals pollution in soil around industrial areas

Soil heavy metal pollution denotes the presence of heightened levels of metallic elements characterized by high atomic weights and densities. This contamination has the potential to harm organisms and plants by disrupting the metabolic functions of crucial organs and glands (Timothy & Tagui Williams, 2019). Heavy metals are elements with high atomic weights and densities, and some of the most common ones of concern in soil contamination include lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), and chromium (Cr). Children and pregnant women are particularly vulnerable to the effects of heavy metals (Aiman et al., 2018); Ali & Khan, 2018). These metals can be toxic to plants, animals, and microorganisms in the soil, disrupting ecosystems (Anyanwu et al., 2018). Sun et al., (2021) explained that human exposure to heavy metals can occur through ingestion of contaminated food or water, inhalation of dust, or direct contact with contaminated soil. Heavy metals in soil in industrial areas are a significant environmental concern due to their potential for harm to ecosystems and human health (Malikula et al., 2022). Mussa et al. (2019) further stated that the contamination of resources arises from human activities that have modified the configuration of rural landscapes and augmented the volume of substances discharged into rivers and lake systems. Kaninga et al. (2020) highlighted that it is crucial to assess the concentrations of trace metals in soils near pollution sources for both agricultural management and human health considerations. There are various sources of heavy metal contamination emanating from industrial processes like metal smelting, mining mineral processing, chemical manufacturing, and electronics production which release heavy metals into the environment (Kaonga et al., 2021; Li et al., 2020). This involves extracting and processing ores that release heavy metals into the soil and water, waste disposal which revolves around landfill use, waste incineration, and improper disposal of hazardous materials (Ukah et al., 2019; Olatunde et al., 2020). Zhang et al. (2018) explained that this further includes atmospheric deposition which can deposit heavy metals onto the soil through air pollution. This corresponds well with the heavy metal contaminated effluent from a matchstick factory in the city of Blantyre in Malawi (Schütz, 2013). Kaonga et al. (2017) also found that metal processing operations, the use of phosphate fertilizers, and the deposition of metal products are additional contributors to the presence of heavy metals.

Mlangeni et al. (2022) revealed that heavy metals can persist in soil for a long time, leading to chronic exposure risks including neurological disorders (e.g., lead poisoning), kidney damage (e.g., cadmium), and cancer (e.g., arsenic and chromium). The mobility and bioavailability of arsenic (As), cadmium (Cd), lead (Pb), and uranium (U) in soil, as well as their uptake and accumulation in rice, are significantly influenced by the presence or absence of sorbents, including iron (Fe), zinc (Zn), manganese (Mn) hydroxides, and clay particles. This resonates well with another study conducted in Malawi where utilizing mixed clays for the detoxification of heavy metals was regarded as an economical and environmentally friendly approach for removing cations such as Cd^{2+}, Cr^{3+}, Cu^{2+}, Pb^{2+}, and Zn^{2+} from aqueous solutions (Sajidu et al., 2006). Ukaogo et al. (2020) further stated that heavy metal contamination can harm soil quality and fertility. It can also disrupt aquatic ecosystems when washed into rivers and streams, impacting aquatic life (Masindi & Muedi, 2018). Chemical mass balance (CMB) methods are often used for source apportionment to quantify the contributions from all sources which are independent using mass-balance equations that include all chemical compositions in the samples at hand (Karagulian & Belis, 2012; Chen et al., 2015; Huang et al., 2018).

2.6 Regulatory frameworks and policies

Aguilar-Gomez et al. (2022) highlighted that one of the growing concerns related to environment which many scientists, policy makers and individuals at large are trying to control and manage is pollution of the air. Increasingly, industries are adopting sustainable practices to reduce their environmental footprint, including emissions reduction (Shi et al., 2020). Anwar et al. (2021) stated that this may involve energy efficiency improvements, renewable energy adoption, and the use of eco-friendly materials and processes. Engaging with local communities is vital to addressing industrial air pollution as it allows for public input, awareness campaigns, and collaborative efforts to reduce pollution impacts on nearby residents (Liu et al., 2018). As industries evolve and new technologies emerge, addressing air pollution in industrial areas will continue to be a dynamic challenge. Chaturvedi, (2018) emphasized that climate change considerations, such as reducing greenhouse gas emissions, also intersect with industrial air pollution control efforts. As such, efforts to reduce air pollution in industrial areas involves a combination of regulatory, technological, and societal actions. Sustainability, innovation, and improved collaboration between industry, government, and communities are key to mitigating the adverse effects of industrial air pollution (World Bank, 2019). Nahar et al. (2021) highlighted that the effectiveness of these regulations varies by region, and enforcement can be a challenge. Goal number 3 of the Sustainable Development Goals (SDGs) goal 3 promotes “ensuring healthy lives and promoting well-being for all ages” and that noise as well as pollution of the air are inclining on a global scale. The (World Health Organization (2021) stated that this has made many nations create regulations to govern them. Peoples efforts have led to the development of applications relevant to management strategies in policy intervention and designing of clean air movement and healthier navigation modes to reduce being exposed to pollutants (Rebeiro-Hargrave et al., 2020). As stated by (Rafaj et al., 2018), for the first time, the SDGs incorporate many policy objectives, taking note of, for example, that ensuring prosperity of the masses must align with strategies that enhance the growth in economy and target a broad spectrum of social requirements. This is done while managing the change in climate and boosting protection of the environment. Furthermore, the present effort in policy, as put to trial by the New Policies Scenario, lead to noticeable improvements in line with past findings related to energy demand management, release of carbon dioxide as well as pollution of the local areas which shows that well rounded and systematic assessment of policies is needed to curb negative impact on the environment from developmental activities. Moreno-Cruz (2019) highlighted that in the USA, the findings showcased a direct relationship between policies linked to the industrial sector and policy of the environment.

Anyanwu et al. (2018) stated that heavy metal contamination can lead to community health concerns, particularly in areas near industrial facilities. Nahar et al. (2021) further iterated that communities need to continuously advocate for stricter regulations, monitoring, and remediation efforts to address the issue. Addressing heavy metal contamination in industrial areas requires a multidisciplinary approach involving government regulations, industry practices, environmental monitoring, and public awareness to minimize its adverse effects on both the environment and human health (Yan et al., 2021). Additionally, many countries have established regulations and guidelines for acceptable levels of heavy metals in soil. Monitoring and testing of soil in industrial areas are often required to ensure compliance with these regulations (Olatunde et al., 2020). Xu et al., (2021) stated that remediation techniques include soil washing, phytoremediation (using plants to extract or stabilize metals), and in-situ chemical immobilization. Kuerban et al. (2020) explained that prevention is often the most effective approach, such as controlling industrial emissions and proper disposal of hazardous waste. A study was conducted which presented important data on pollution of soils by heavy metals around Dangote cement factory, Ibese, that showed the need for an overhaul of the waste management initiatives of the factory and an emphasis of complying with the regulatory from relevant agencies was iterated (Olatunde et al., 2020). Furthermore they stated that the availability of heavy metals in soils above allowable limits is deleterious to biota. Vongdala et al. (2019) conducted a study which stated that it was the first kind to reveal increased levels of heavy metals in soil, water and plants around the municipal solid waste landfill of Vientiane, Laos, which requires immediate phytoremediation. This same study showed that there was more cadmium and copper pollution during the dry season than that which was rainy. Yang et al. (2018) provided a detailed ecological and health risk assessment on the heavy metals in soils from Chinese industries and agricultural areas thus developing information for policy formulation related to reducing exposure as well as management. Wang et al. (2021) utilized three-factor solution of the PMF model to showcase the sources of heavy metals in a precise way from the perspective of orchard agricultural soils with future uses. Limited studies quantified pollution of heavy metals from the coal mining area of Tai'an, China, which is relevant to develop and conduct effective policies and regulations of soil pollution control. Yan et al. (2021) further stated that most of the studies showed that the levels of heavy metals were higher than the background value in reference. Anyanwu et al. (2018) stated that in sub-Saharan Africa (SSA), it has been shown in the recent years that implementation of policies in a less stringent manner has led to excessive pollution related to heavy metals. Wokekoro (2020a) explained that noise pollution can be noticeably controlled through regulations, advocacy programs and prevention by the polluting party using the polluter pays principle. Noise from industries should be managed by engineering controls as a first measure along with noise suppressing materials used in textile mill walls. Awareness campaigns sensitizing people on use of protective equipment like ear plugs and earmuffs should be done on a planned basis and associated penalties should be applied when violations occur (Majid et al., 2021). A study conducted by Wokekoro (2020b) emphasized the need to conduct sensitization campaigns with the public on the harm caused by excessive noise emission on their well-being as well as the need to apply strict controls on noise pollution. As outlined by King (2022) a directive was set to conduct environmental noise studies, many member countries have created policies related to environmental noise mapping and planning of actions usually in liaison with international organizations whilst obeying best international practice. The same author went on to say that in cases where the noise levels are above stipulated limits, complementary mitigation methods and policies should be observed thus linking to SDGs aimed at ensuring sustainable growth of the economy. As mentioned by Berglund et al. (2000) the United Nation's Agenda 21 utilizes many principles on environment management which the government incorporates in its policies such as the principle of precaution; the polluter pays principle; and noise prevention aimed at alleviating excessive noise emissions. Shrivastava et al. (2018) stated that in India there are regulations not to go above the normal range (65 decibel) of sound level so that pollution is curbed.

The World Bank (2019) revealed that in Malawi, policies have been established to respond to pollution of the air, change in climate as well as products which destroy the ozone layer in the atmosphere. Kambale (2021) stated that this is linked to dynamic social and economic factors that have been playing major roles in boosting and/or reducing the progress to improved quality of air in the country. Governments and international organizations have established regulatory frameworks and policies to control industrial pollution. This includes emissions standards, effluent limits, and guidelines for hazardous waste management. As elaborated by Mapoma & Xie. (2013) there is no applicable climate and air quality Act in Malawi, however, there are many legal applications such as the Environmental Management Act, National Environmental Policy, Malawi Energy Policy and other sectoral targeted Acts that entail the importance of considering air pollution in the collective processes which means that protecting quality of air is included in many Acts present in Malawi. The authors further state that the environmental impact assessments targetted at the sector level namely Mining, Irrigation, Sanitation and Waste Management guidelines which originate from EIA guidelines adopted in 1997 emphasize the relevance of conducting EIA while including air quality management. They also iterate the availability of the Millennium Development Goals (MDGs) for Malawi, Vision 2020 and Malawi Growth and Development Strategy (MGDS) which implore the incorporation of air quality management for an improved environment for citizens in Malawi and sustainability in development initiatives in the country. Mlangeni et al. (2022) explained that the paddy soils in Malawi had As, Co, Mn, Pb, Cd, U, and Ga levels from two to five times below the respective global mean concentrations and maximum contaminant limits, regulated by a number of regulatory bodies which are found at national as well as international levels, such as the World Health Organization (WHO), Alimentarius Commission, European Commission (EC), and Chinese Environmental Quality Standards (CEQS) for paddy soils. Malawi as a nation has brought on board the United Nations Sustainable Development goals by complementing them with many policies formulated by the government and one of these is to ensure enhanced exportation in a sustainable manner thus leading to creation of intentional policies, that aim at boosting development in the industrial sector (Kamzati et al., 2019). Malawi also set up laws (Government of Malawi, 1997) and publicized Malawi Standards (Government of Malawi, 2005) to assist industries in setting up noise induced hearing loss reduction or management programs. Chirwa et al. (2019) stated that with this in mind the level at which these laws and Standards are being followed by industries in Malawi is unknown. However, according to the Government of Malawi (2005), any industry emitting sound levels equal or above 85dBA per 8-hour period on any day was determined a noise hazardous area as per stipulation.

CHAPTER THREE: MATERIALS AND METHODS

This chapter gives an account of standard methods and materials used in the research covering sampling methods, research design, laboratory as well as data analysis. The study applied a quantitative observational research design in data collection and analysis. This employed active data collection using calibrated gadgets, statistical analysis and comparison with permissible legal standards.

3.1 Description of study area

Blantyre City is the urban center of Blantyre District in Malawi, which is found in the southern region of this nation. Deemed as Malawi's commercial city, this city is located at −15°29′59.99″S, 35°00′0.00″E and has an area of 240 km^2. Furthermore, it has most of the country's industrial and business establishments. Blantyre District has an overall population of 809,397 people (National Statistical Office, 2019) and is at an estimated elevation of 1039 meters above sea level which is significant in moderating the climate which is tropical (Government of Malawi, 2020). In terms of the climate, like most of the districts in Malawi, Blantyre has two dominant seasons during the year namely the dry and rainy respectively. Britannica (2018) stated that the rainy season spans from November to May and the rest of the year is dry, with temperature rising until the next rains arrival. 20.7°C is the average temperature in Blantyre, and approximately 1086 millimeters of rain is received each year in the region. The main part of the highlands is the well spread northeasterly trending ridge hills starting from Thyolo, in the south to the northern area in Zomba. The northwest is bordered by the edge of the rift valley, but its southeastern limits are connected to the Phalombe plain. Kayulayula and Banda (2015) stated that this area is hilly, with Ndirande Hill determined at 1595 meters above sea level which is the highest point. The hills are sources of several streams, which flow outwards from the district. The geology and soils in Blantyre city are created mostly from intermediate or basic charnockitic rocks where the former is commonly found. Tsunogae et al. (2021) highlighted that the rocks are mostly of granulite facies and diapthoresis to the east part of Shire Highland ridge. Initially, the Shire Highlands was greatly covered with forest which were evergreen and closed off, allowing the flow of the many ever flowing streams and capping hills as well as mountains above 1370 m. With problems of deforestation during recent years, only scattered fragments of the original Brachystegia woodland are still in existence, mostly on estates which are private and along the lower slopes of rocky hills. Currently, a significant part of the landscape has exotic trees plantations mainly the pervasive Bluegum in the genus *Eucalyptus saligna* and *E. grandis* (Wild Orchids Southern Africa, 2018; Coutts et al., 2019).

Since Blantyre City is a commercial capital city, urbanization is apparent and this is mostly due to natural phenomena, people moving from the rural areas to urban points for opportunities as well as expansion of urban boundaries (National Statistical Office, 2019; World Bank, 2019). Migration of people to the urban areas has been influenced by the vast economic prospects which entice people to relocate as such. As stated by the World Bank (2019), the GDP of Malawi hiked at a rate of 3.9 percent yearly between 1998 and 2013 which correlated with the boom in manufacturing and construction industries. Some of Blantyre's economic activities contributing most to this GDP are related to the food manufacturing, retail, automobile sales and maintenance, construction, transportation, textile, as well as public administration industries, making it one of the country's largest employment centers. Figure 1 shows the location of Blantyre (Gondwe et al., 2021).

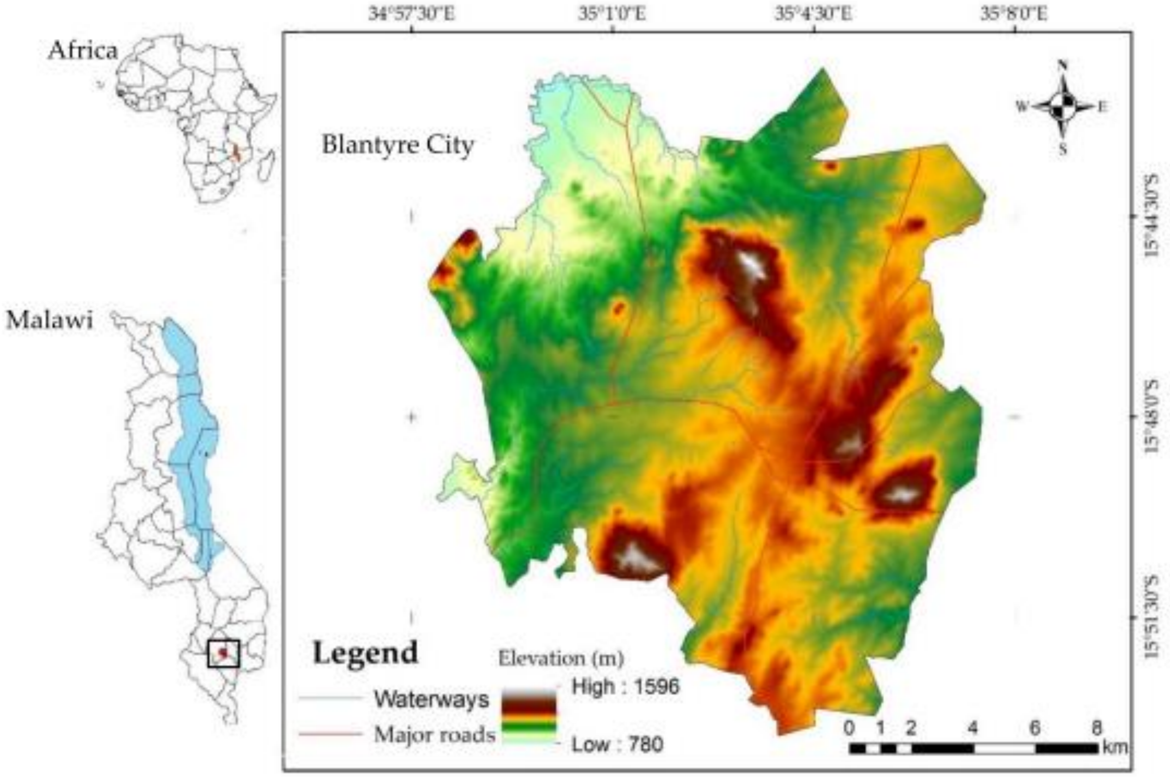


Figure 1. Map of Malawi showing position of Blantyre City. Source: Diva GIS website and The Shuttle Radar Topographic Mission (SRTM) Digital Elevation Models (DEM) data

3.1.1 Industrial sites in Blantyre city

The study took place in 5 industrial areas namely Makata, Limbe, Maselema, Chirimba and Maone (Figure 2) with locations as per table in appendix 1. These five industrial areas were selected because they are a composed of both light and heavy-duty industries which means it allows for a comparative analysis of environmental impacts, helping to develop strategies for sustainability and environmental management. Blantyre has eight designated industrial areas namely Makata, Ginnery corner, Maselema, Limbe, Chirimba, South Lunzu, Maone and Chitawira. Of these, Makata, Ginnery corner, Maselema, Limbe, Chirimba and Maone are actively hosting industries whilst South Lunzu is yet to be developed. The existing industrial sites are further categorized into heavy and light industrial sites. Makata and Limbe, for example are the sole heavy industrial sites hosting more than thirty companies whilst Chirimba industrial area though designated a heavy industrial area, is the least developed in terms of number of industries in the area. BCA (2006) iterated that apart from Makata, Ginnery corner industrial site is another active site followed by Limbe and Maselema and the least is Chirimba and Maone industrial sites. Chitawira and Maselema are classic examples of light industrial areas. All the industrial areas are located along the banks of the main rivers or streams of Blantyre city. Makata industrial area lies between Mudi and Nasolo streams whilst Ginnery corner industrial area is along Mudi River. Maselema industrial area exists along the Naperi river and Chirimba stream hosts Chirimba industrial area. Industries which are within Blantyre city are grouped into either wet or dry type depending on the volume of the water used in the industries. BCA (2006) highlighted that industries which use water as part of the production process and cleaning production line are described as wet industries because they generate a lot of effluent whilst dry industries are those that use water for ordinary sanitary usage within the premises. In addition, Portland Cement Company is a typical example of dry industry whilst Southern Bottlers (currently called Castel Malawi Brewery Limited) is listed as wet industry.

Companies in Blantyre fall under the following categories: textile and leather products, paints, pharmaceuticals and other chemicals, metal and wood processing, petroleum and plastics, power distribution, dairy products and abattoir, beer breweries, tobacco processing and food processing (BCA, 1995) as per figure 3.

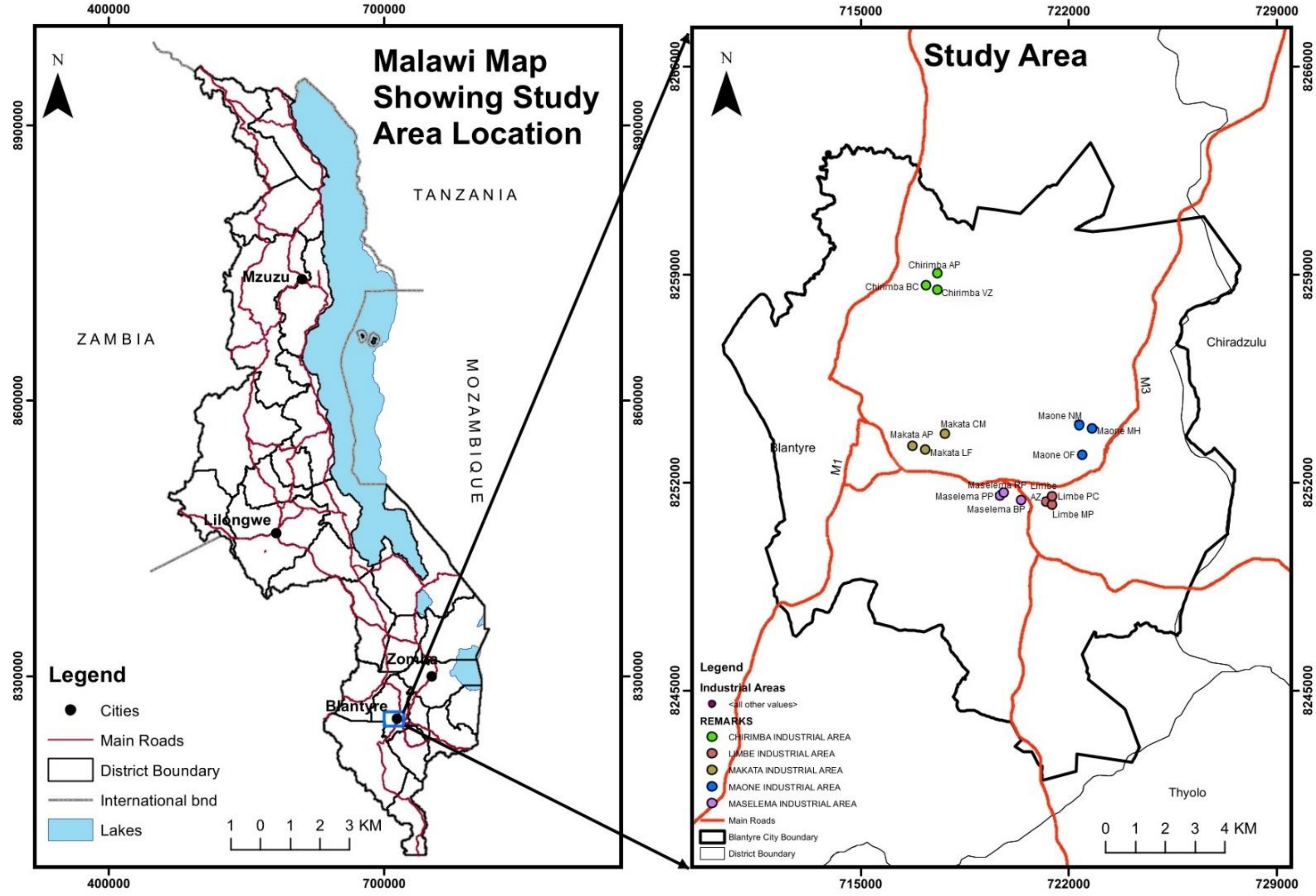


Figure 2. Map of Blantyre showing sampling points

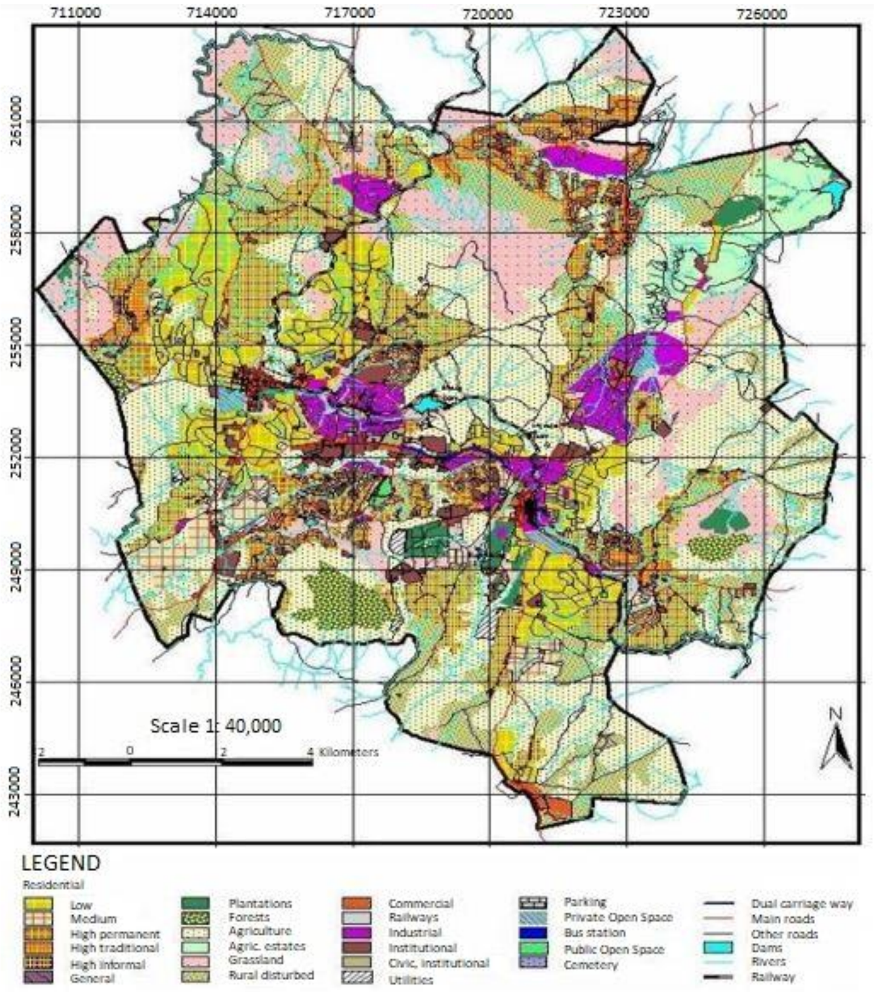


Figure 3. Map of Blantyre city showing land use (BCA, 1995)

3.2 Sampling

3.2.1 Sampling strategy and considerations

A purposive sampling strategy was employed for this study just as Nofri et al., (2017) did for their study which focused on analyzing SO_2, NO_2 and CO from areas considered to be polluted due to heavy traffic. Sampling points were selected based on their potential to capture variations in air, noise, and soil quality, influenced by their homogeneity and work-related characteristics. Consideration was also given to the time available for research, financial limitations, and accessibility of the sampling points in both seasons. Effectively, a total of 15 sampling points (Figure 2) comprising industrial sites were selected for sampling. Air, noise, and soil samples were collected from each of the 15 samplings points, with three points selected from each of the five industrial areas as per section 3.3. Malawi has typically three seasons namely warm-wet

(November to April), cool-dry (May to August) and hot-dry (September to October) (Britannica, 2018). As such, to enable the assessment of differences in chemical concentrations between dates in rainy and dry seasons, sampling was conducted in February and August 2023 respectively. This approach also ensured that research timelines were met. This study utilized a conceptual framework as per figure 4 (Adza et al. 2022) because it correlates well with specific objectives of the research and is applicable to the real-world issues under investigation.

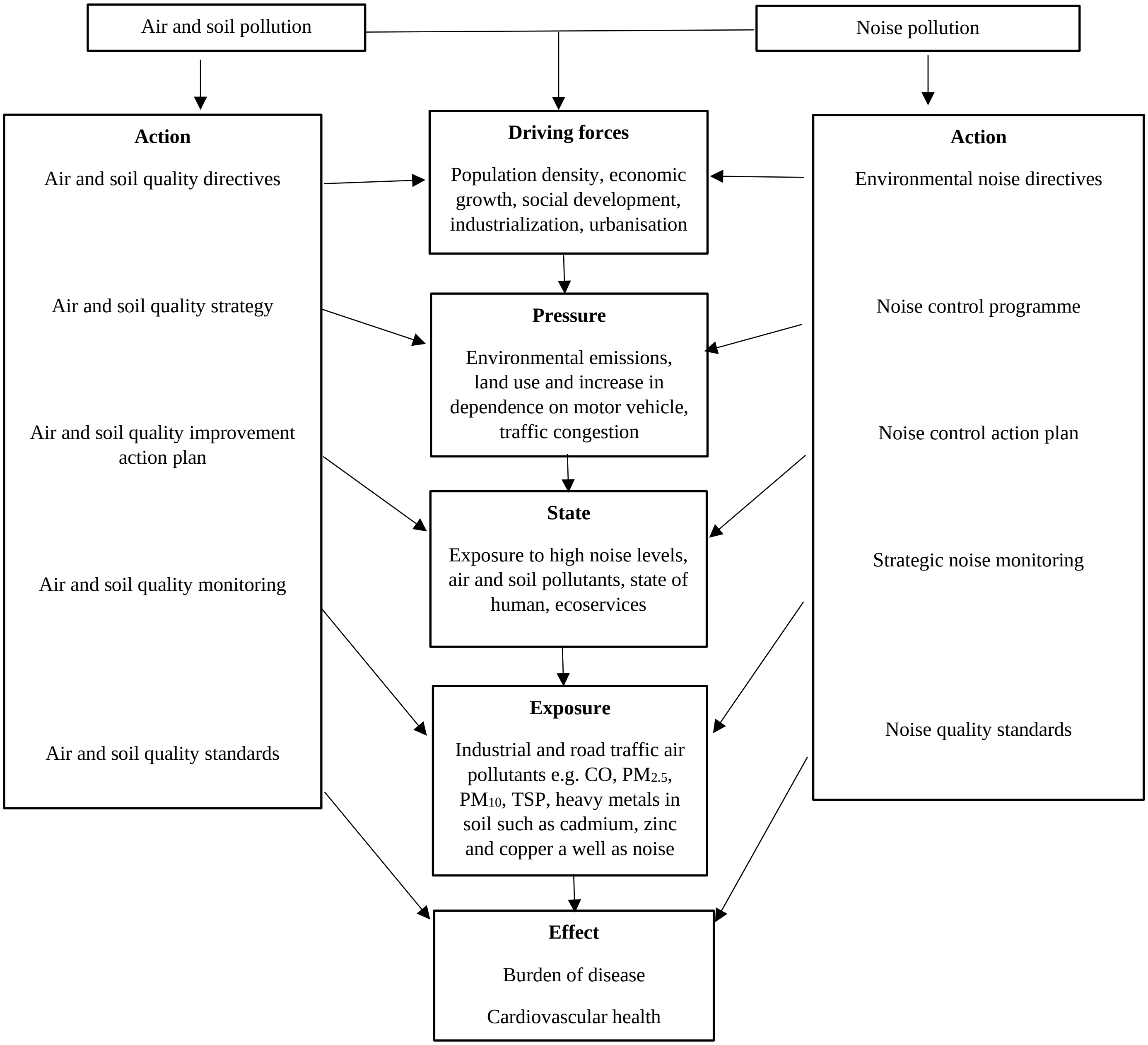


Figure 4. Modified Conceptual framework for the assessment of the joint cause–effect relationship between air and soil pollution, noise, industrialisation, traffic, and burden of disease (Adza et al., 2022)

3.3 Data collection methods

3.3.1 Air sampling

Data collection was done using an active mobile multi-gas monitor (Drager X-am 7000 (Online www.draeger.co.uk)). Equipped with electrochemical sensors that measured continuous concentrations of Particulate Matter and CO throughout each 1 h and 30 min sampling session. In all the locations, the equipment was placed at a minimum of 1.5 m from the ground to capture wider range of emissions from both vehicles and industrial sources. MSB (2021a) stated that the distance from the anticipated emission source was at least 1.5 m from the nearest building. The instrument underwent accurate calibration within the flow range of 0 to 3 L per min. During data collection, 10 min consecutive average measurements were recorded in an excel sheet during morning (09:00 - 10:30 h), midday (11:30 - 13:00 h) and afternoon (15:30 - 17:00 h), providing 10 sets of values per session per day which assisted in minimizing the volume of captured data. This was aimed at ensuring accuracy and reliability of results (MSB, 2021a).

3.3.2 Noise sampling

Integrated Sound Level Meter (ISLM) was utilized for the assessment of noise levels. The selection of ISLM was made due to its appropriate statistic averaging technique, enabling the derivation of a succinct measure of the equivalent continuous sound pressure level (Leq). Prior to conducting measurements at each chosen site, the meter underwent calibration using the Castle Acoustic Calibrator, with the model specified as GA 601. Castle Group Ltd (2014) stated that the calibration was carried out according to the instrument operational manual provided by the manufacturer. Noise measurement was conducted manually, with the instrument held at a height of 1.2 m above the ground and positioned 3 m away from the noise source. The microphone was directed towards the primary noise source's front, following the guidelines outlined by Castle Group Ltd (2014), in order to minimize sound field. LAi (A-weighted instantaneous sound pressure level), which is an “A fast” scale, was used to record 30 measurements through 10 min consecutive average measurements during morning (09:00 - 10:30 h), midday (11:30 - 13:00 h) and afternoon (15:30 - 17:00 h), providing 10 sets of values per session per day (MSB, 2021b).

3.3.3 Soil sampling

Soil samples were collected within the topsoil range (0-15 cm) using a soil auger. Five soil samples were collected randomly at each point and were mixed in a bucket before sub sampling (quartering) (Ahmed et al., 2019). The samples were collected in plastic bags and taken to the Malawi University of Science and Technology (MUST) laboratory for analysis as per APHA (2017) standard.

3.3.4 Determination of heavy metals in soil

APHA (2017) iterated that preparation of soil samples was done by removing any waste matter as well as plant residue and were oven dried as well as fragmented into powder to blend the samples. 1 g of the dried-up soil sample was then weighed by utilising an analytical balance in triplicates. This was then placed in a digester which is a vessel made of Teflon or quartz. A combination of strong acids, mostly made of nitric acid (HNO_3) and hydrochloric acid (HCl) was incorporated in the vessel. The metals were thus broken down in the solid phase of soils due to the reaction of the acids. Digestion of the soils which were weighed was done with a blend of 10 mL concentrated hydrochloric acid (HCl) and 3.5 mL of concentrated nitric acid (HNO_3). The blends were left under a fume hood throughout the night and were exposed to 105 °C of heat for a period of 2 h during the next day by utilizing an adjustable heating block or microwave digestion system. Afterwards, distilled water was incorporated and using the Whatman filter paper filtration of the sample was done. "The filtrate was topped up to 100 mL in a volumetric flask with distilled water up to the mark". After this, the samples were analysed using AAS machine with GBC 32AB MODEL.

3.3.5 Preparation of standard solutions

3.3.5.1 Copper, zinc and cadmium

Preparation of Cu, Zn and Cd stock solution of 1000 mg/L was done by dissolving 1.000 gm of Cu, Zn and Cd metals respectively in 14 mL of water and 7 mL of concentrated HNO_3 in a 1 L flask which was diluted to the mark using distilled water. Intermediate Cu, Zn and Cd standards were prepared by pipetting 10 ml of 1000 mg/L to 100 ml volumetric flask and diluted to the mark using distilled water. A series of Cu, Zn and Cd standards namely 2 mg/L, 4 mg/L, 6 mg/L and 8 mg/L were produced by pipetting 2 ml, 4 ml, 6 ml and 8 ml of 100 mg/L to 100 ml volumetric flask and were diluted to the mark utilising distilled water as per standard procedure (APHA, 2017).

3.3.6 Determination of soil pH

APHA (2017) stated that 40 ml of distilled water was mixed with 40 g of dried and sieved soil in a beaker. This mixture was then mixed thoroughly up to a point where a suspension of soil in water was reached. The stirring process was conducted for 30 s each 3 min within 5 mixing cycles. For a period of 5 min, the mixture was left to settle to a point of forming a supernatant which is the clearer liquid floating on top of the settled soil. After this, a pH electrode of the pH meter was dipped into the supernatant liquid to measure the pH. This process was done after the pH meter was calibrated using pH 4 and 9 buffers.

3.3.7 Determination of soil heavy metals and air quality parameters

In order to identify quantitatively the source of the soil heavy metals and air quality parameters in the study area, the PMF model was used to analyze the data by using EPA PMF 5.0 (US) software (USEPA, 2014).

3.4 Data analysis

The open-source software R Studio version 4.3.1 was used to analyze the data (Team, 2017). T-test was used to observe the variations among the sample means and between the sample types, respectively, at 95% confidence interval. Furthermore, Pearson (r) correlation examined the relationship between the levels of parameters in air with those in soil as well as noise. Correlation analysis was also used to examine the relationship between heavy metals and other physico-chemical parameters. The paired sample T-test was used to evaluate differences in levels of parameters from the selected sites. Microsoft Excel 2007 windows program (correlations and graphs) were used to analyze the data. A significance level (α) of 0.05 was used for all statistical tests in this study.

The HYSPLIT model by Air Resources Lab (National Oceanic and Atmospheric Administration, USA) was used to collect and determine the movement pattern of air pollutants through backward and forward trajectories (Lv et al., 2015).

$$X_{ij} = \sum_{k=1}^{p} g_{ij} f_{kj} + e_{ij} \qquad eq.\ (1)$$

PMF is calculated using the equation 1 where xij is composed of the j-th compound concentration measured in the i-th sample, source contribution matrix gik represents the contribution of the k-th source to the i-th sample, source profile matrix fkj is made up of the j-th compound from the k-th source, and eij is the residual matrix.

The objective of PMF analysis is to minimize Q as per equation 2.

$$Q = \sum_{i=1}^{n}\sum_{j=1}^{m}\left[\frac{x_{ij}-\sum_{k=1}^{p} g_{ik}f_{kj}}{u_{ij}}\right]^{2} \text{ subject to } g_{ik} \geq 0 \text{ and } f_{kj} \geq 0 \qquad eq.\ (2)$$

PMF 5.0 requires the input of concentration of samples species as well as uncertainty. Equation 3 is used to calculate uncertainty of the concentrations.

$\sqrt{(error\ fraction \times c)^2 + MDL^2}$ For c ≤ MDL, uij= 5/6 × MDL For c > MDL, u_{ij} *eq. (3)*

The factor numbers were configured to 2, 3, 4, 5, and 6, with 40 runs as a total to ensure stability of the model (Guan et al., 2016).

Pollution risk assessment was conducted using the Geo-accumulation index (I_{geo}) to express the gravity of contamination of the soil which is exposed to people and is applied to evaluate pollution due to a single element as stated by Li et al. (2020b).

$$I_{geo} = Log_2 \frac{C_n}{1.5 \times B_n} \qquad eq.\ (4)$$

The Geo-accumulation Index (I_{geo}) was calculated using the equation as presented by Pathak et al. (2015) where C_n is the concentration of heavy metal n of soil and 1.5 is the constant used to neutralize changes caused by diagenesis. B_n is the geochemical value of background of heavy metal n.

3.5 Validity and reliability

The ambient air measuring instrument underwent accurate calibration within the flow range of 0 to 3 L per min and the calibration of noise level measuring equipment was carried out according to the instrument operational manual provided by the manufacturer. If this was not done, it would have affected the quality of data collected. During data acquisition, 10 min consecutive average measurements were recorded during morning (09:00 - 10:30 h), midday (11:30 - 13:00 h) and afternoon (15:30 - 17:00 hrs), providing 10 sets of values per session per day (Mapoma et al., 2013).

3.6 Ethical considerations

Ethical approval was obtained from NCST for the study as pollution risk assessment was conducted. The results reflected the work that was done and not copied from someone else, and the data was not manipulated in any way. Authorization from the Blantyre City Council was acquired before sampling around the industrial sites commenced.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

This chapter presents the results and discusses the findings of the study.

4.1 Air quality parameters

The values for air quality and noise levels in Table 2 are presented in comparison to the limits set by the World Health Organization (World Health Organization, 2021) and Malawi Standards (MSB, 2021a; MSB, 2021b) for specific parameters.

Table 2: Air quality and noise level values against prescribed limits

Sampling Point	CO (mg/m^3)		TSP (µg/m$^{3)}$		PM$_{10}$ (µg/m^3)		PM$_{2.5}$ (µg/m^3)		Noise (dB)	
	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season
Maone MH	ND	ND	30.5± 13.37	112± 39.02	13.8± 2.70	21.3± 8.41	10.3± 2.61	16± 6.21	38.5± 5.90	49.1± 10.23
Maone NM	0.667± 0.58	1.7± 1.13	45.4± 19.97	95.9± 29.47	25.4± 11.25	27± 12.98	19± 8.35	20.3± 9.80	42.4± 8.26	47.5± 3.88
Maone OF	ND	ND	15± 6.10	75.7± 9.00	5.33± 1.89	13.6± 3.65	3.67± 1.36	10.3± 2.65	34.8± 1.30	45.6± 1.22
Limbe AZ	ND	ND	66.3± 52.10	105± 44.09	17± 15.97	24.7± 7.15	12.8± 11.87	18.7± 5.16	48.9± 2.24	47.8± 2.58
Limbe MP	0.333± 0.58	1.67± 0.58	214± 76.46	147± 37.82	36.2± 17.72	47.8± 16.68	27.1± 13.32	35.8± 12.58	51.9± 2.82	50.8± 5.99
Limbe PC	ND	ND	23.9± 14.11	115± 11.57	6.93± 3.52	26.6± 6.65	5.17± 2.63	20± 4.95	43.4± 6.02	48.9± 6.26
Maselema BP	2± 3.46	4.33± 2.31	174± 90.06	184± 114.00	18.3± 8.24	25.7± 7.91	13.8± 6.17	19.3± 5.91	58.4± 1.69	58.1± 2.69
Maselema PP	2.67± 3.06	3.67± 2.08	46.7± 25.67	184± 5.86	13.5± 7.82	25.7± 4.49	10.1± 5.84	19.3± 3.30	41.1± 1.10	47.4± 1.14
Maselema RP	1.33± 1.53	3± 2.00	44.9± 20.32	105± 27.59	4.3± 0.17	45.7± 13.36	12.5± 15.93	34.3± 10.00	39.4± 1.83	47.4± 3.32
Chirimba AP	ND	0.667± 1.15	319± 319.35	52.3± 5.61	23.1± 17.63	13.6± 5.98	17.1± 13.34	10.1± 4.61	53.5± 2.47	52.4± 5.09
Chirimba BC	0.33± 0.58	1.33± 0.58	18.3± 5.44	76.3± 37.86	5.07± 1.01	13.3± 6.91	3.6± 0.85	9.83± 5.27	39± 3.60	46.2± 0.67
Chirimba VZ	ND	ND	26.4± 6.92	68.7± 15.72	7.03± 2.03	15.7± 1.81	5.13± 1.46	11.8± 1.32	38.7± 3.95	46.7± 1.93
Makata AP	ND	1.33± 0.58	22± 6.75	51± 20.44	9.23± 2.35	21.6± 19.92	6.87± 1.76	16.4± 14.85	40.3± 2.27	51.6± 3.23
Makata CM	ND	0.667± 1.15	41± 3.79	50.4± 29.98	9.5± 2.51	17.1± 15.70	7.1± 1.91	12.7± 11.84	52.5± 4.82	47± 1.96
Makata LF	ND	1.33± 0.58	188± 272.32	75.6± 22.86	25.1± 27.10	25.9± 11.34	18.6± 20.50	19.4± 8.66	38.9± 5.53	42.5± 0.66
Malawi Standard	10 mg/m^3		230 µg/m^3		150 µg/m^3		25 µg/m^3		85 dB	
WHO Standard	10 mg/m^3		N/A		45 µg/m^3		15 µg/m^3		110 dB	

4.1.1 Carbon monoxide levels in the air

In the rainy season, the range of CO concentration in air was 0 to 2.67 mg/m^3 while in the dry season it was from 0 to 4.33 mg/m^3 (Figure 5). Comparison of rainy season and dry season air CO values indicated a significant difference (p = 0.01647) as per Appendix 2. The air sampled from Maselema BP exhibited the highest concentrations of CO, measuring 2 mg/m^3 during the rainy season and 4.33 mg/m^3 during the dry season. These elevated levels, potentially originating from vehicle emissions due to the nearby highway, align with the air mass trajectory at 500 m (depicted in Figure 6). The figure indicates a predominant flow of air mass from the western side, contributing to the peak CO levels at the site. The trajectory on Figure 7 shows that shows that air was moving from the study area going towards the southeast. The concentrations recorded corresponded well with a study conducted by Mapoma et al. (2013) on spatial variation of volatile organic compounds and carbon monoxide in Blantyre City, Malawi which showed that the CO levels were found to be significantly higher ($p < 0.05$) than those found in a similar study of 2004. In a research conducted by Ukpebor et al. (2021) in Benin City, Nigeria, examining the effects of enhanced traffic control measures on air quality and noise levels in both commercial and unrestricted traffic areas, comparable findings were observed. The study revealed that CO levels ranged from 1.30 to 3.20 ppm after the implementation of traffic control measures. The concentration of CO was generally below the limit of Malawi (MSB, 2021a) and WHO standards of 10 mg/m^3 (World Health Organization, 2021) as per Figure 5. In the dry and rainy season 100% of CO values were within the Malawian and WHO Standards respectively. This shows that the current CO levels are not of concern but just need to be monitored.

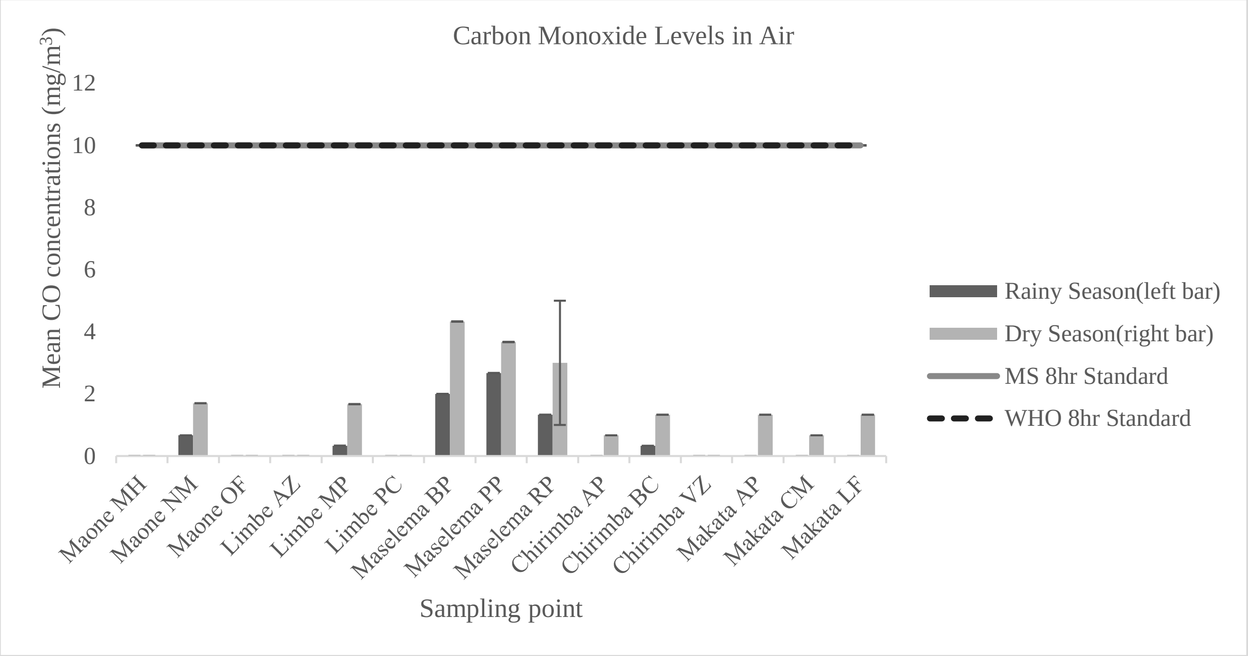


Figure 5. Carbon monoxide levels in the air for rainy and dry season

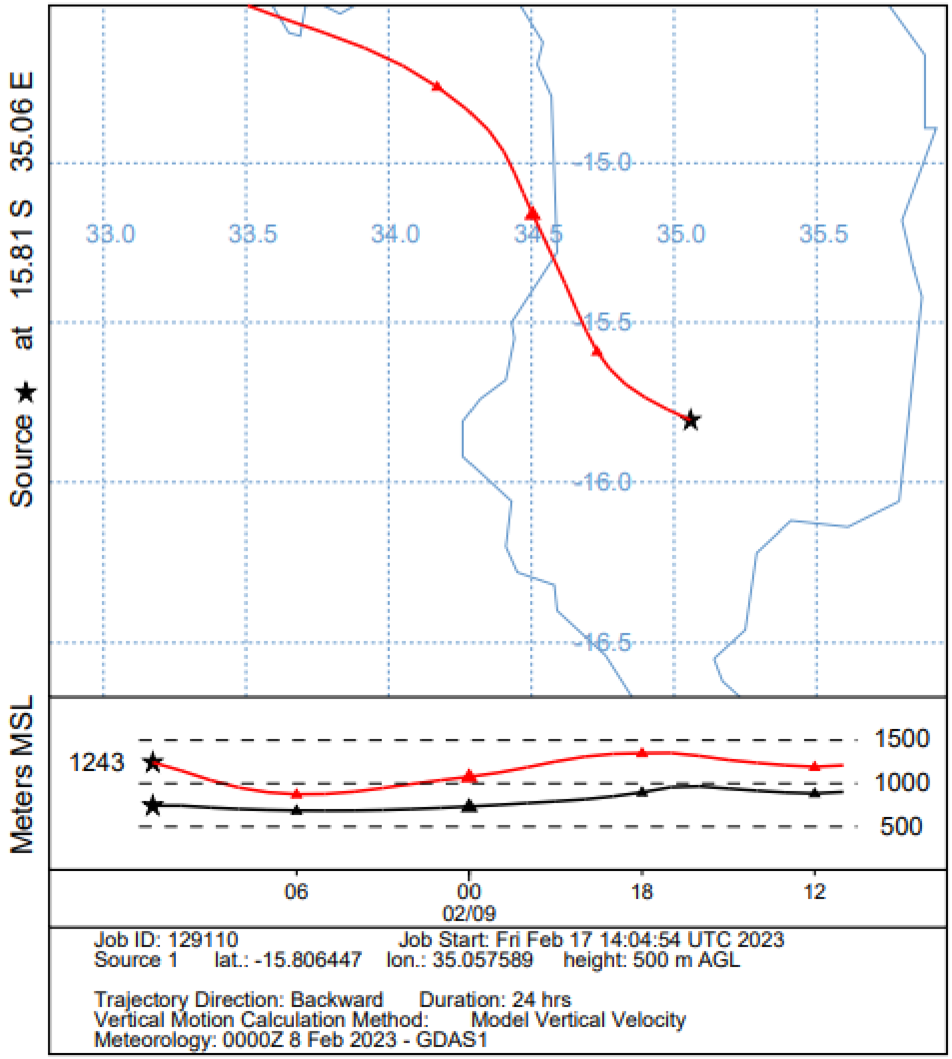


Figure 6. NOAA HYSPLIT MODEL backward trajectory generated during the rainy season for Maselema BP located in Maselema industrial area

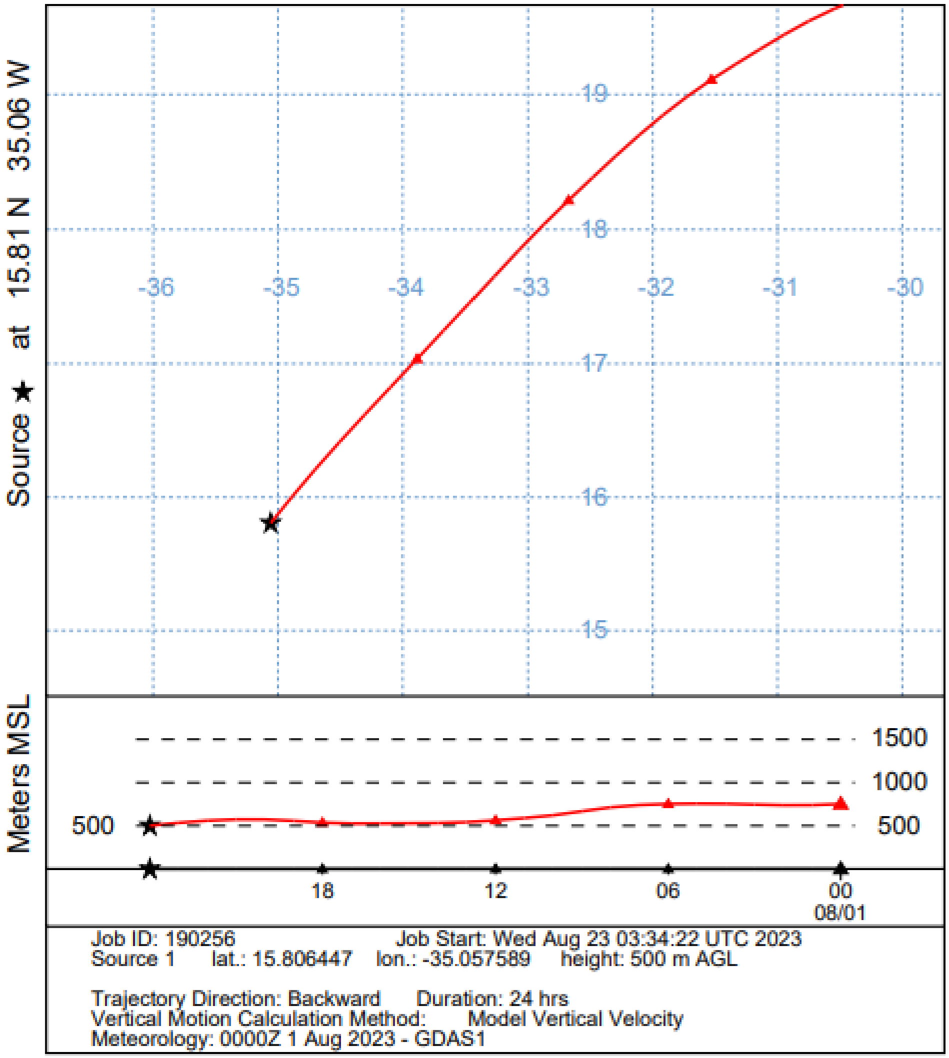


Figure 7. NOAA HYSPLIT MODEL Backward trajectory generated during the dry season for Maselema BP located in Maselema industrial area

4.1.2 Total suspended particles in the air

In the rainy season, maximum TSP concentration in air was 319 µg/m^3 while in the dry season it was 76.3 µg/m^3 (Figure 8). Comparison of rainy season and dry season air TSP values indicated no significant difference ($p = 0.638$) as per Appendix 2. The highest TSP concentrations were observed from air sampled from Chirimba AP and were 319 µg/m^3 as well as 52.3 µg/m^3 during the rainy season and dry seasons respectively (which may have come from operations related emissions as more air mass at 500 m trajectory was moving from the sampling point to other surroundings within Malawi during the rainy season while in the dry season the levels could be emanating from surrounding areas as per trajectories in Figures 9 and 10. The concentrations recorded were much higher than 75 µg/m^3 recorded by Sarpong et al. (2021) who studied PM$_{2.5}$,

PM_{10}, and Total Suspended Particle Exposure in the Tema Metropolitan Area of Ghana as well as by Sabuti & Mohamed (2018) who found the level of TSP to be within the range of 13 to 74 µg/m^3. The concentration of TSP was generally below the limit of Malawi Standard (MSB, 2021a) of 230 µg/m^3 as per Figure 8. In the rainy season 93 % of TSP values were within the Malawi Standard while 7 % were above and in the dry season 100 % of the TSP values were within the allowable Malawi Standard. The TSP levels at Chirimba AP during the rainy season may be of concern and as these may be attributed to industrial emissions.

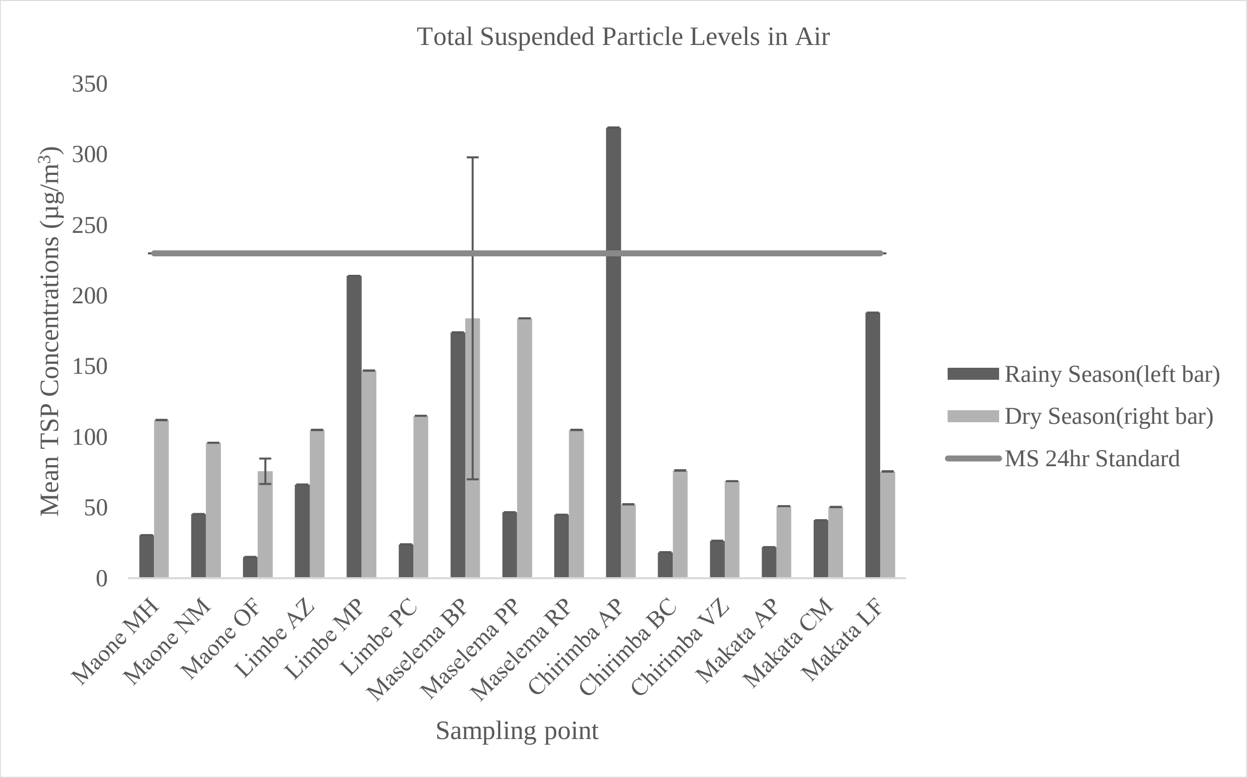


Figure 8. Total suspended particle levels in air for rainy and dry seasons

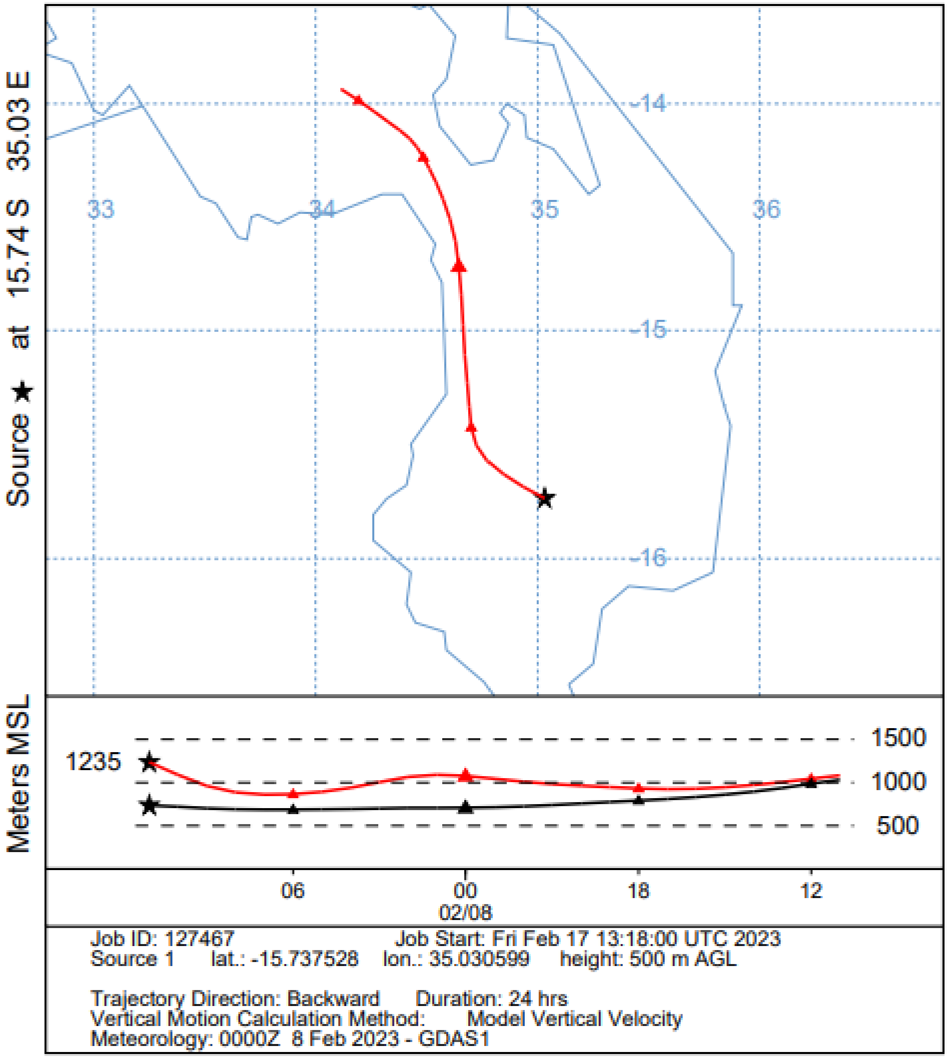


Figure 9. NOAA HYSPLIT MODEL backward trajectory generated during the rainy season for Chirimba AP located in Chirimba industrial area

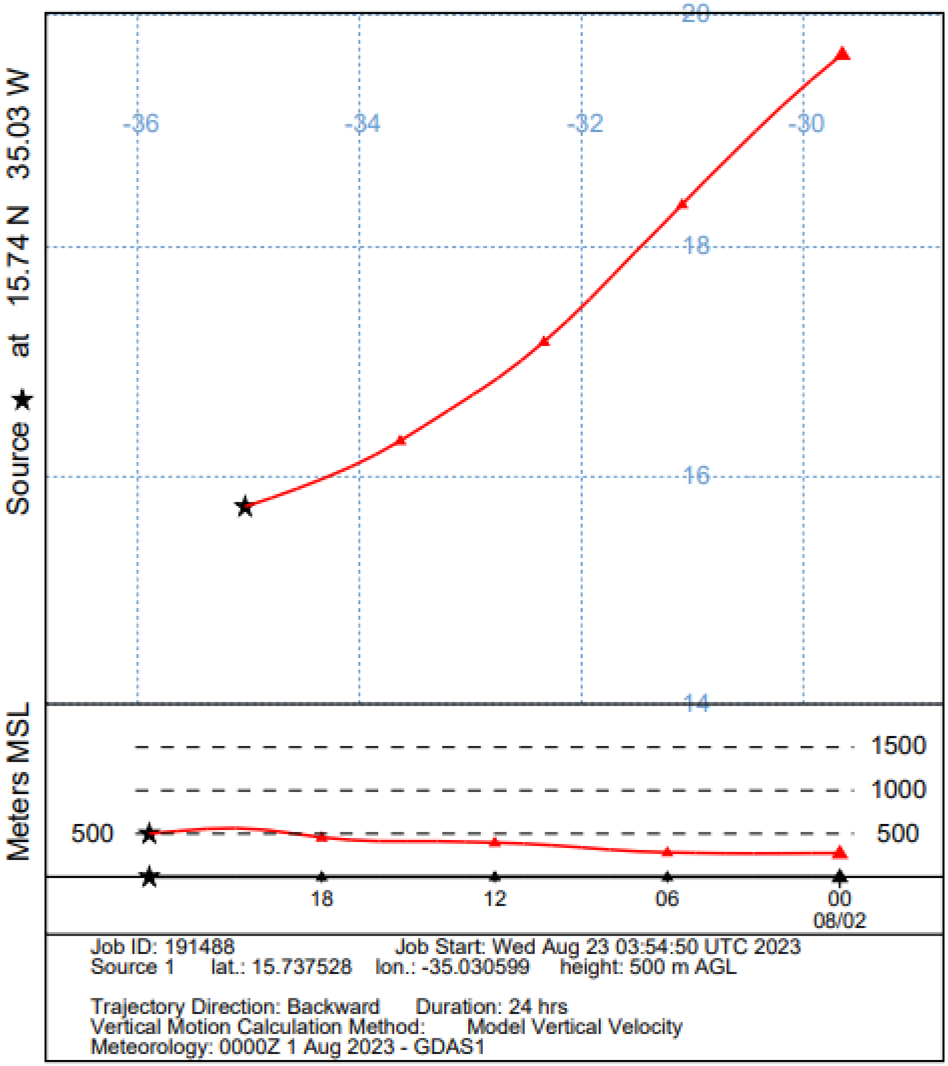


Figure 10. NOAA HYSPLIT MODEL Backward trajectory generated during the dry season for Chirimba AP located in Chirimba industrial area

4.1.3 Particulate matter 10 levels in the air

In the rainy season, the range of PM_{10} concentration in air was from 4.3 to 36.2 µg/m^3 while in the dry season it was from 13.3 to 47.8 µg/m^3 (Figure 11). Comparison of rainy season and dry season air PM_{10} values indicated a significant difference ($p = 0.0004$) as per Appendix 2. The highest PM_{10} concentrations were observed from air sampled from Limbe MP and were 36.2 µg/m^3 as well as 47.8 µg/m^3 during the rainy season and dry seasons respectively which may have come from operations related emissions as more air mass at 500 m trajectory was moving from the sampling point to other surroundings within Malawi in the rainy season while in the dry season the levels could be emanating from surrounding industries in Malawi as per trajectories in figures 12 and 13. The concentrations recorded were lower than 56.24 µg/m^3 recorded by Sarpong et al. (2021) who studied $PM_{2.5}$, PM_{10}, and total suspended particle exposure in the Tema Metropolitan Area of Ghana but were higher than the 20.7 µg/m^3 concentration recorded in 2017 found by Rovira et al. (2020) in a study conducted in Catalonia, Spain on air quality, health impacts and burden of disease due to air pollution (PM_{10}, $PM_{2.5}$, NO_2 and O_3): Application of AirQ+ model to the Camp de Tarragona County. The concentration of PM_{10} was generally below the limit of Malawian (MSB, 2021a) and WHO (World Health Organization, 2021) standards of 150 and 45 µg/m^3 as in Figure 11. In the rainy season 100 % of TSP values were within the Malawian and WHO Standards respectively. In the dry season 100 % of the values were within Malawi Standard and 87 % were within the WHO standard while the remainder of 13 % of were above. This shows that PM_{10} levels may be of concern during the dry season but may be attributed to deposition from surrounding areas.

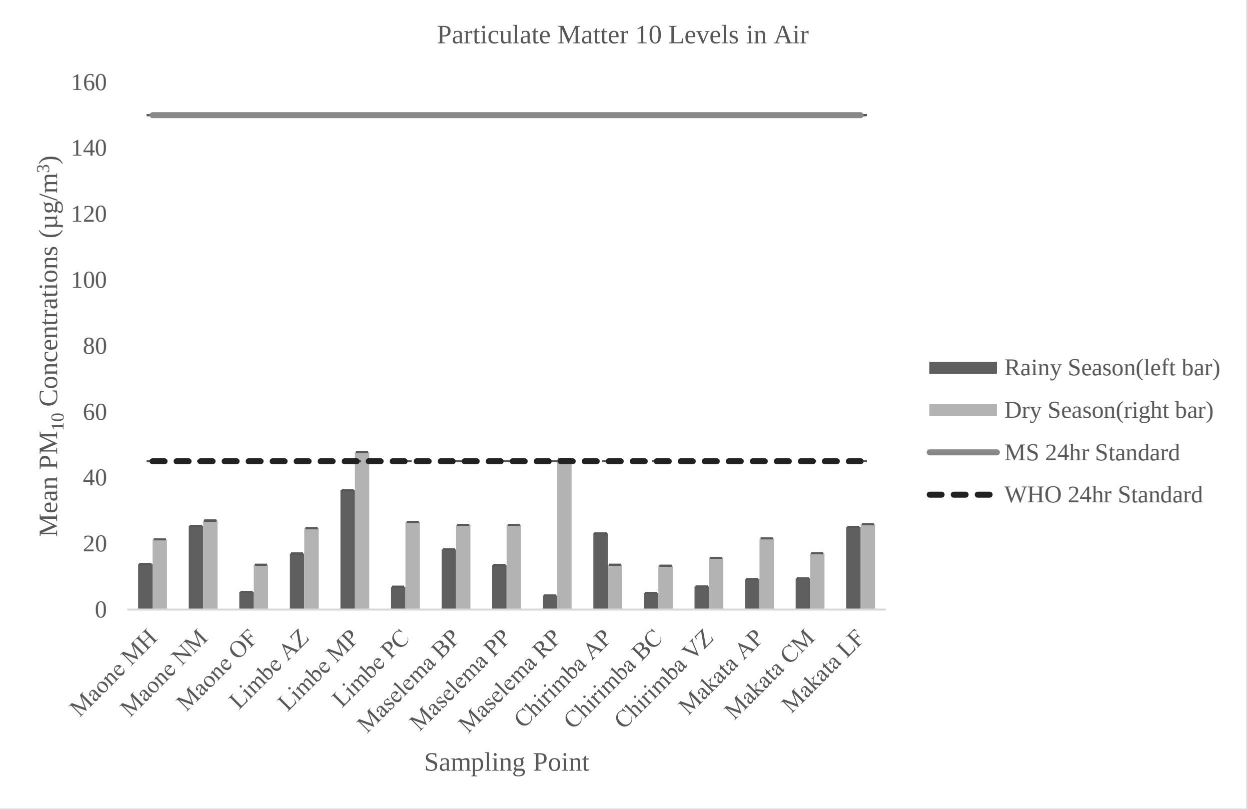


Figure 11. Particulate matter 10 levels in air for rainy and dry seasons

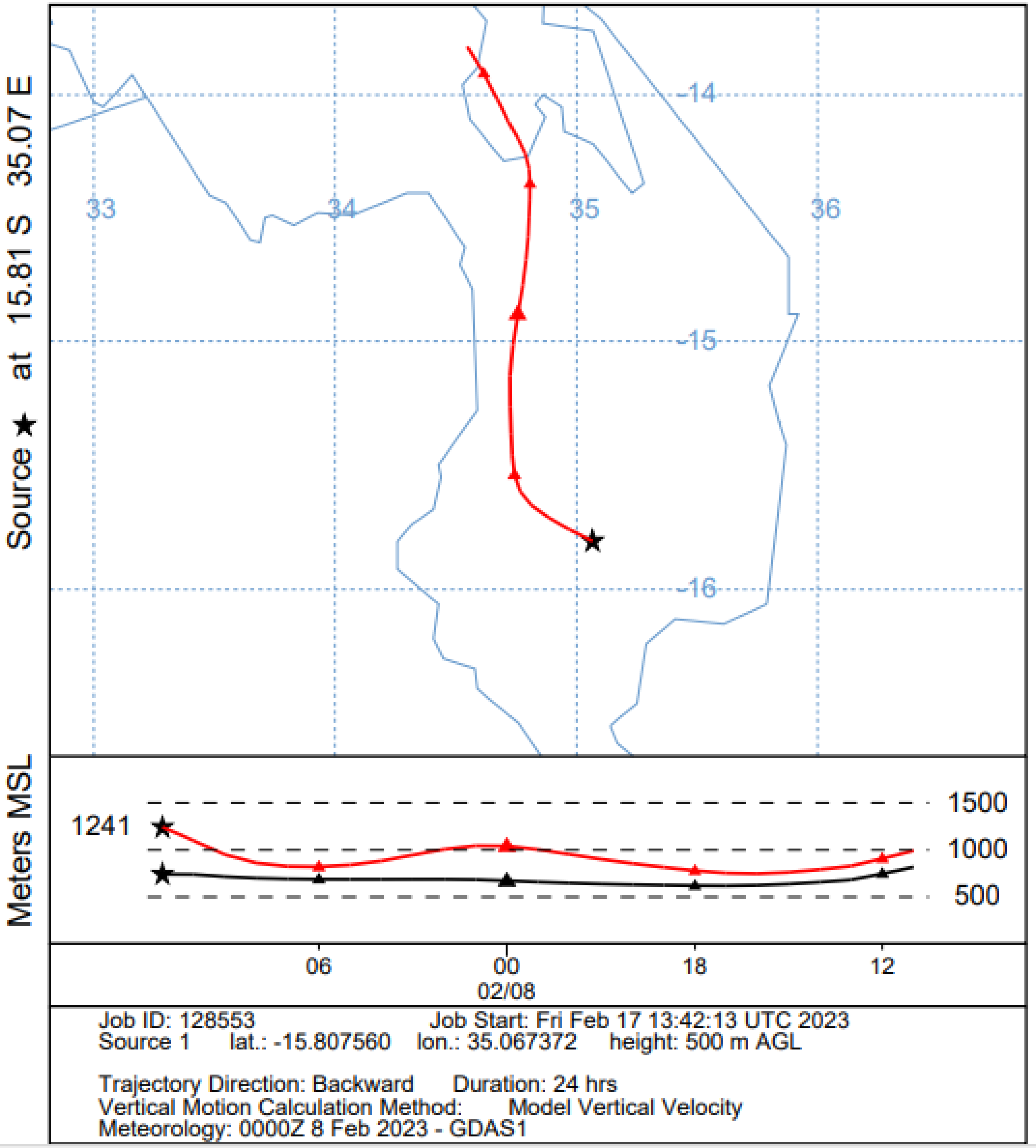


Figure 12. NOAA HYSPLIT MODEL backward trajectory generated during the rainy season for Limbe MP located in Limbe industrial area

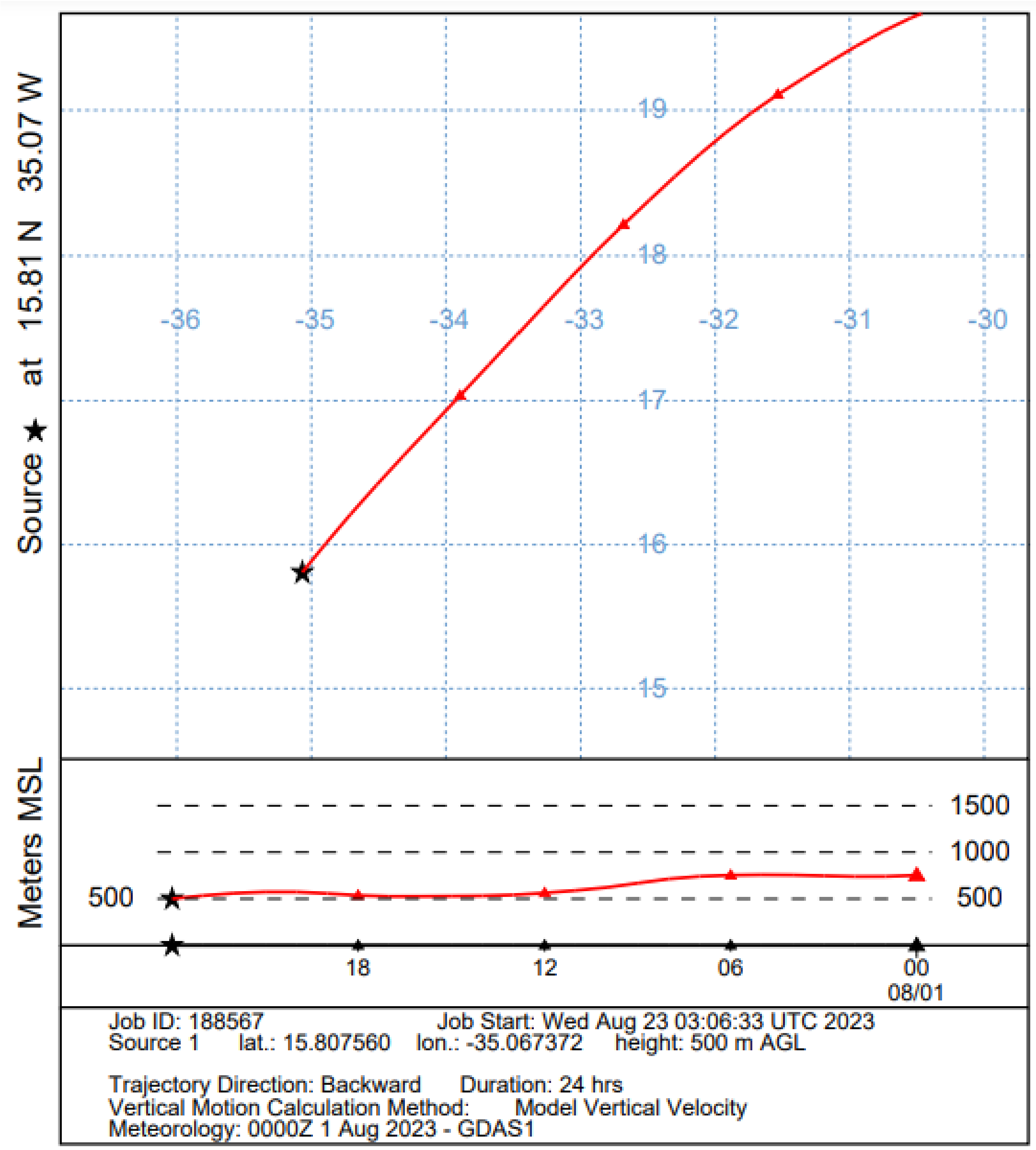


Figure 13. NOAA HYSPLIT MODEL Backward trajectory generated during the dry season for Limbe MP located in Limbe industrial area

4.1.4 Particulate matter 2.5 levels in the air

In the rainy season, the range of $PM_{2.5}$ concentration in air was from 3.6 to 27.1 µg/m^3 while in the dry season it was from 9.83 to 35.8 µg/m^3 (Figure 14). Comparison of rainy season and dry season air $PM_{2.5}$ values indicated a significant difference ($p = 0.0016$) and per Appendix 2. The highest $PM_{2.5}$ concentrations were observed from air sampled from Limbe MP and were 27.1 µg/m^3 as well as 35.8 µg/m^3 during the rainy season and dry seasons respectively (which may have come from operations related emissions as more air mass at 500 m trajectory was moving from the sampling point to other surroundings in the rainy season while in the dry season the levels could be emanating from surrounding industries as per trajectories in figures 15 and 16. The concentrations recorded were lower than 38.09 µg/m^3 recorded by Sarpong et al. (2021) who studied $PM_{2.5}$, PM_{10}, and total suspended particle exposure in the Tema Metropolitan Area of Ghana but were higher than the 11.8 µg/m^3 concentration recorded in 2017 found by Rovira et al. (2020) in a study conducted in Catalonia, Spain on air quality, health impacts and burden of disease due to air pollution (PM_{10}, $PM_{2.5}$, NO_2 and O_3): Application of AirQ+ model to the Camp de Tarragona County. The concentration of $PM_{2.5}$ was generally below the limit of Malawian (MSB, 2021a) and WHO (World Health Organization, 2021) standards of 25 and 15 µg/m^3 as per Figure 14. In the rainy season 93 % of $PM_{2.5}$ values were within the Malawian while 7 % were above and 73 % of the values were within WHO Standards while 27 % of these were above. In the dry season 93% of the values were within Malawi Standard while 7 % were above and 40 % were within the WHO standard while the remainder of 60 % were above. This means that the concentrations of $PM_{2.5}$ during both dry and rainy seasons is of concern and may be attributed to deposition from surrounding areas as well as industrial emission.

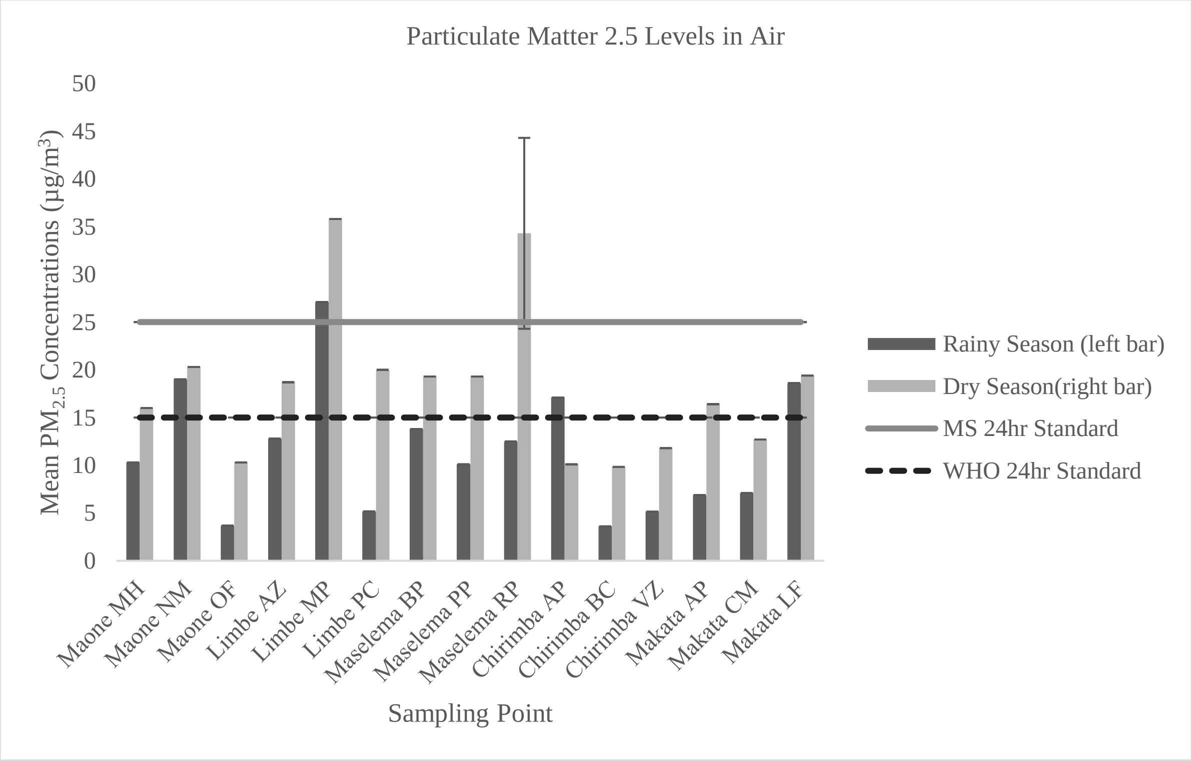
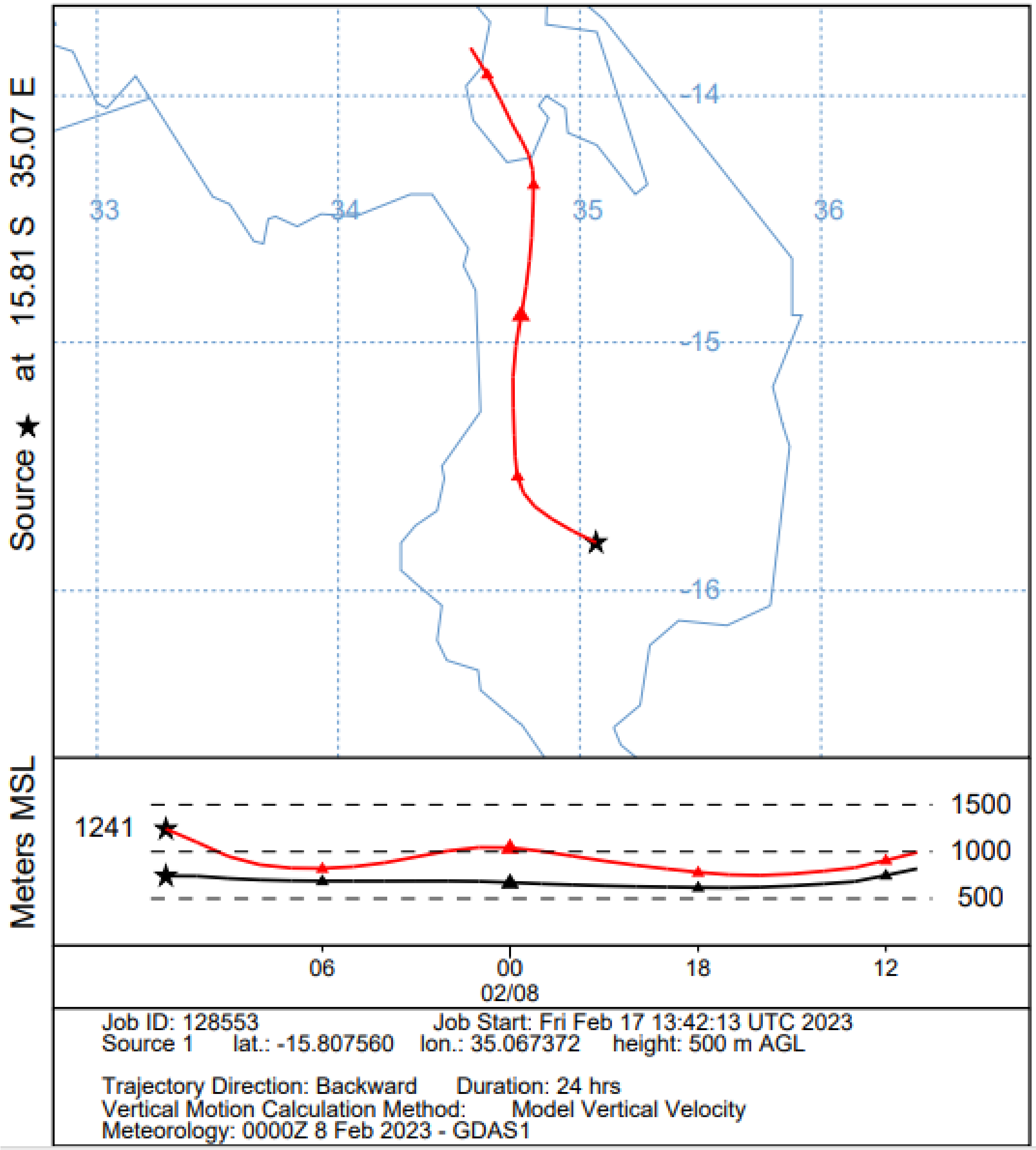


Figure 14. Particulate matter 2.5 levels in the air for rainy and dry seasons



Job ID: 128553 Job Start: Fri Feb 17 13:42:13 UTC 2023
Source 1 lat.: -15.807560 lon.: 35.067372 height: 500 m AGL

Trajectory Direction: Backward Duration: 24 hrs
Vertical Motion Calculation Method: Model Vertical Velocity
Meteorology: 0000Z 8 Feb 2023 - GDAS1

Figure 15. NOAA HYSPLIT MODEL backward trajectory generated during the rainy season for Limbe MP located in Limbe industrial area

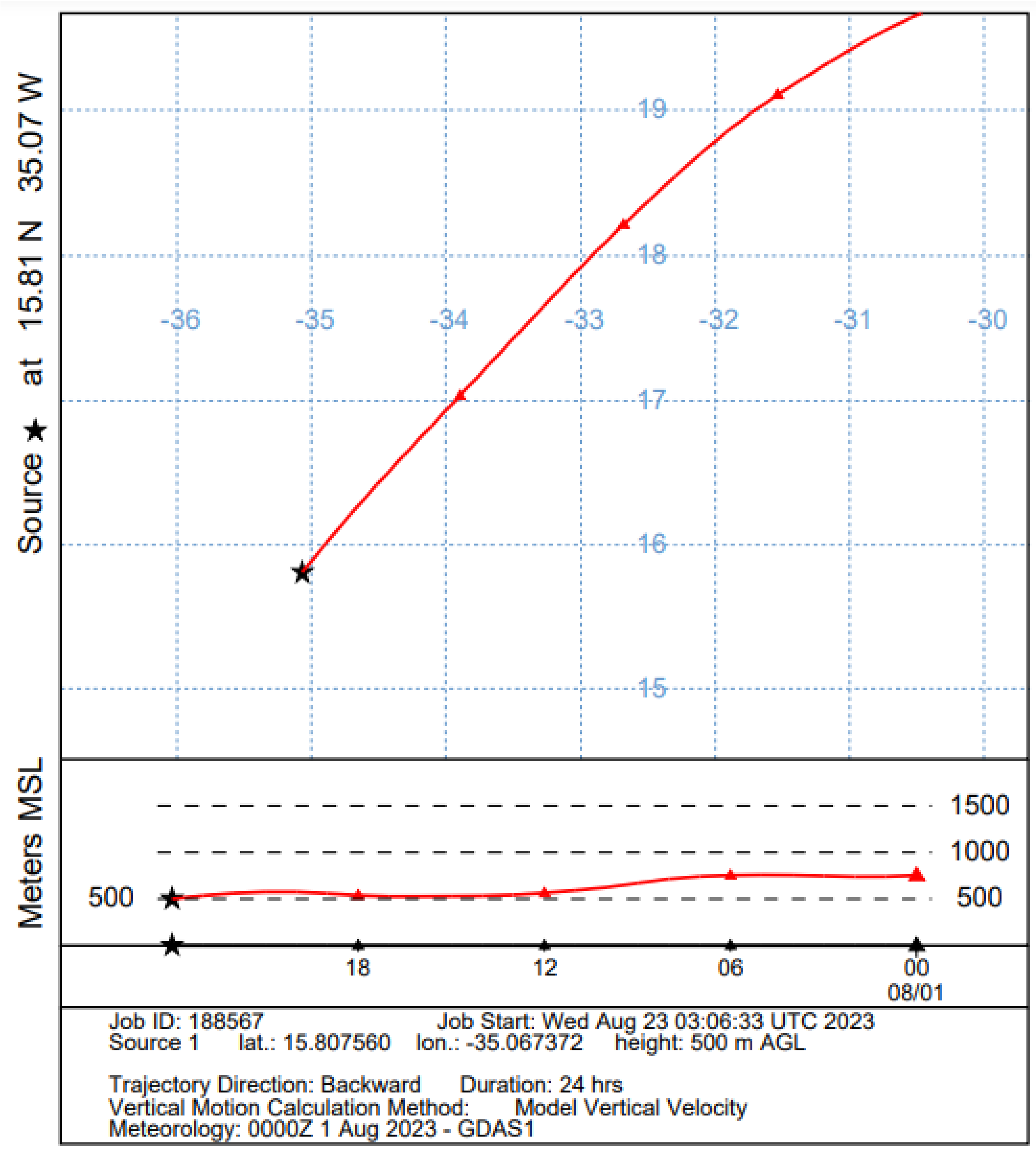


Figure 16. NOAA HYSPLIT MODEL Backward trajectory generated during the dry season for Limbe MP located in Limbe industrial area

Figure 17 shows air mass generated during the rainy (left) and dry (right) season for Maone OF located in Maone industrial area at 500 m trajectory. The trajectory on the left shows that air mass was flowing from the site to the north then in a circular motion to the southeastern region which shows that there was no influence from air mass movement on air quality parameters for the Maone OF site during the rainy season. The trajectory on the right shows that air mass was flowing into the site from the northeastern region to the site located in the southwestern region which shows that there was influence from air mass movement on air quality parameters for the Maone OF site during the dry season.

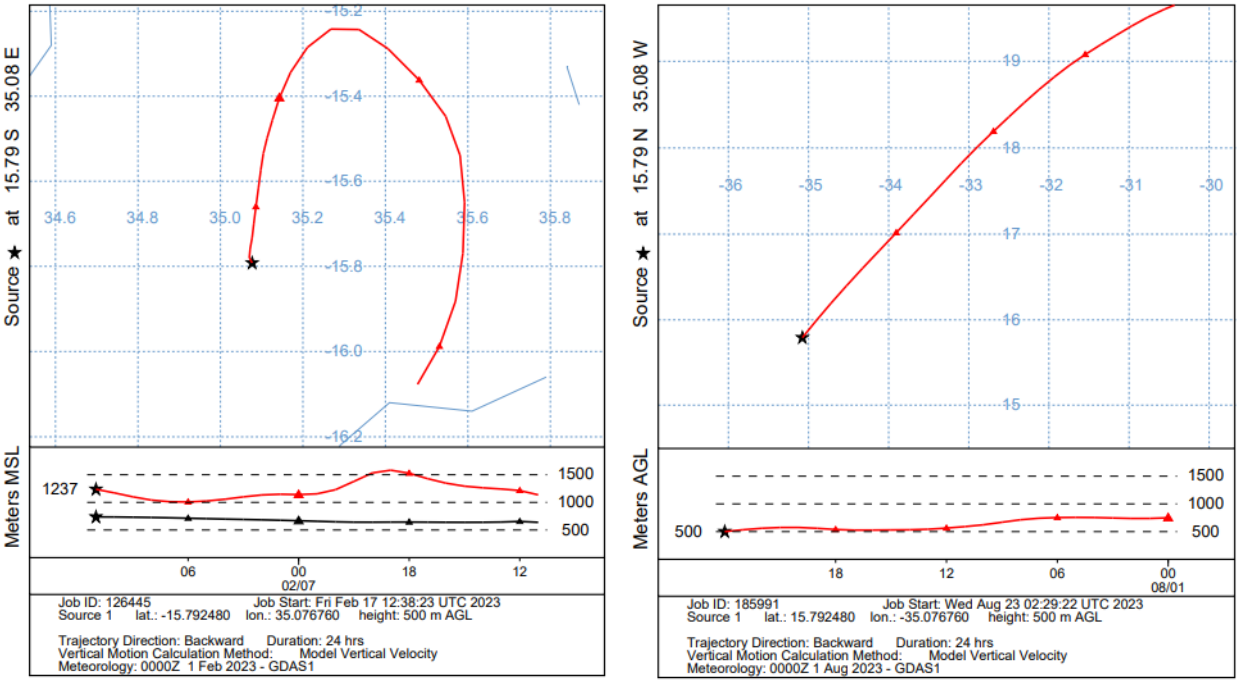


Figure 17. NOAA HYSPLIT MODEL Backward trajectory generated during the rainy (left) and dry (right) season for Maone OF located in Maone industrial area

Figure 18 shows air mass generated during the rainy (left) and dry (right) season for Maone MH located in Maone industrial area at 500 meters trajectory. The trajectory on the left shows that air mass was flowing from the site to the north then in a circular motion to the southeastern region which shows that there was no influence from air mass movement on air quality parameters for the Maone MH site during the rainy season. The trajectory on the right shows that air mass was flowing into the site from the northeastern region to the site located in the southwestern region which shows that there was influence from air mass movement on air quality parameters for the Maone MH site during the dry season.

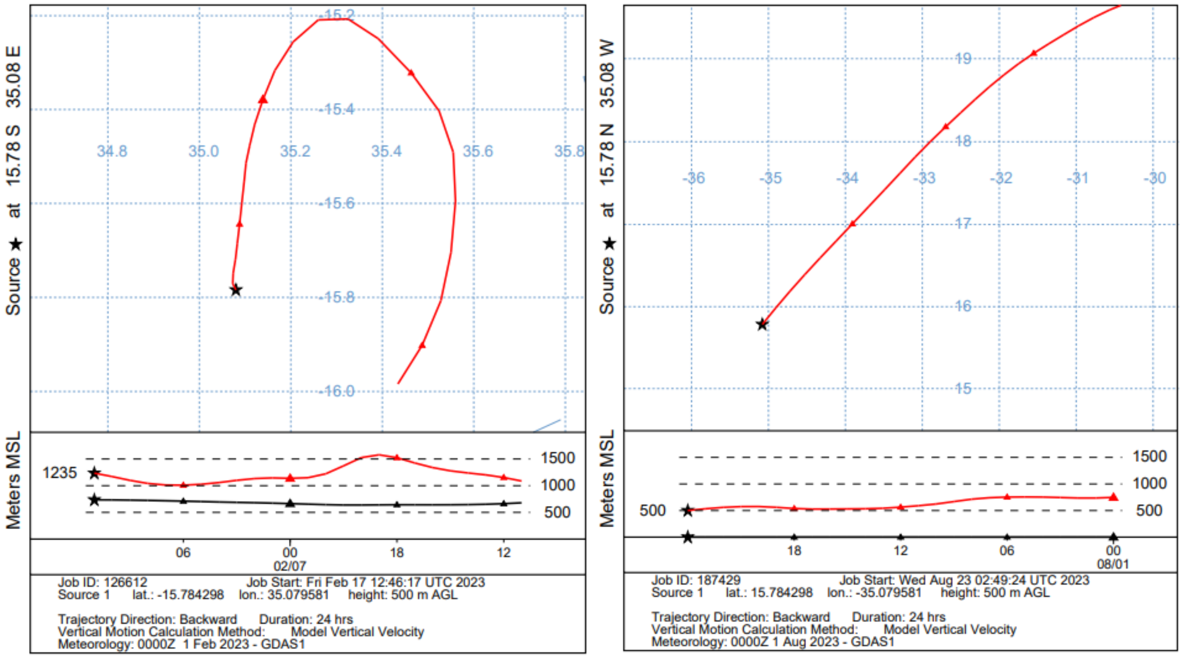


Figure 18. NOAA HYSPLIT MODEL Backward trajectory generated during the rainy (left) and dry (right) season for Maone MH located in Maone industrial area

Figure 19 shows air mass generated during the rainy (left) and dry (right) season for Maone NM located in Maone industrial area at 500 m trajectory. The trajectory on the left shows that air mass was flowing from the site to the north then in a circular motion to the southeastern region which shows that there was no influence from air mass movement on air quality parameters for the Maone NM site during the rainy season. The trajectory on the right shows that air mass was flowing into the site from the northeastern region to the site located in the southwestern region which shows that there was influence from air mass movement on air quality parameters for the Maone NM site during the dry season.

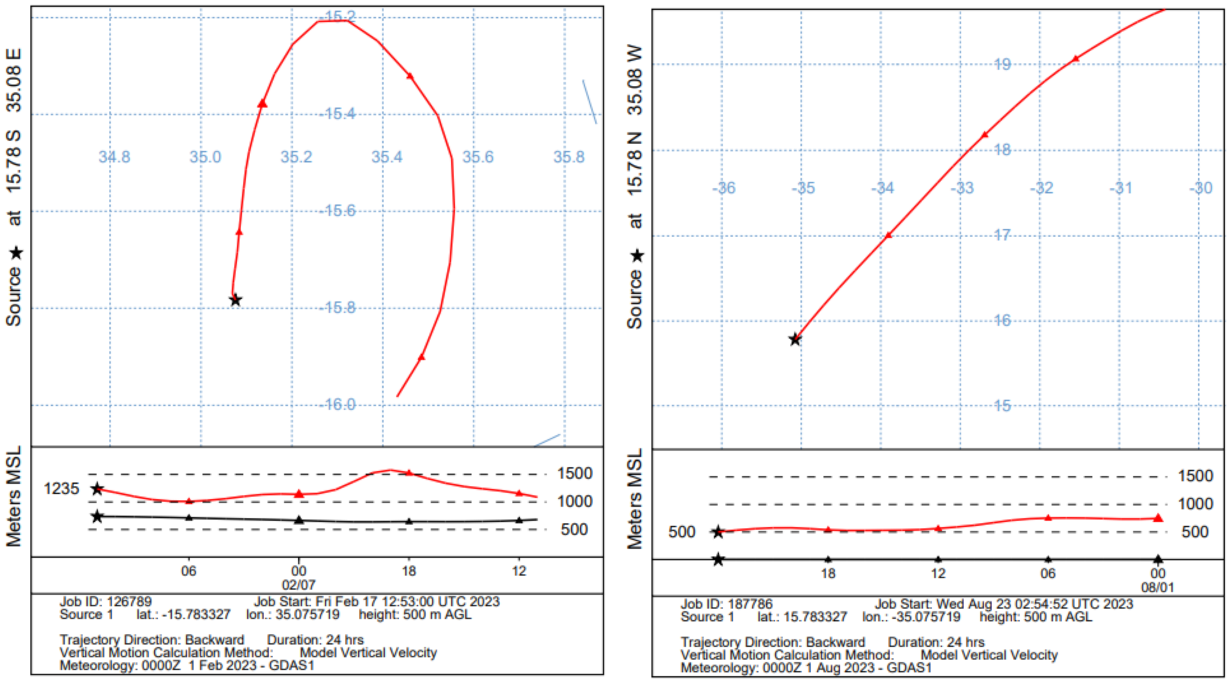


Figure 19. NOAA HYSPLIT MODEL Backward trajectory generated during the rainy (left) and dry (right) season for Maone NM located in Maone industrial area

Figure 20 shows air mass generated during the rainy (left) and dry (right) season for Makata LF located in Makata industrial area at 500 m trajectory. The trajectory on the left shows that air mass was flowing from the site to the north in a wave-like motion which shows that there was no influence from air mass movement on air quality parameters for the Makata LF site during the rainy season. The trajectory on the right shows that air mass was flowing into the site from the northeastern region to the site located in the southwestern region which shows that there was influence from air mass movement on air quality parameters for the Makata LF site during the dry season.

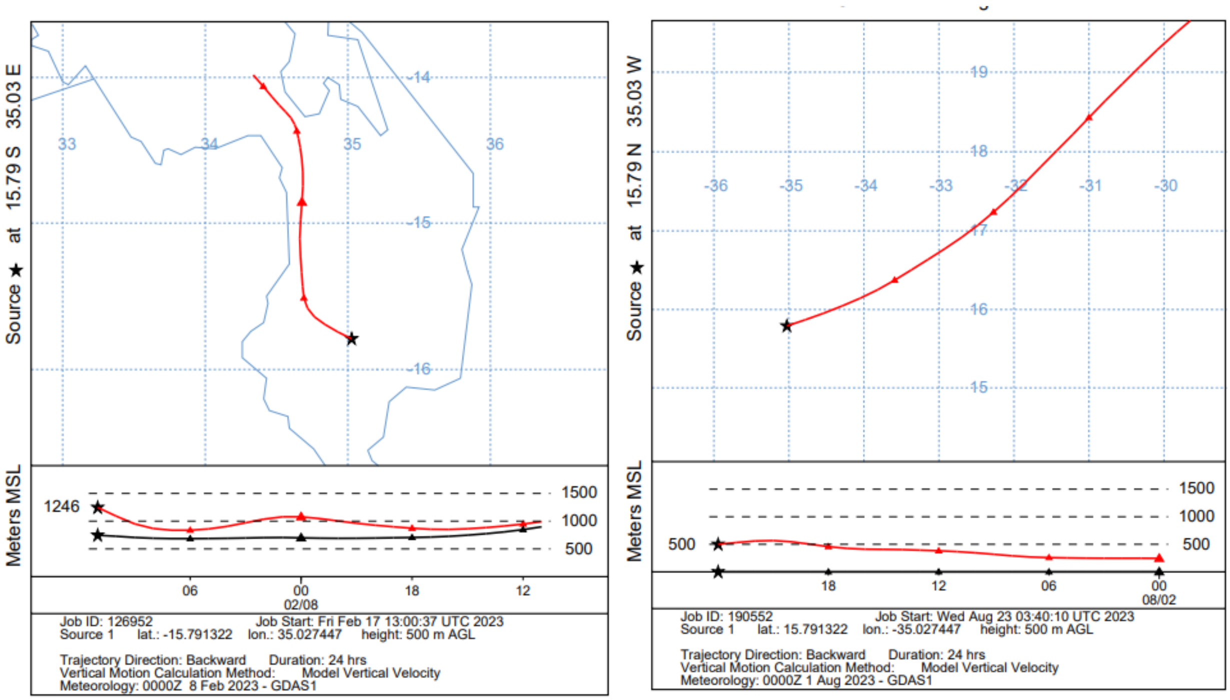


Figure 20. NOAA HYSPLIT MODEL Backward trajectory generated during the rainy (left) and dry (right) season for Makata LF located in Makata industrial area

Figure 21 shows air mass generated during the rainy (left) and dry (right) season for Makata AP located in Makata industrial area at 500 m trajectory. The trajectory on the left shows that air mass was flowing from the site to the north in a wave-like motion which shows that there was no influence from air mass movement on air quality parameters for the Makata AP site during the rainy season. The trajectory on the right shows that air mass was flowing into the site from the northeastern region to the site located in the southwestern region which shows that there was influence from air mass movement on air quality parameters for the Makata AP site during the dry season.

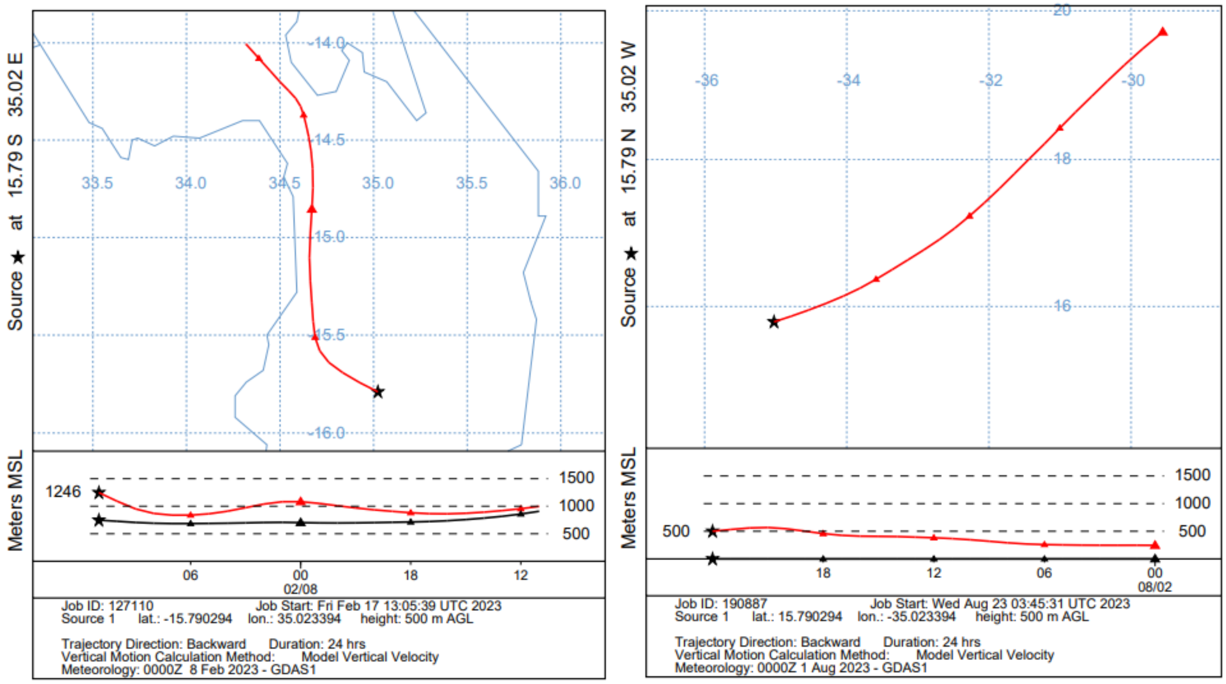


Figure 21. NOAA HYSPLIT MODEL Backward trajectory generated during the rainy (left) and dry (right) season for Makata AP located in Makata industrial area

Figure 22 shows air mass generated during the rainy (left) and dry (right) season for Makata CM located in Makata industrial area at 500 m trajectory. The trajectory on the left shows that air mass was flowing from the site to the north in a wave-like motion which shows that there was no influence from air mass movement on air quality parameters for the Makata CM site during the rainy season. The trajectory on the right shows that air mass was flowing into the site from the northeastern region to the site located in the southwestern region which shows that there was influence from air mass movement on air quality parameters for the Makata CM site during the dry season.

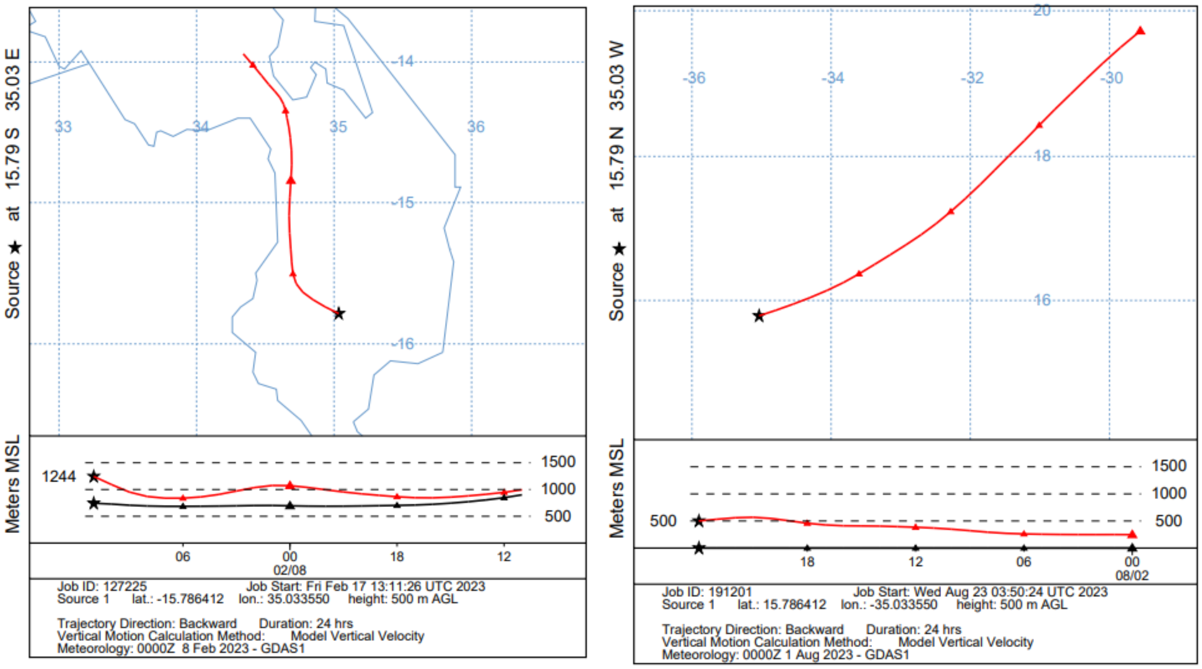


Figure 22. NOAA HYSPLIT MODEL Backward trajectory generated during the rainy (left) and dry (right) season for Makata CM Malawi Ltd located in Makata industrial area

Figure 23 shows air mass generated during the rainy (left) and dry (right) season for Chirimba BC located in Chirimba industrial area at 500 m trajectory. The trajectory on the left shows that air mass was flowing from the site to the north in a wave-like motion which shows that there was no influence from air mass movement on air quality parameters for the Chirimba BC site during the rainy season. The trajectory on the right shows that air mass was flowing into the site from the northeastern region to the site located in the southwestern region which shows that there was influence from air mass movement on air quality parameters for the Chirimba BC site during the dry season.

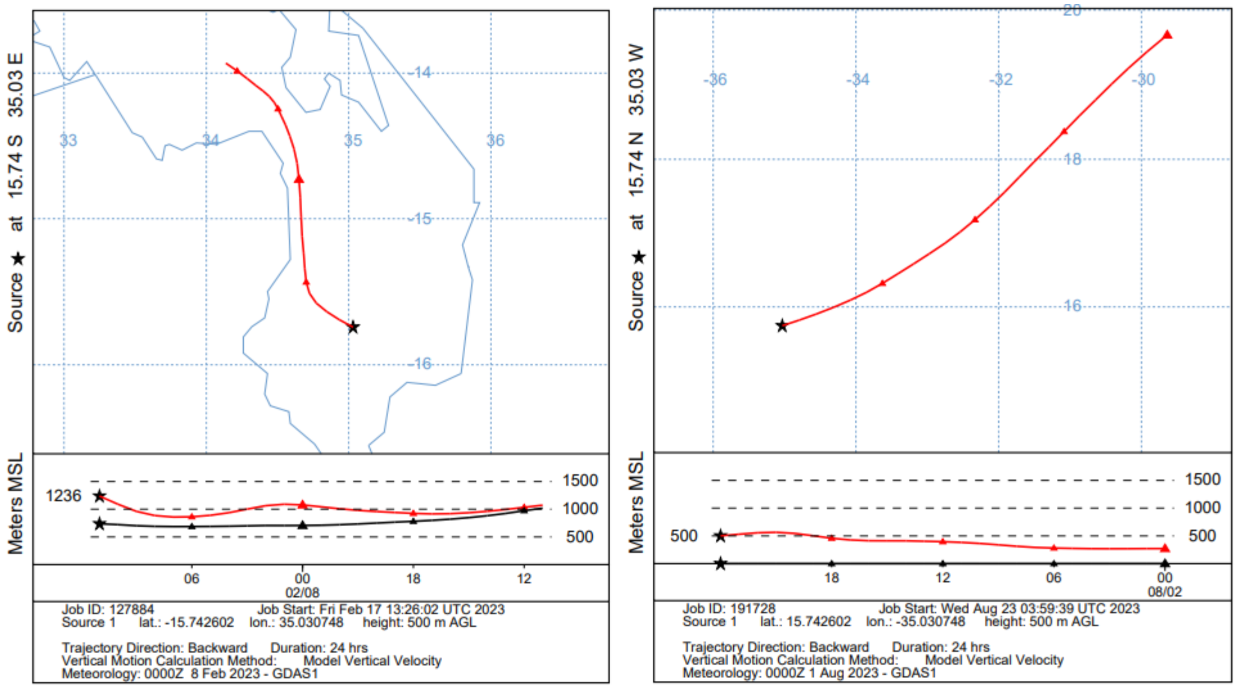


Figure 23. NOAA HYSPLIT MODEL Backward trajectory generated during the rainy (left) and dry (right) season for Chirimba BC located in Chirimba industrial area

Figure 24 shows air mass generated during the rainy (left) and dry (right) season for Chirimba VZ located in Chirimba industrial area at 500 m trajectory. The trajectory on the left shows that air mass was flowing from the site to the northwest in a wave-like motion which shows that there was no influence from air mass movement on air quality parameters for the Chirimba VZ site during the rainy season. The trajectory on the right shows that air mass was flowing into the site from the northeastern region to the site located in the southwestern region which shows that there was influence from air mass movement on air quality parameters for the Chirimba VZ site during the dry season.

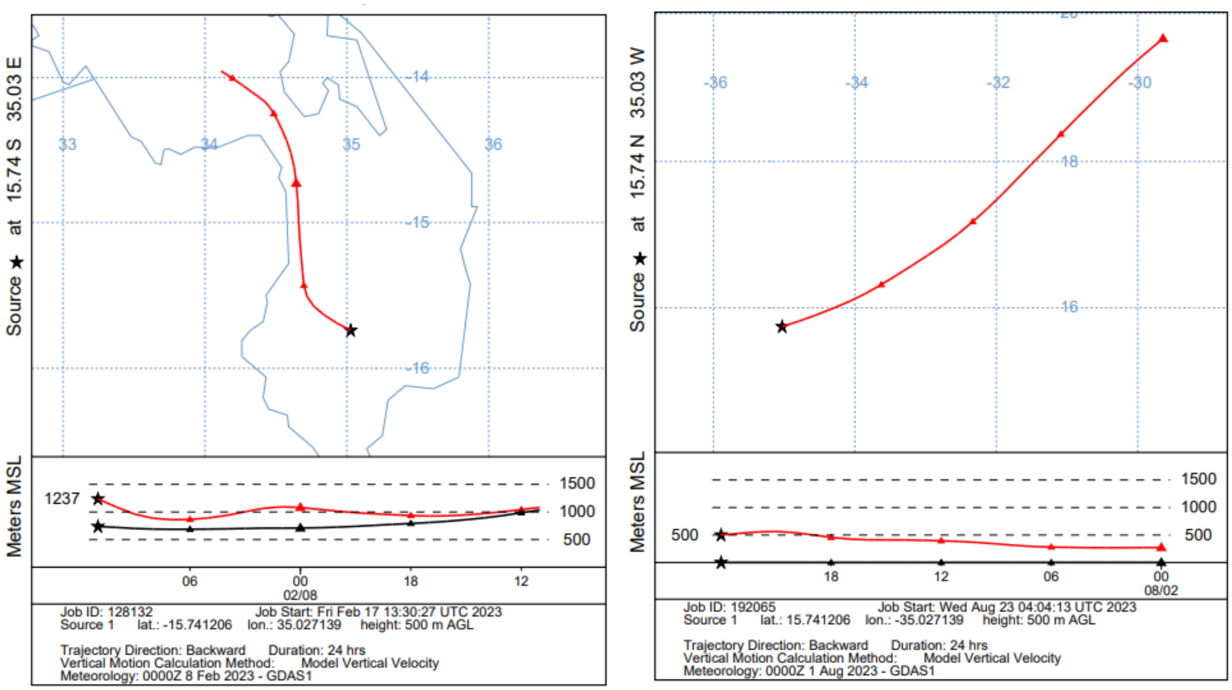


Figure 24. NOAA HYSPLIT MODEL Backward trajectory generated during the rainy (left) and dry (right) season for Chirimba VZ located in Chirimba industrial area

Figure 25 shows air mass generated during the rainy (left) and dry (right) season for Limbe AZ located in Limbe industrial area at 500 m trajectory. The trajectory on the left shows that air mass was flowing from the site to the northwest in a wave-like motion which shows that there was no influence from air mass movement on air quality parameters for the Limbe AZ site during the rainy season. The trajectory on the right shows that air mass was flowing into the site from the northeastern region to the site located in the southwestern region which shows that there was influence from air mass movement on air quality parameters for the Limbe AZ site during the dry season.

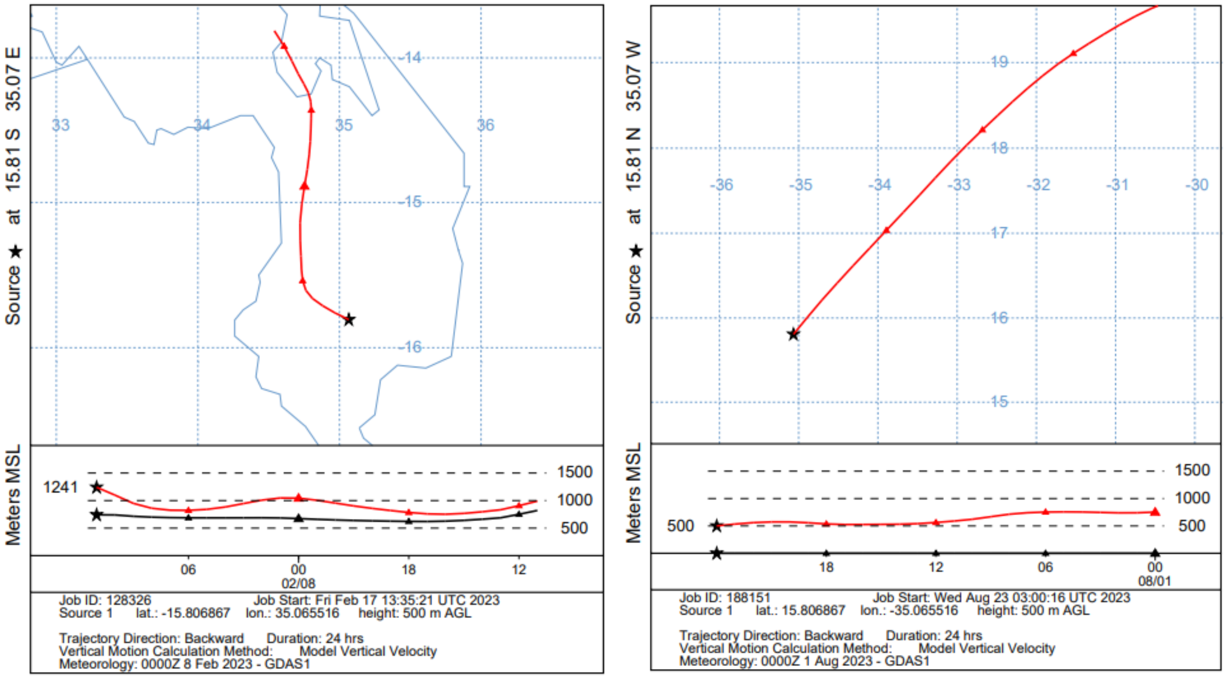


Figure 25. NOAA HYSPLIT MODEL Backward trajectory generated during the rainy (left) and dry (right) season for Limbe AZ located in Limbe industrial area

Figure 26 shows air mass generated during the rainy (left) and dry (right) season for Limbe PC located in Limbe industrial area at 500 m trajectory. The trajectory on the left shows that air mass was flowing from the site to the northwest in a wave-like motion which shows that there was no influence from air mass movement on air quality parameters for the Limbe PC site during the rainy season. The trajectory on the right shows that air mass was flowing into the site from the northeastern region to the site located in the southwestern region which shows that there was influence from air mass movement on air quality parameters for the Limbe PC site during the dry season.

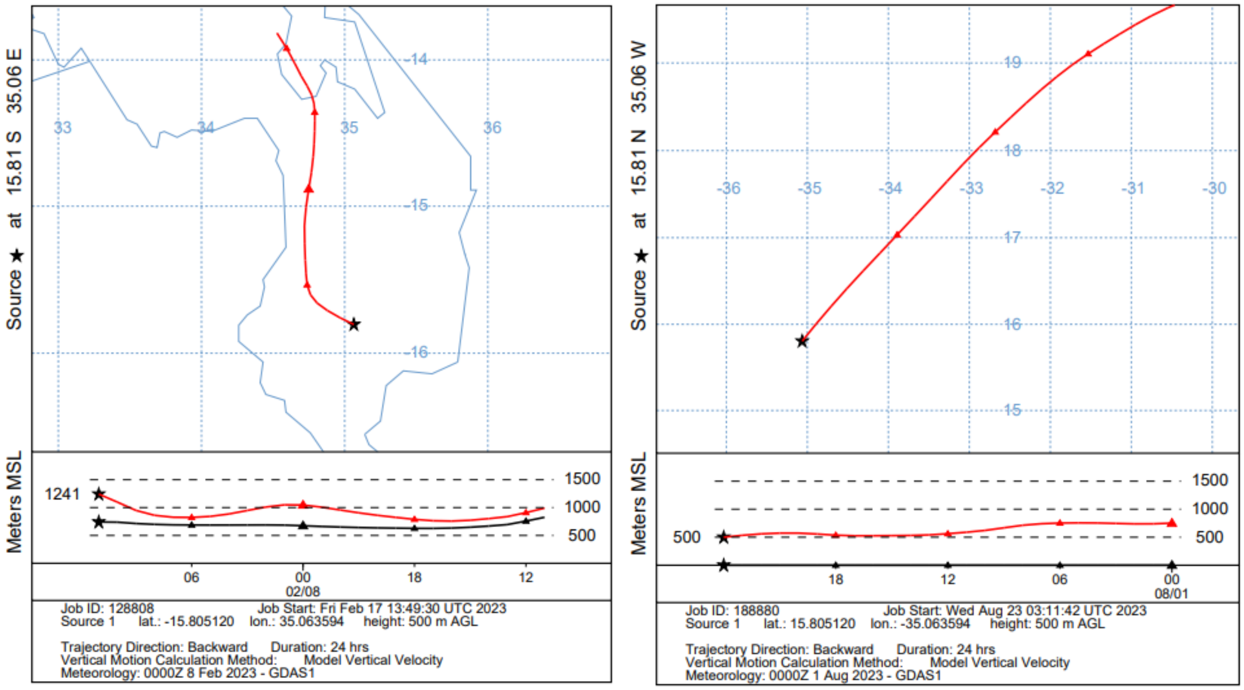


Figure 26. NOAA HYSPLIT MODEL Backward trajectory generated during the rainy (left) and dry (right) season for Limbe PC located in Limbe industrial area

Figure 27 shows air mass generated during the rainy (left) and dry (right) season for Maselema PP located in Maselema industrial area at 500 m trajectory. The trajectory on the left shows that air mass was flowing into the site from the northwest which shows that there was influence from air mass movement on air quality parameters for the Maselema PP site during the rainy season. The trajectory on the right shows that air mass was flowing into the site from the northeastern region to the site located in the southwestern region which shows that there was influence from air mass movement on air quality parameters for the Maselema PP site during the dry season.

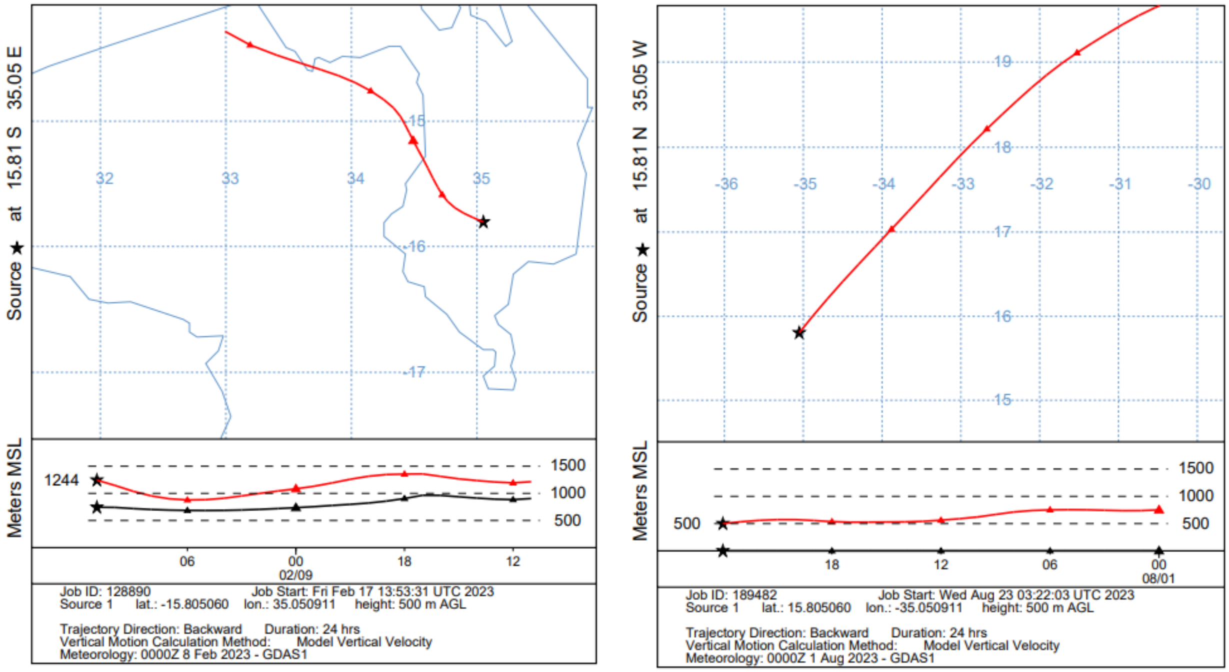


Figure 27. NOAA HYSPLIT MODEL Backward trajectory generated during the rainy (left) and dry (right) season for Maselema PP located in Maselema industrial area

Figure 28 shows air mass generated during the rainy (left) and dry (right) season for Maselema RP located in Maselema industrial area at 500 m trajectory. The trajectory on the left shows that air mass was flowing into the site from the northwest which shows that there was influence from air mass movement on air quality parameters for the Maselema RP site during the rainy season. The trajectory on the right shows that air mass was flowing into the site from the northeastern region to the site located in the southwestern region which shows that there was influence from air mass movement on air quality parameters for the Maselema RP site during the dry season.

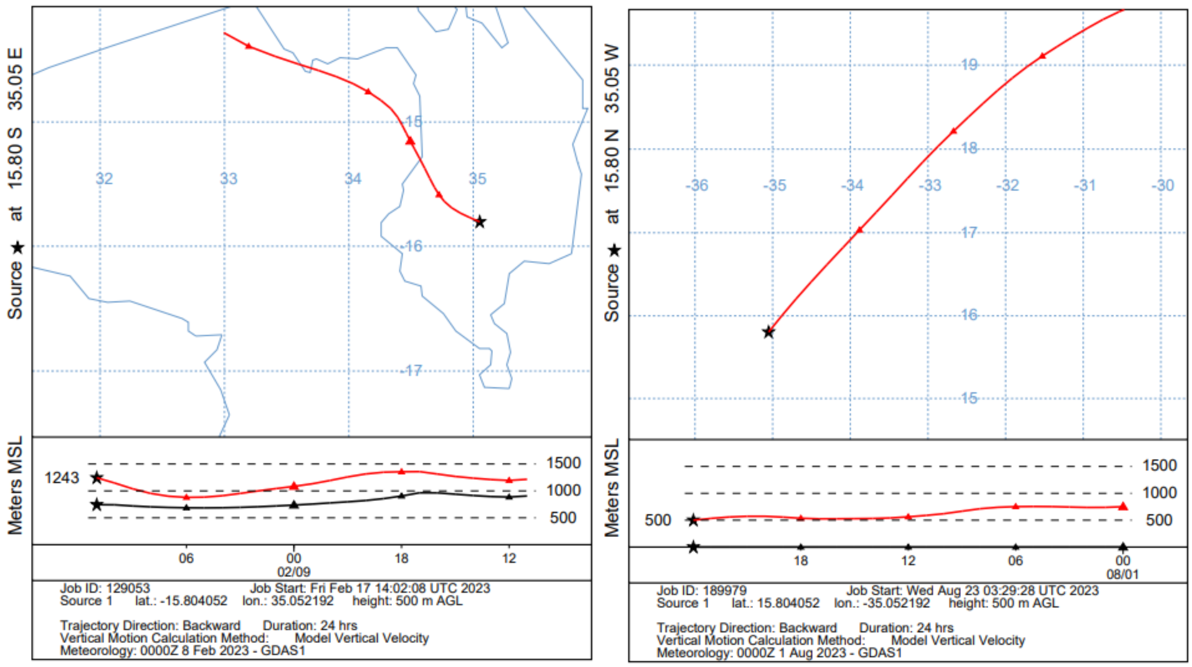


Figure 28. NOAA HYSPLIT MODEL Backward trajectory generated during the rainy (left) and dry (right) season for Maselema RP located in Maselema industrial area.

4.2 Noise levels

In the rainy season, the range of noise level was from 34.8 to 58.4 dB while in the dry season it was from 42.5 to 58.1 dB (Figure 29). Comparison of rainy season and dry season noise level values indicated a significant difference ($p = 0.0011$) as per Appendix 2. The highest noise level readings were observed from Maselema BP and were 58.4 dB as well as 58.1 dB during the rainy season and dry seasons respectively (which may have come from vehicle movement and honking as the highway is in proximity). The concentrations recorded were much higher within the range of 67-87 dB as recorded by Manojkumar et al. (2019) who conducted the assessment, prediction and mapping of noise levels in Vellore City, India. A study on impacts of improved traffic control measures on air quality and noise level in Benin City, Nigeria by Ukpebor et al. (2021) found different results of noise levels which were much higher in the range of 70 to 79 dB after traffic control measures were put in place. The noise level was generally below the limit of Malawian (MSB, 2021b) and WHO (Berglund et al., 2000) standards of 85 and 110 dB respectively as per Figure 29. In the rainy and dry seasons 100 % of the noise level values were within the Malawian and WHO Standards.

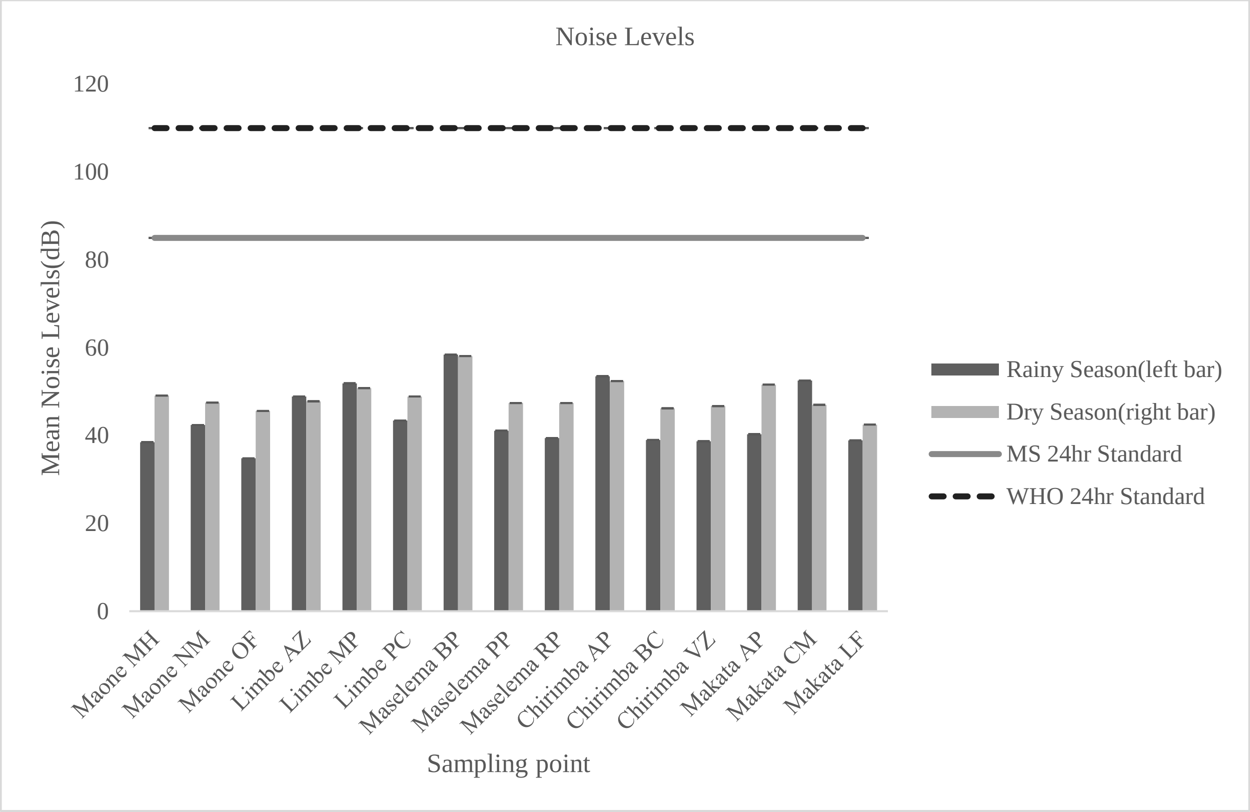


Figure 29. Noise levels for the rainy and dry seasons

4.3 Physicochemical parameters of soil

Due to the absence of soil quality standards in Malawi, the table features prescribed thresholds from international Soil Quality Standards. Table 3 shows the physicochemical values of soil against limits prescribed for certain parameters for Canada and England Standards.

Table 3: The values of physical and chemical parameters of soil in the dry and rainy seasons

Sampling Point	**` Cu (mg/kg)**		**Zn (mg/kg)**		**Cd (mg/kg)**		**pH**		**EC (µS/cm)**	
	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season	Rainy Season	Dry Season
Maone MH	ND	ND	30.7 ± 2.907	27.9± 3.747	ND	ND	6.93	6.75	88.4± 0.335	43.8± 0.494
Maone NM	3.21 ± 0.383	3.11± 0.841	68.4± 0.588	105± 11.088	2.09± 0.096	3.06± 0.104	7.65	8.15	95.5± 0.429	95.4± 0.042
Maone OF	1.15 ± 0.235	ND	71.2± 2.355	0.263± 0.110	ND	ND	6.52	7.75	24.3± 0.352	44.7± 0.297
Limbe AZ	ND	ND	81.4± 1.297	69.3± 8.990	0.072± 0.011	ND	7.31	6.77	89.5± 0.015	95.2± 0.378
Limbe MP	1.51± 0.020	3.66± 0.585	192± 1.061	185± 13.765	0.015± 0.004	ND	7.54	7.61	246± 0.015	2353 ± 5.508
Limbe PC	0.384±0.046	1.26± 0.210	41.3± 1.045	59.6± 7.320	0.044± 0.037	0.104± 0.058	7.83	7.63	84± .0154	213± 0.379
Maselema BP	21.8±0.664	14.3± 3.239	111± 0.866	94.8± 8.245	ND	ND	6.5	7.86	265± 0.419	96.4± 0.395
Maselema PP	ND	5.31± 1.706	104± 0.182	96.5± 1.702	ND	0.257± 0.072	7.68	7.61	81.7± 0.026	115± 0.404
Maselema RP	14.6± 0.970	14.6± 0.971	70± 1.887	42.9± 1.926	ND	ND	7.2	6.67	153± 0.010	132± 0.404
Chirimba AP	79± 1.368	105± 8.621	822± 2.323	579± 50.136	0.005± 0.001	ND	6.6	6.84	117± 0.549	93.9± 1.511
Chirimba BC	ND	0.005± 0.004	51.2± 3.878	66.5± 10.837	ND	ND	6.75	7.38	68.6± 0.056	74± 0.025
Chirimba VZ	ND	ND	3.95± 0.226	9.29± 8.990	ND	ND	6.48	7.01	29± 0.080	95± 0.068
Makata AP	0.046± 0.005	0.224± 0.070	16.2± 0.330	39.1± 3.672	0.167± 0.013	0.088± 0.007	7.03	7.79	62± 0.015	120± 0.265
Makata CM	ND	ND	55.5± 1.080	48.1± 3.295	ND	ND	6.3	6.77	43.1± 0.015	147± 0.361
Makata LF	3.73± 0.191	6.13± 0.855	275± 10.540	408± 66.223	0.309± 0.388	0.865± 0.208	7.36	8.11	133± 0.015	307± 0.352
England Standard	100 mg/kg		300 mg/kg		7 mg/kg		N/A		N/A	
Canada Standard	30 mg/kg		60 mg/kg		0.5 mg/kg		N/A		N/A	

4.3.1 pH levels in soil

In the rainy season, the range of soil pH was 6.3 -7.83 while in the dry season it was 6.67 - 8.15 (Figure 30). Dry season soil pH levels were significantly higher than those of rainy season (p = 0.0052) as per Appendix 2. The levels of soil pH (53% in the rainy season and 67% in the dry season) were conducive to the availability of heavy metals in soils since cations are strongly sorbed at high pH (Section 2.5). These values were not far from pH values found by Bamgbose et al. (2000) in their study in Abeokuta, Nigeria who found that soil pH range for contaminated sites was 7.44- 10.10 while in uncontaminated sites was 5.90 - 6.70. Average soil pH values for soils in India, Noonmati area of Kamrup District, vary from mildly alkaline (7.39) to 4.34 which is strongly acidic Deka & Sarma (2012).

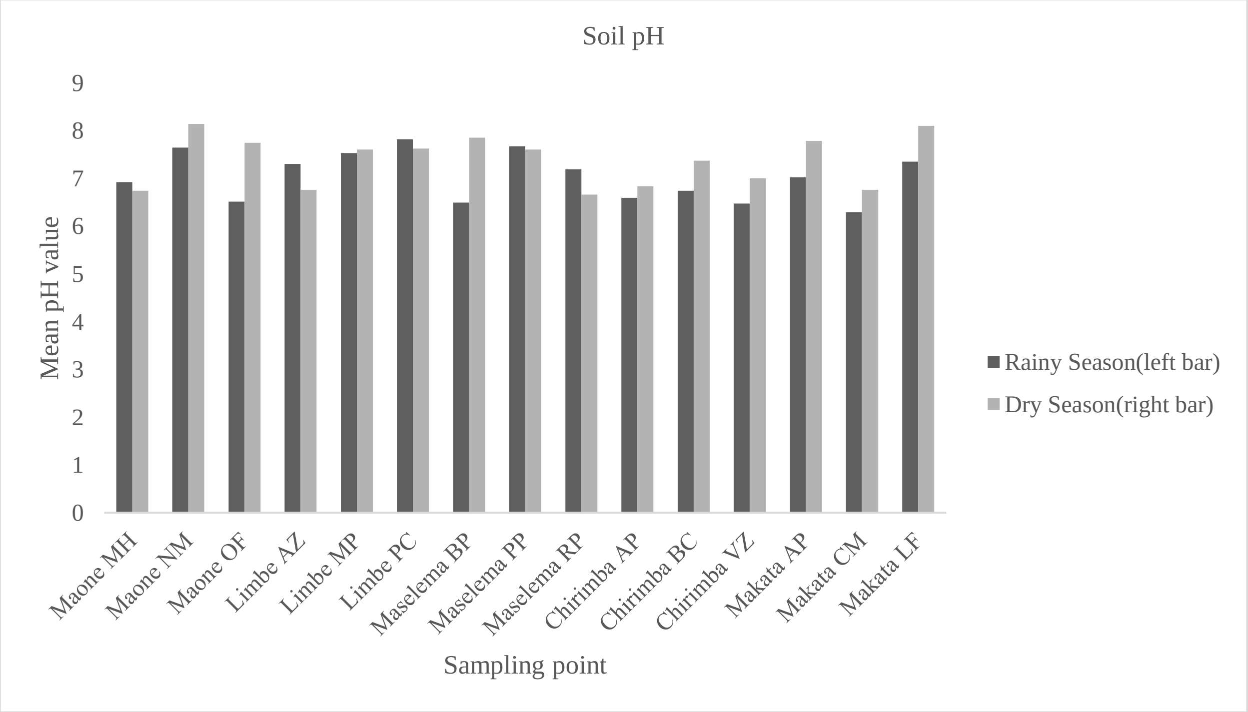


Figure 30. Soil pH for rainy and dry seasons

4.3.2 Electrical conductivity levels in soil

In the rainy season, the range of soil electrical conductivity was 24.3 µS/cm - 265 µS/cm while in the dry season it was 43.8 µS/cm - 2353 µS/cm (Figure 31). Comparison of rainy season and dry season soil electrical conductivity values indicated an insignificant difference (p= 0.0659) as per Appendix 2. These values were not far from EC values found elsewhere. As highlighted by Gomaa et al. (2020) increased levels of values Mn, Ni, and Zn heavy elements has the same effect on the conductivity in soil while the high concentration values of the Pb and Cu heavy elements reduces the conductivity as shown by Chu et al. (2018) who in their study based in Eastern China found that the increase in concentrations of ions heightens the connectivity of particles in soil and pore in fluid, which causes an increase in electric current path thus increasing conductivity.

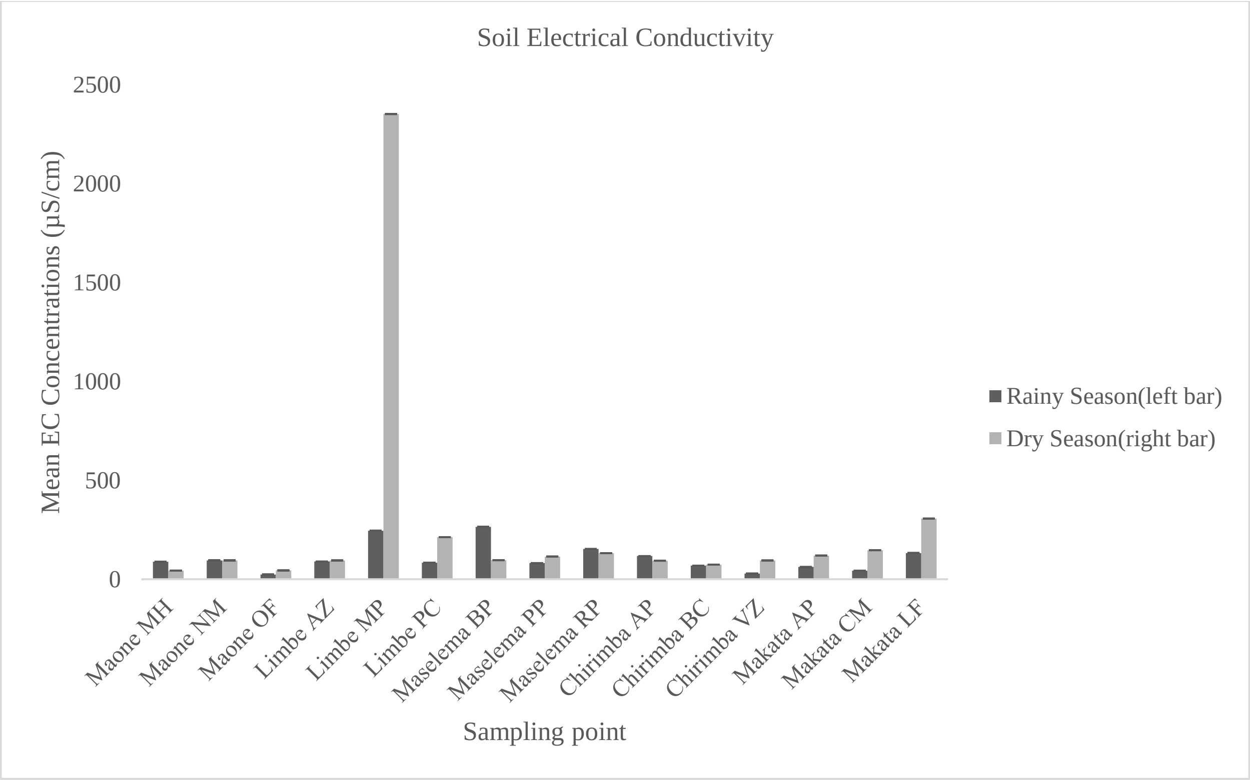


Figure 31. Soil electrical conductivity for rainy and dry seasons

4.3.3 Copper levels in soil

Observations of the soil have revealed variations in copper levels between rainy and dry seasons, with a concentration ranging from 0.001 to 79 mg/kg during the rainy season and 0.001 to 105 mg/kg during the dry season (Figure 32). However, the comparison of copper values during the rainy and dry seasons did not show any significant difference (p = 0.7246) as per Appendix 2. The highest Cu concentrations, potentially influenced by atmospheric deposition, were observed from soils taken from Chirimba AP and were 105 mg/kg as well as 79 mg/kg during the dry season and rainy seasons respectively. Atmospheric deposition is the likely cause because precipitation plays a significant role in reducing heavy metal depositions as established in a study by Sharma et al. (2008) who found that notable fluctuations in the deposition rates of heavy metals throughout different seasons indicate that weather variables play a significant role in the temporal variability of atmospheric depositions. The concentrations recorded were much higher than 10 mg/kg recorded by Saka & Ambali (2000) who studied river bank soil as well as by Zhang et al. (2020) who found the level of Cu from sediments to be within the range of 30.9 to 44.3 mg/kg. The concentration of copper was generally below the limit of England standard of 100 mg/kg (Bohn et al., 1979) but higher than the Canada Standard of 30 mg/kg (Alloway and Ayres, 1997) as in Figure 32. The study found that copper levels in the soil of the investigated area were generally within acceptable limits according to England standards 100% and 93% in rainy and dry season respectively but exceeded the Canada standard in 7% of the cases. These findings not only contribute valuable information about the local soil quality and its variations over different seasons, but it also shows that Cu concentrations are of concern during both rainy and dry seasons especially at Chirima AP. This may be attributed to with atmospheric deposition as well as poor waste management practices.

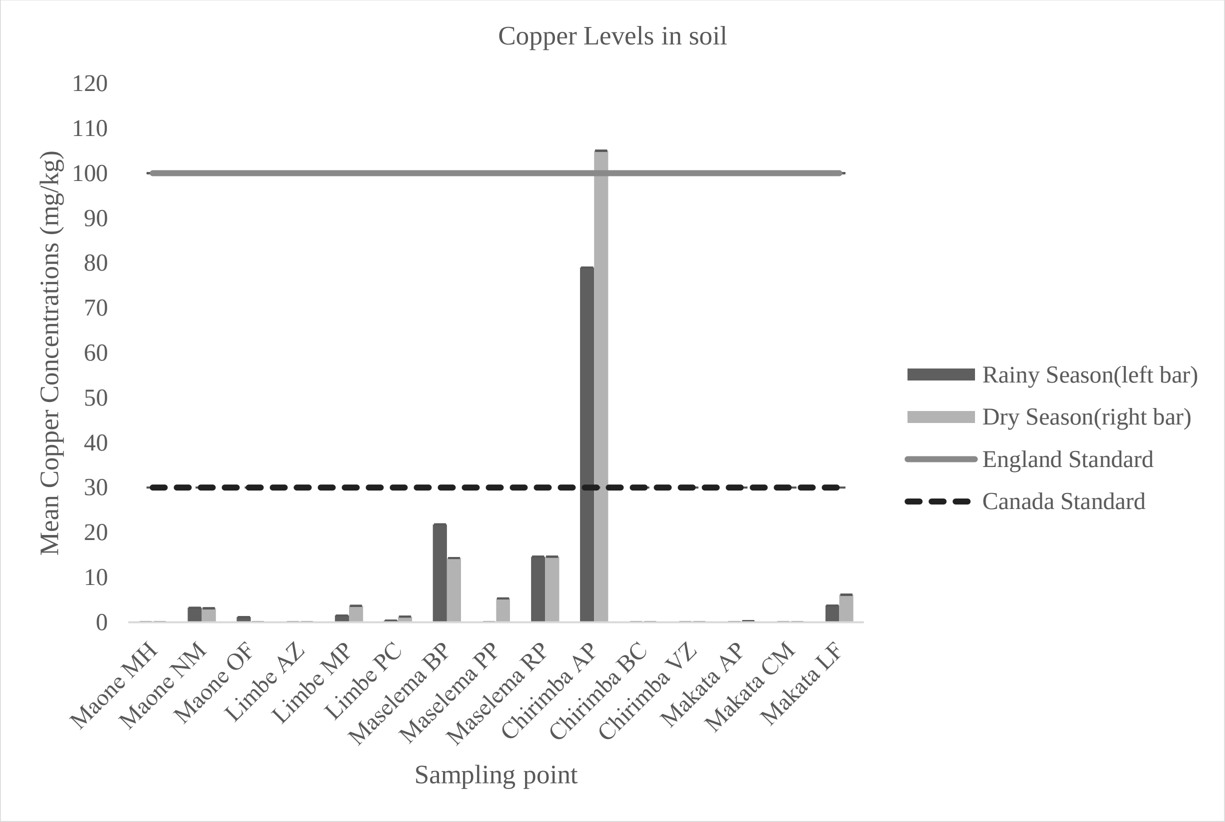


Figure 32. Copper levels in soil for rainy and dry seasons

4.3.4 Zinc levels in soil

In the rainy season, the range of zinc concentration in soils was 3.95 - 822 mg/kg while in the dry season it was 0.263 - 579 mg/kg (Figure 33). Comparison of rainy season and dry season soil zinc values indicated no significant difference (p= 0.793) as per Appendix 2. The highest Zn concentrations were observed from soils taken from Chirimba AP and were 822 mg/kg as well as 579 mg/kg during the rainy season and dry seasons respectively (which may have come from surface run-off from metal processing industries). The concentrations recorded were much higher than the range of 31.78 - 461 mg/kg recorded by Kumar et al. (2018) who studied heavy metals in industrial soils of India as well as by Orvestedt (2015) who found the level of Zn from Zomba City soils to be within the range of 130 to 210 mg/kg. The concentration of Zn was generally below the limit of England standard of 300 mg/kg (Bohn et al., 1979) but higher than the Canada Standard of 60 mg/kg (Alloway and Ayres, 1997) as per Figure 33. In the rainy season 93 % of Zn values were within the England Standard and 40 % of the values were within the Canada standard. In the dry season, 87 and 13 % of Zn values were within the England and Canada Standards respectively. This shows that Zn concentrations were of a concern mostly during the rainy season at Chirimba AP and the possible sources of Zn pollution in soils are metal processing industries and waste disposal.

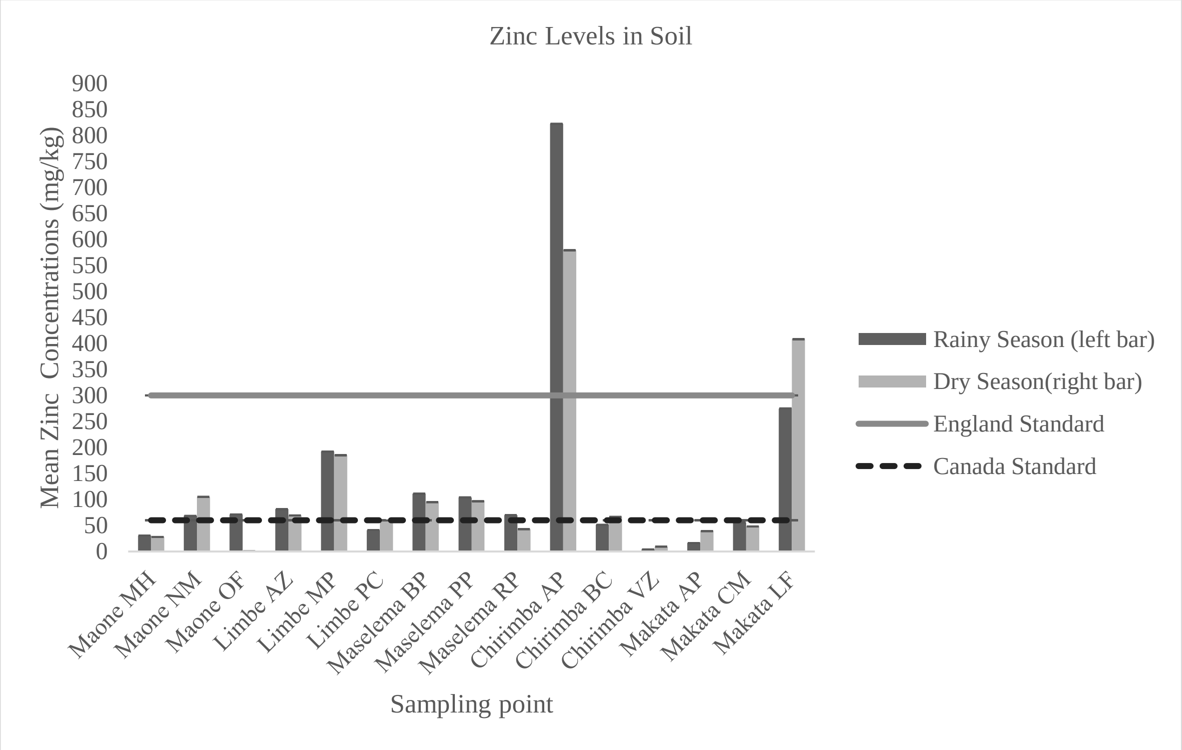


Figure 33. Zinc levels in soil for rainy and dry seasons

4.3.5 Cadmium levels in soil

In the rainy season, the range of cadmium concentration in soils was below detection limit (0.001) to 2.09 mg/kg while in the dry season it was from below 0.001 to 3.06 mg/kg (Figure 34). Comparison of rainy season and dry season soil cadmium values indicated a significant difference (p = 0.0374) as per Appendix 2. The highest Cd concentrations were observed from soils taken from Maone NM and were 2.09 mg/kg as well as 3.06 mg/kg during the rainy season and dry seasons respectively (which may have come from surface run-off from metal processing industries). This was emphasized in a study by Ignatavičius et al. (2017) which highlighted that sediments deposited by urban surface runoff dischargers reveal the existence of sources within impervious urban areas providing surface runoff with particle-bound pollutants, including heavy metals. The concentrations recorded were within the 4-10 mg/kg recorded by Orvestedt (2015) who studied Zomba City soil as well as by Kumar (2018) who researched heavy metals in industrial soils of India and found them to be within the range of 0.15 to 34.9 mg/kg. The concentration of cadmium was generally below the limit of England standard of 7 mg/kg (Bohn et al., 1979) but higher than the Canada Standard of 0.5 mg/kg Canada 46 (Alloway and Ayres, 1997) as per Figure 34. In the rainy season 100 % of Cd values were within the England Standard while approximately 93 % of the values were within the Canada standard. In the dry season, 100 % of Cd values were within the England standard and approximately 93% of the values were within the Canada standard. This means that Cd concentrations at Maone NM are of concern during both rainy and dry seasons. The possible sources of cadmium pollution for the industrial soils are waste disposal, coal combustion, iron and steel production, vehicle emissions and phosphate fertilizer manufacture and use.

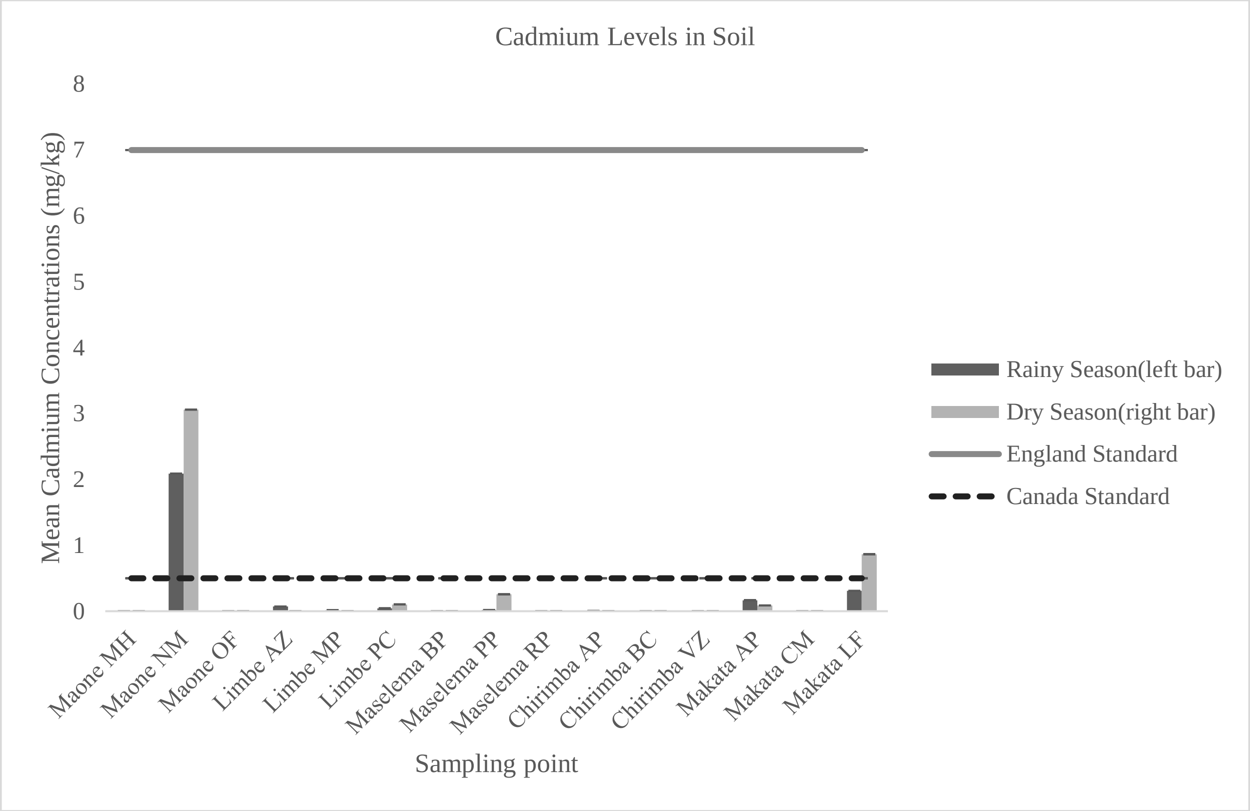


Figure 34. Cadmium levels in soil for rainy and dry seasons

4.4 Correlation between physiochemical parameters (soil EC and pH) and heavy metals

Correlations were done between physiochemical parameters and heavy metal concentrations for both seasons. This was done to determine whether physiochemical can be used as an indicator for heavy metal pollution. The following were the correlations as per Table 4. From the Table 4, the correlation between pH and Cadmium is strong and positive (r= 0.525) during dry season and moderate in the rainy season. EC and Cadmium have very weak negative correlations (r= -0.086 and r= -0.020) during both dry and rainy season respectively. We conclude that EC and pH can be used as an indicator for heavy metal pollution. However, the influence varies during dry and rainy seasons as shown from the table.

Table 4: Correlation (r) between Physiochemical parameters (Soil EC and pH) and heavy metals

variables	**Copper**		**Zinc**		**Cadmium**	
	DS	WS	DS	WS	DS	WS
EC	-0.075	0.259	0.151	0.234	-0.086	-0.020
pH	-0.257	-0.284	0.073	-0.120	0.525	0.377

4.5 Correlations between air quality parameters, heavy metals, and noise level

Correlations were done among air quality parameters, heavy metals, and noise levels for both seasons. This was done to determine whether air quality parameters can be used as an indicator for heavy metal and noise level pollution. The following were the correlations as per Table 5. The table 5 shows that air quality has an influence on heavy metal levels. Seasonal variation is also clearly depicted, as we can see a strong positive correlation (r= 0.600) between TSP and Zinc during w season as compared to the dry season where there is a weak negative correlation (r= -0.150). CO is shown to decrease during rainy season. It is also shown from the table that air quality has an influence on noise levels with seasonality effect as we can see the correlations between (TSP, PM_{10} and $PM_{2.5}$) and noise level changes from weak during dry season to moderately strong in the rainy season. The positive correlations among heavy metals, air quality parameters, and noise levels suggest potential shared sources or synergistic effects and as such further investigations are needed to understand the mechanisms driving these associations. This is kind of correlation is also seen in various studies such as the one conducted by Choi et al. (2012) who discovered that Cadmium has the potential to induce hearing loss, and there is a synergistic effect when exposed to both cadmium fumes and occupational noise. Lacerda et al. (2005) conducted a study comparing the hearing thresholds of two groups of workers-one exposed to both noise (90 dB(A)) and CO and another exposed solely to noise (90 dB(A)). The findings indicated a significant increase in hearing thresholds (at high frequencies of 3, 4, and 6 kHz) in the "noise + CO group" when compared to the "noise group."

Table 5: Correlations (r) between air quality parameters, heavy metals, and noise level

Variable	Copper		Zinc		Cadmium		Noise Level	
	DS	WS	DS	WS	DS	RS	DS	RS
CO	0.024	0.010	0.018	-0.065	0.077	0.016	0.205	0.062
TSP	-0.143	0.531	-0.150	0.600	-0.011	0.026	0.241	0.401
PM_{10}	-0.143	0.181	-0.051	0.329	0.066	0.336	0.011	0.358
$PM_{2.5}$	-0.146	0.193	-0.055	0.293	0.067	0.304	0.011	0.306

4.6 Source apportionment for air quality parameters and heavy metals

After using the PMF model with a factor count of 6, the difference between Qtrue and Qrobust were minimum and stable. The values of scaled residuals for heavy metals during the dry season were between 0.00001 and 0.00040 and were at 0.00003 for the rainy season (Table 7) which signifies that the parameters are normally distributed since the values are between +3 and -3 (USEPA, 2014). This further on means that the model is reliable and the Factor Analysis in section 4.6.1 is accurate. In the dry season, the signal-to-noise (S/N) ratios for all heavy metals varied between 1.769 and 7.319, while during the rainy season, the range was 2.290 to 5.123 (refer to Table 6). This indicates that Zinc, Copper, and Cadmium exhibited "strong" signals, with Zinc having the highest concentration. These findings underscore the necessity for the food and manufacturing industries to improve their emission management practices during both dry and rainy seasons. On the other hand, the values of scaled residuals for air quality parameters during the dry season were between 0.00746 and 0.00773 and were at 0.00002 for the rainy season (Table 7) which signifies that the parameters are normally distributed since the values are between +3 and -3 (USEPA, 2014). This further on means that the model is reliable and the Factor Analysis in section 4.6.2 is accurate. In the dry season, the signal-to-noise (S/N) ratios for all air quality parameters varied between 0.609 and 3.693, while during the rainy season, the range was 0.091 to 2.314 (refer to Table 6). This variability indicates that CO, TSP, PM_{10}, and $PM_{2.5}$ exhibited signals ranging from "poor" to "strong," with TSP registering the highest concentration. This underscores the importance for industries engaged in metal processing and beverage manufacturing to enhance their emission management practices throughout both dry and rainy seasons.

Table 6: The signal to noise ratio of heavy metals and air quality parameters during the dry and rainy seasons

	S/N Values	
Species	Dry Season	Rainy Season
Copper	3.162	5.123
Zinc	7.319	9.956
Cadmium	1.769	2.289
CO	0.609	0.091
TSP	3.693	1.843
PM_{10}	2.426	2.314
$PM_{2.5}$	2.466	1.528

Table 7: The Qtrue and Qrobust values for heavy metals and air quality parameters during the dry and rainy seasons

	Q_{true}	**Q_{robust}**	**Q_{true}**	**Q_{robust}**
Species	Dry Season		Rainy Season	
Heavy Metals	0.00001	0.00040	0.00003	0.00003
Air Quality Parameters	0.00746	0.00773	0.00002	0.00002

4.6.1 Source apportionment of heavy metals in soil

As per Figures 35 to 38, during the dry season in Factor 1, Zinc and Copper provided 35.8 % and 3.1 % respective contributions. Zinc might come from vehicle tires which is related to traffic emissions as well as burning of oil (Hsu et al., 2021). Zinc may be closely associated with anthropogenic activities, such as petroleum smelting, fossil fuel burning, production of cement, and other industrial activities (Jin et al., 2019). Xiao et al. (2019) also found similar anthropogenic sources such as smelting to be associated with for Zinc contribution. Chai et al. (2021) reiterated the same as having Zinc contribution closely linked to industrial sources. In line with the element concentration distribution, Factor 1 represents the food manufacturing industries. During rainy season in Factor 1, Zinc and Copper contributed 52.9 % and 6.3 % respectively.

During the dry season in Factor 2, Cadmium and Zinc provided 1.0 % and 0.1 % respective contributions. During rainy season in Factor 2, Copper and Zinc provided 40.3 % and 2.8 % respective contributions. A study by Wang et al. (2020) revealed that cadmium contribution from electroplating processes is quite minimal. This is also in line with study conducted by Ali et al.

(2017) who iterated that Cd contributions are linked to corrosion resistant plating processes in the industry. As such Factor 2 represents the furniture manufacturing industries.

During the dry season in Factor 3, Cadmium, Zinc and Copper provided 96.2 %, 8.3 % and 4.1 % respective contributions. During rainy season in Factor 3, Cadmium and Zinc provided 95.4% and 5.1 % respective contributions. Numerous studies demonstrated that Cd among other elements often originated from various industrial activities, such as mining, smelting of ores, coal usage, steel production of steel, and processing of metal (Shrivastava et al., 2018; Zhang et al., 2018). As such, Factor 3 represents the metal processing and manufacturing industries. Liao et al. (2017) also stated that Cd is mainly derived from industrial activities such as smelting.

During the dry season in Factor 4, Cadmium provided 1.1 % contribution. During rainy season in Factor 4, Copper, Zinc and Cadmium provided 24.1 %, 9.4 % and 1.2 % respective contributions. A study was done in China which showed that Copper contribution was linked to combustion of fuels in production processes (Jiang et al., 2017). A study done by Engida et al. (2020) revealed low levels of Cadmium linked to production industries. Another study showed that Cd was sourced from coal consumption in industries (Qu et al., 2013). As such, Factor 4 represents that of the beverage manufacturing industries.

During the dry season in Factor 5, Copper and Zinc provided 92.8% and 4.6% respective contributions. During rainy season in Factor 5, Zinc, Cadmium and Copper provided 14.2%, 1.4% and 0.9% respective contributions. As Copper is also used in plastic pipe manufacturing among other uses (Messner, 2001), their enhancement in the environment is apparent (Liu et al., 2020). Li et al. (2020b) also stated the contribution of copper in building materials industries of which some are plastic. Therefore, Factor 5 is the plastic manufacturing industries.

During the dry season in Factor 6, Zinc and Cadmium provided 51.1 % and 1.7 % contributions. Zinc may come from cement production processes due to deposition (Egbe et al., 2019). During rainy season in Factor 6, Copper, Zinc and Cadmium provided 28 %, 15.6 % and 2.0 % respective contributions. Researchers also stated that operative industrial plants such as those dealing with chemical release Zn in the soil (Hoshyari et al., 2023). Yang et al. (2019) further showed that significant part of cement production in China uses vertical kilns, and dust collecting equipment of cement kilns is not always up to standards, which results in more Cd being discharged in form of dust to the environment. As such, Factor 6 is linked to the cement manufacturing industries.

In summary, this means that during both rainy and rainy seasons the metal processing and manufacturing industries contribute highly towards the cadmium levels in soil around the industrial sites. This should be extended to plastic manufacturing industries which are the highest contributing sources of copper in soil during the dry season. In both the rainy and dry season zinc levels are highest from food manufacturing industries which means that the mitigation measures need to target such sites. One other important industry to take note of is the cement manufacturing industry which is the source of zinc as well mainly during the dry season. This means that mitigation measures need to be implemented accordingly for pollution control.

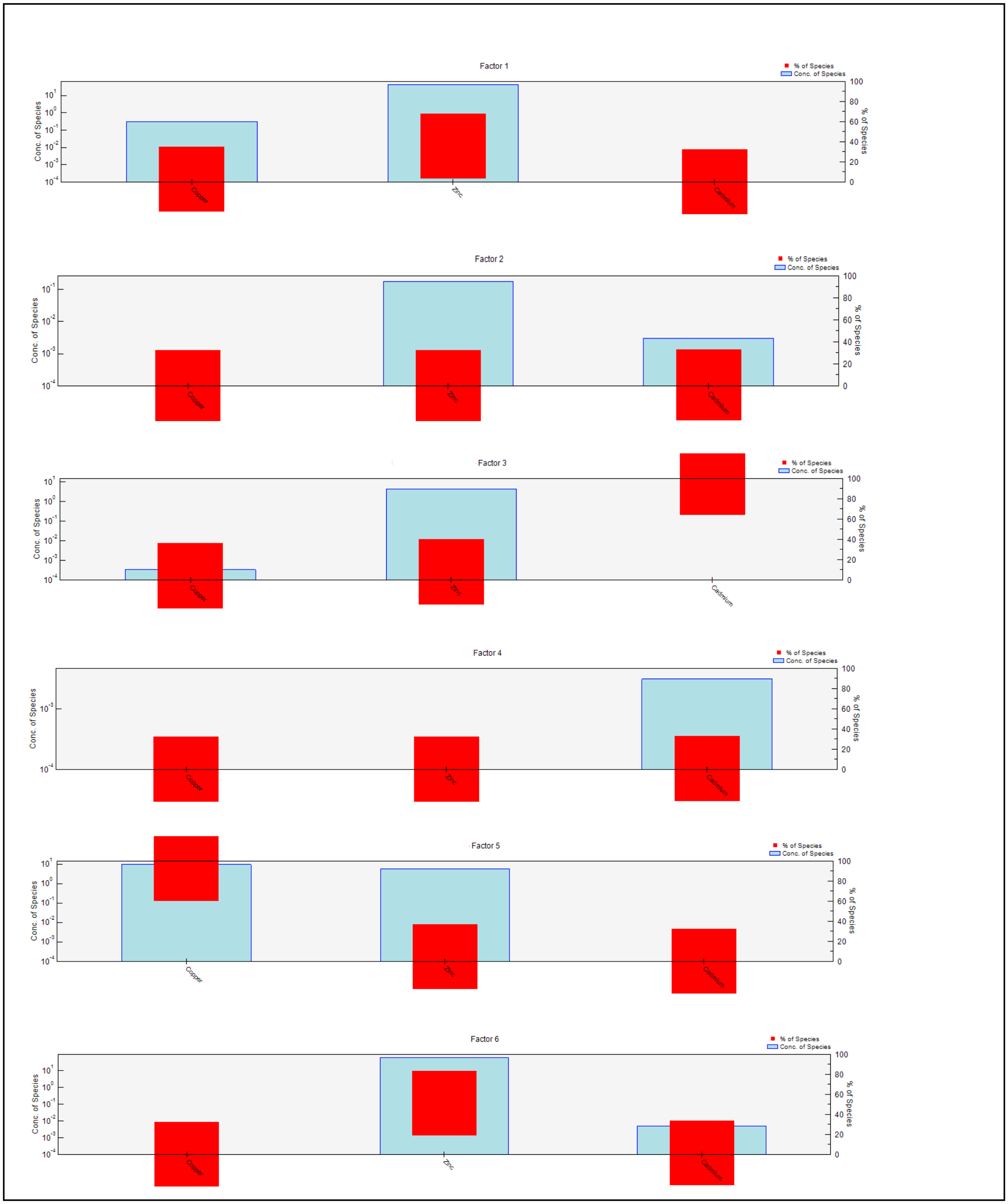


Figure 35: Factor profile and concentration percentage of heavy metals in the soil during the dry season from the PMF model

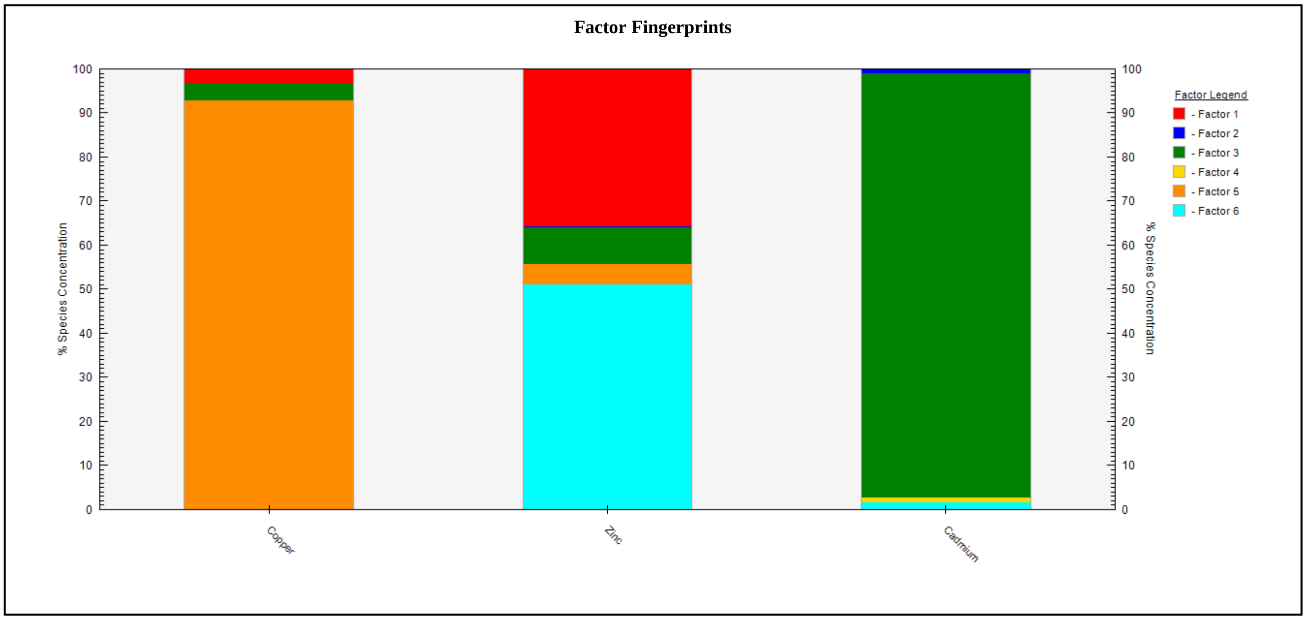


Figure 36. Factor fingerprint of 3 heavy metals based on species concentration (%) for dry season

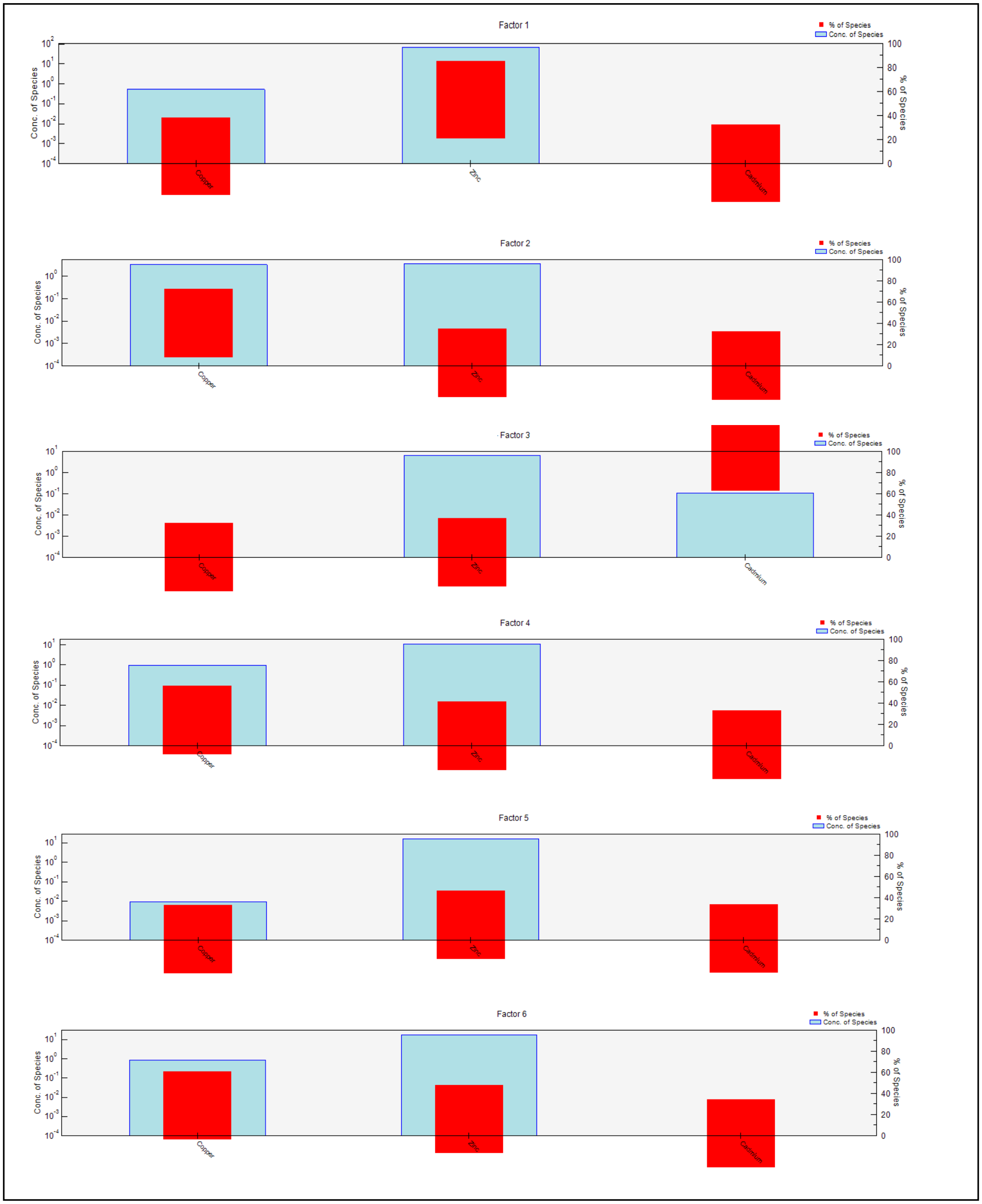


Figure 37. Factor profile and concentration percentage of heavy metals in the soil during the rainy season from the PMF model

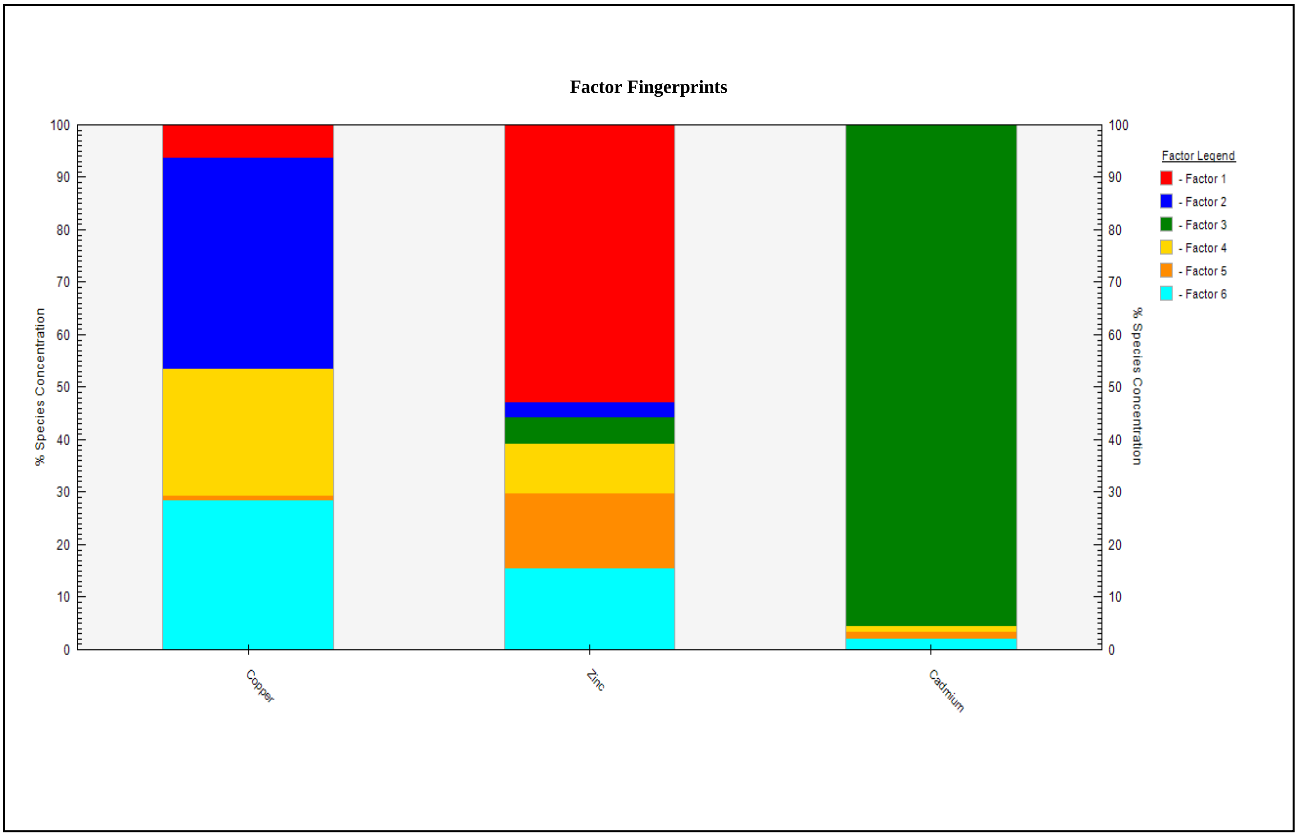


Figure 38. Factor fingerprint of 3 heavy metals based on species concentration (%) during rainy season

4.6.2 Source apportionment of air quality parameters

As per Figures 39 to 42, during dry season in Factor 1, TSP and CO provided 25.1 % and 0.6 % respective contributions. During the rainy season in Factor 1, $PM_{2.5}$, PM_{10} and TSP provided 14.8 %, 14.1 % and 12.7 % respective contributions. As demand for cement is high for development purposes, TSP levels are usually high around cement production plants (Jayadipraja et al., 2016). It was also noted in a study conducted by Xiao et al. (2014) that the coal combustion contributes to TSP levels. Liu et al. (2022) also conducted a study which showed that biomass and coal combustion which are prominent in production industries are sources of TSP. This makes Factor 1 to be linked to cement manufacturing industries.

During dry season in Factor 2, CO, $PM_{2.5}$ and PM_{10} provided 55.1 %, 13.6 % and 13.5 % respective contributions. During rainy season in Factor 2, CO, $PM_{2.5}$, and TSP provided 100%, 3.5 % and 2.1 % respective contributions. The increased levels of CO may be due to emissions coming from the moving vehicles along the roads (Mapoma et al., 2013). Zhenyu et al. (2022) also conducted a study which emphasized the contribution of CO to the environment through vehicular related traffic. As such, whilst considering the parameter concentration distribution as well as aspects in section 4.1, Factor 2 represents the food production industries.

During dry season in Factor 3, $PM_{2.5}$ and PM_{10} provided 11.1 % and 10.9 % respective contributions. During rainy season in Factor 3, $PM_{2.5}$ and TSP provided 15.2 % and 4.5 % respective contributions. The putty and sanding processes in furniture making increases levels of particulate matter less than 2µm (Yuan et al., 2014). Ro'in et al. (2023) also emphasized the contribution $PM_{2.5}$ to the plywood manufacturing industry. A study by Van Harmelen et al. (2002) showed that $PM_{2.5}$ fugitive emissions come from wood or furniture processing industries. This means that Factor 3 includes furniture manufacturing industries.

During dry season in Factor 4, PM_{10}, $PM_{2.5}$, TSP and CO provided 57.8 %, 57.6 %, 46.2 % and 2.0 % respective contributions. During rainy season in Factor 4, PM_{10} and TSP provided 16.7 % and 4.6 % respective contributions. A study by Yusuf et al. (2020) highlighted that the levels of PM_{10} increased significantly in a plastic processing industry which corresponds with the percentage of PM_{10} seen here. Wu et al. (2018) stated their study that PM_{10} is sourced from the process of burning plastics in the industry. Aspects in section 4.1 should also be put into consideration. Therefore, Factor 4 represents the plastic manufacturing industries.

During dry season in Factor 5, TSP and CO provided 26.7 % and 24.7 % respective contributions. During rainy season in Factor 5, PM_{10}, $PM_{2.5}$ and TSP provided 41.9 %, 41.9 % and 1.5 % contributions. Metal production is one of the industrial processes causing the higher value of TSP (Ashrafi et al., 2018). Liu et al. (2022) also elaborated the TSP contribution from coal combustion processes in industries. This means that Factor 5 represents metal processing and manufacturing industries.

During dry season in Factor 6, CO, $PM_{2.5}$, PM_{10}, and TSP provided 18.2 %, 17.7 %, 17.6 %, and 2 % respective contributions. During rainy season in Factor 6, TSP, PM_{10} and $PM_{2.5}$ provided 74.4%, 27 % and 24.6 % respective contributions. Research was conducted which showcased that one of the main sources of particulate matter is the food and beverage industry (Jornet-Martínez et al., 2019). A study by Alfaro et al. (2021) highlighted that TSP contribution from beverage manufacturing industries was significant. Another study conducted by Rasul et al. (2006) showed that TSP contribution from food and beverage industry was very high compared to other industries. As such, it reflects the percentages seen here and means that Factor 6 represents the beverage manufacturing industries.

Therefore, this means that during both rainy seasons the plastic manufacturing industries contribute highly towards TSP in the air around the industrial sites which requires implementation of mitigation measures. This should be extended to food manufacturing industries which are the highest contributing sources of CO in the air during the dry and rainy season. The other industries namely metal processing and beverage manufacturing are also sources of $PM_{2.5}$, PM_{10} and CO and need to be targeted for needed remedial actions.

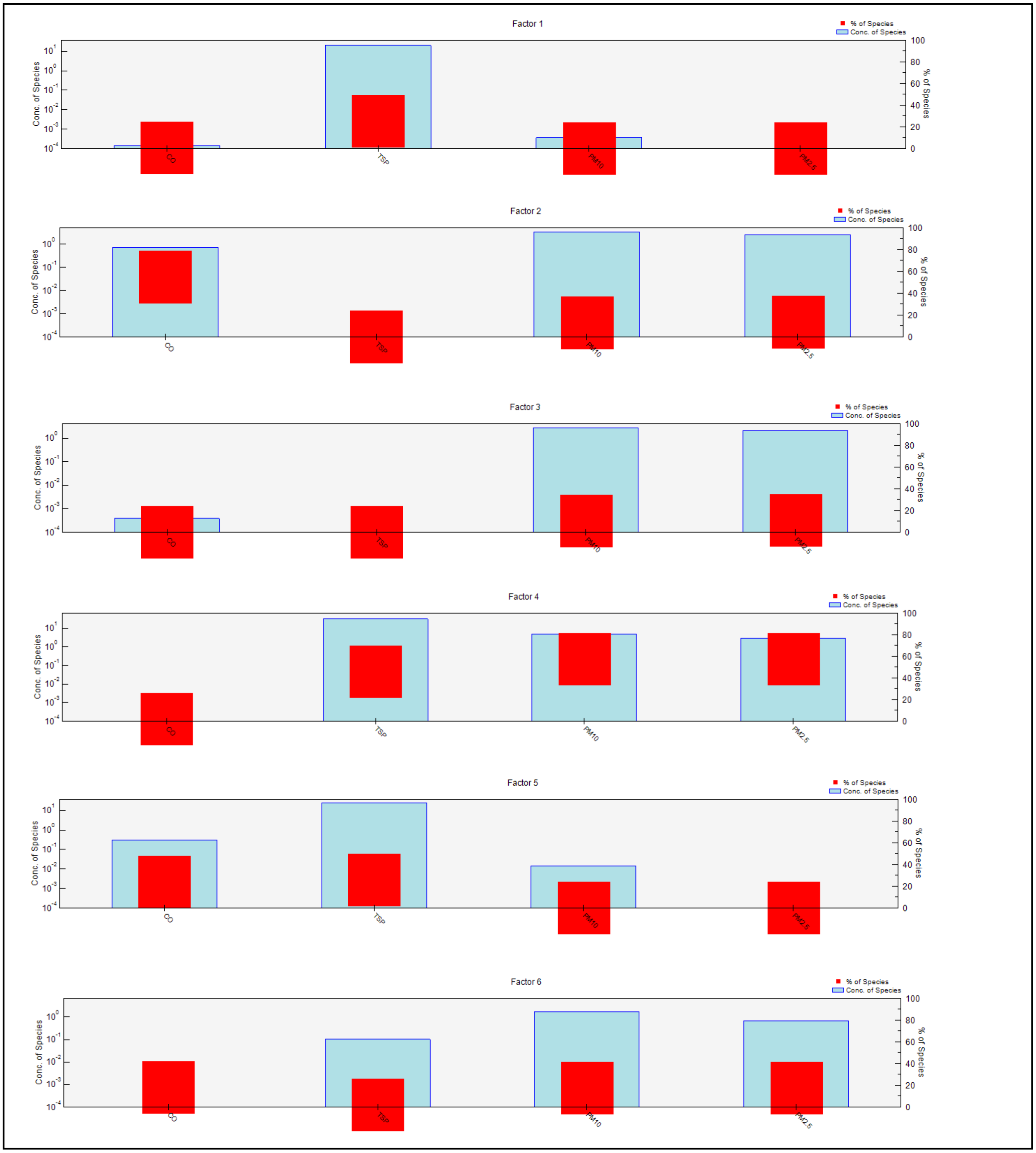


Figure 39. Factor profile and concentration percentage of air quality parameters during the dry season from the PMF model

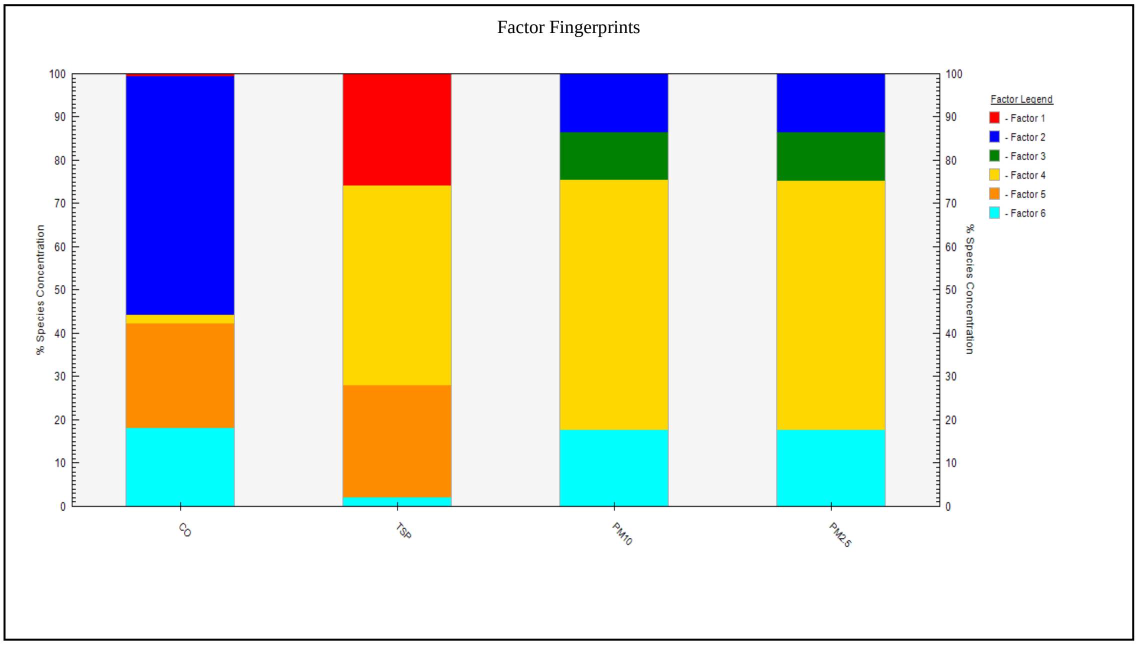


Figure 40. Factor fingerprint of 4 air quality parameters based on species concentration (%) during dry season

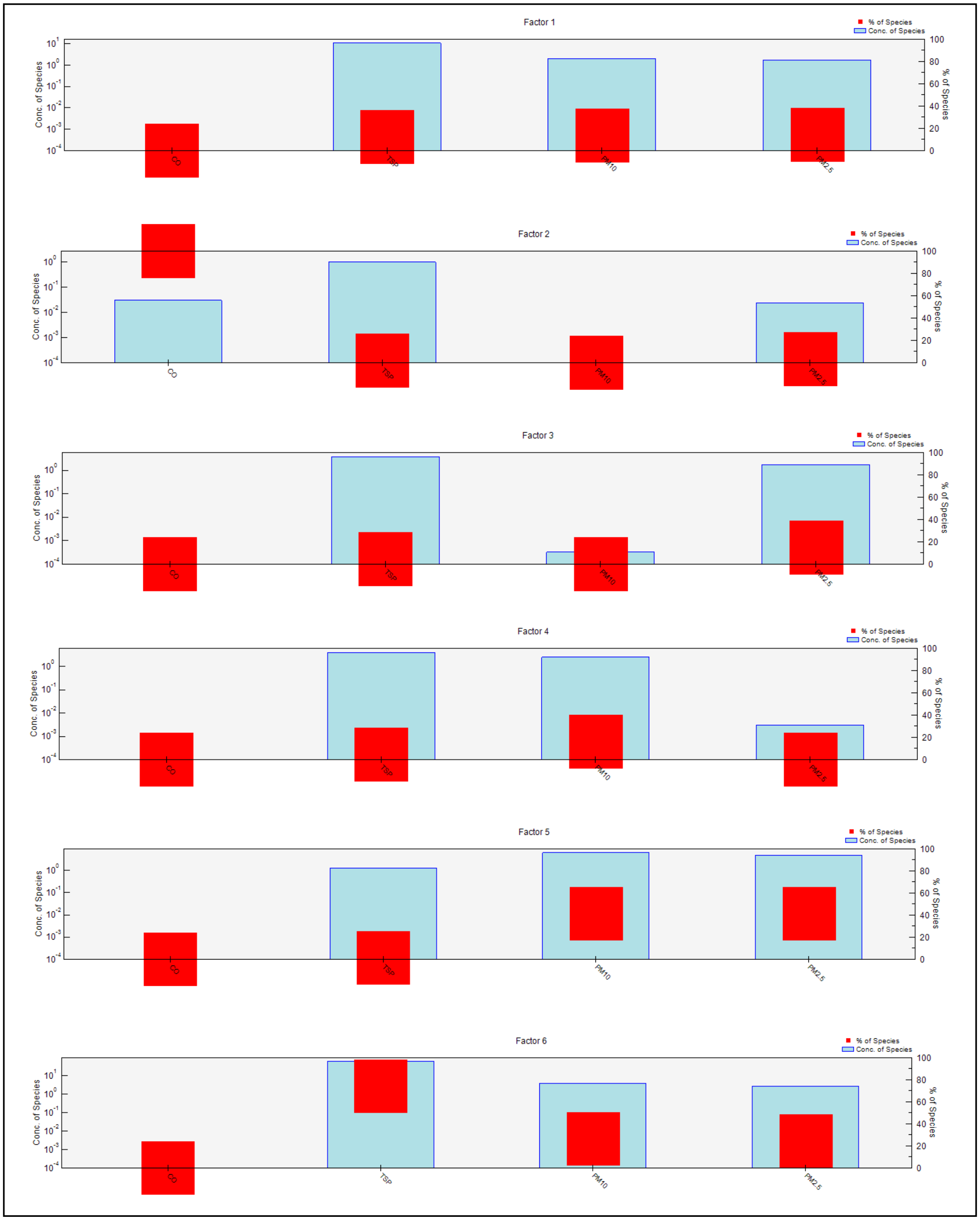


Figure 41. Factor profile and concentration percentage of air quality parameters during the rainy season from the PMF model

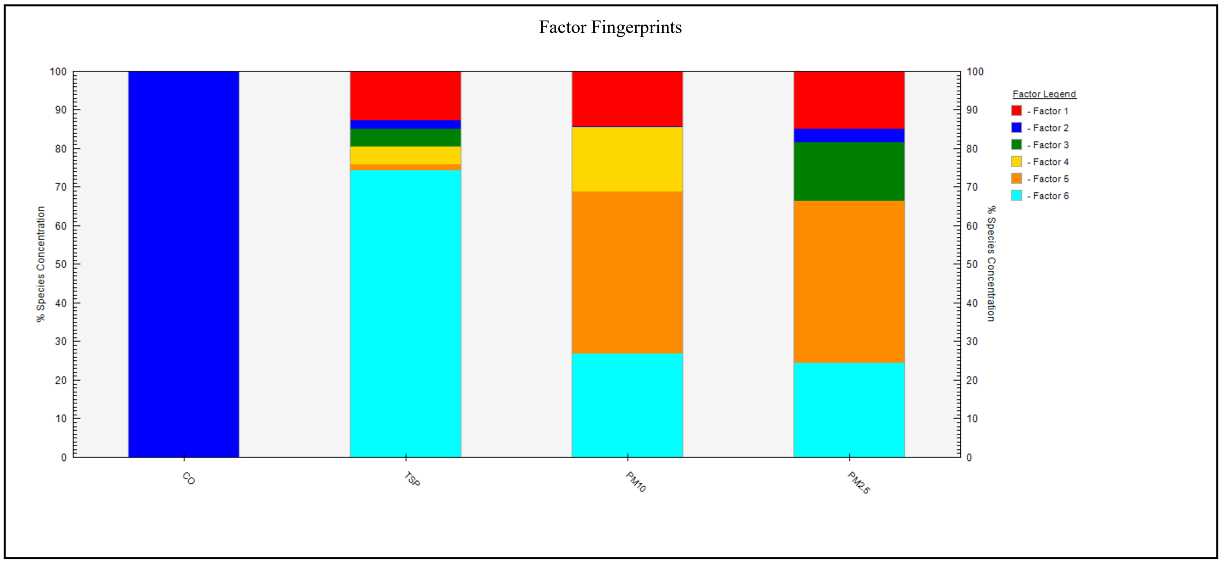


Figure 42. Factor fingerprint of 4 air quality parameters based on species concentration (%) during rainy season.

4.7 Pollution risks of heavy metals in soil

Based on the results of I_{geo} (Figure 43 and 44) and the level of geo-accumulation index from Table 8, during the rainy season most of the sampling sites were not contaminated by Cd, Cu and Zn. The contamination of Zn was much higher than the other heavy metals with its highest I_{geo} value at 3.19 (observed at Chirimba AP industrial site) indicating a "highly contaminated" I_{geo} Class. Copper was in the "not contaminated-moderately contaminated" I_{geo} Class as its I_{geo} value was 0.81 (also observed at Chirimba AP industrial site).

During the dry season also bearing in mind the I_{geo} results, most of the sampling sites were not contaminated by Cd, Cu and Zn but varied from "not contaminated" to "highly contaminated" I_{geo} value. It was worth noting that the contamination of heavy metals was at their highest at some sites with I_{geo} values of 2.18 (observed at Makata LF industrial site) and 2.69 (detected at Chirimba AP industrial site) for Zn as well as 2.03 (detected at Maone NM industrial site) for Cd.

This therefore shows that Zinc was the main contaminant as it was prominent in both seasons thus presenting a high risk. This means that the release of heavy metals to the environment through the manufacturing processes is the prominent factor causing the fluctuating levels of these elements in the soil (Li et al., 2020).

Table 8: The levels of geo-accumulation index (Muller, 1971)

I_{geo} Class	I_{geo} Value	Level of contamination Classification
0	$I_{geo} \leq 0$	Not contaminated
1	$0 < I_{geo} < 1$	Not contaminated-moderately contaminated
2	$1 < I_{geo} < 2$	Moderately contaminated
3	$2 < I_{geo} < 3$	Moderately to highly contaminated
4	$3 < I_{geo} < 4$	Highly contaminated
5	$4 < I_{geo} < 5$	Highly to extremely contaminated
6	$I_{geo} \geq 6$	Extremely contaminated

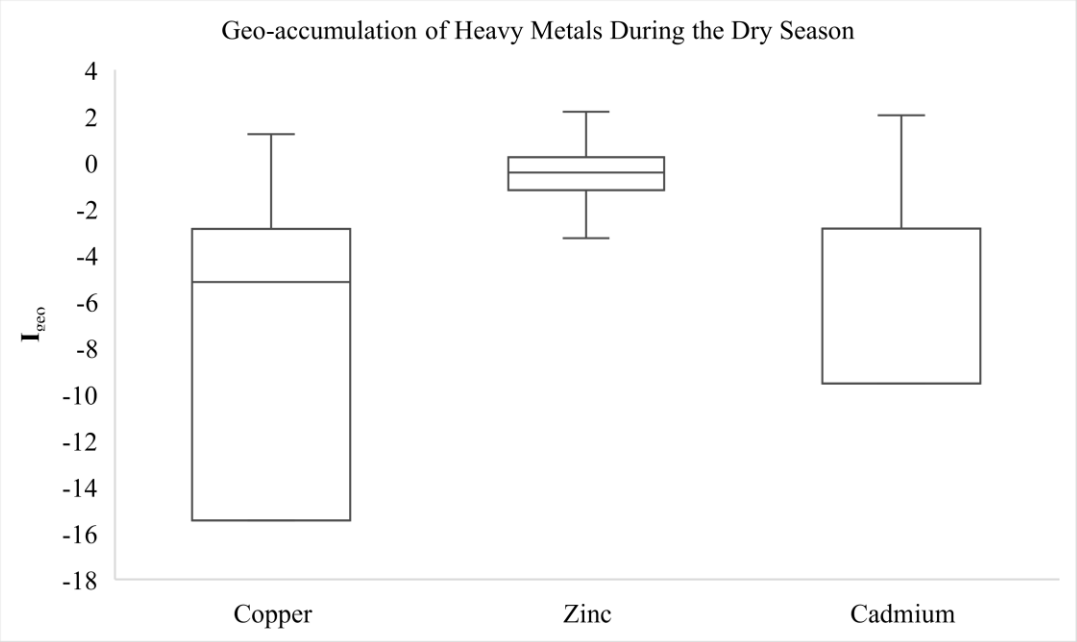


Figure 43. Risk assessment (I_{geo}) results of heavy metals by the study area during dry season

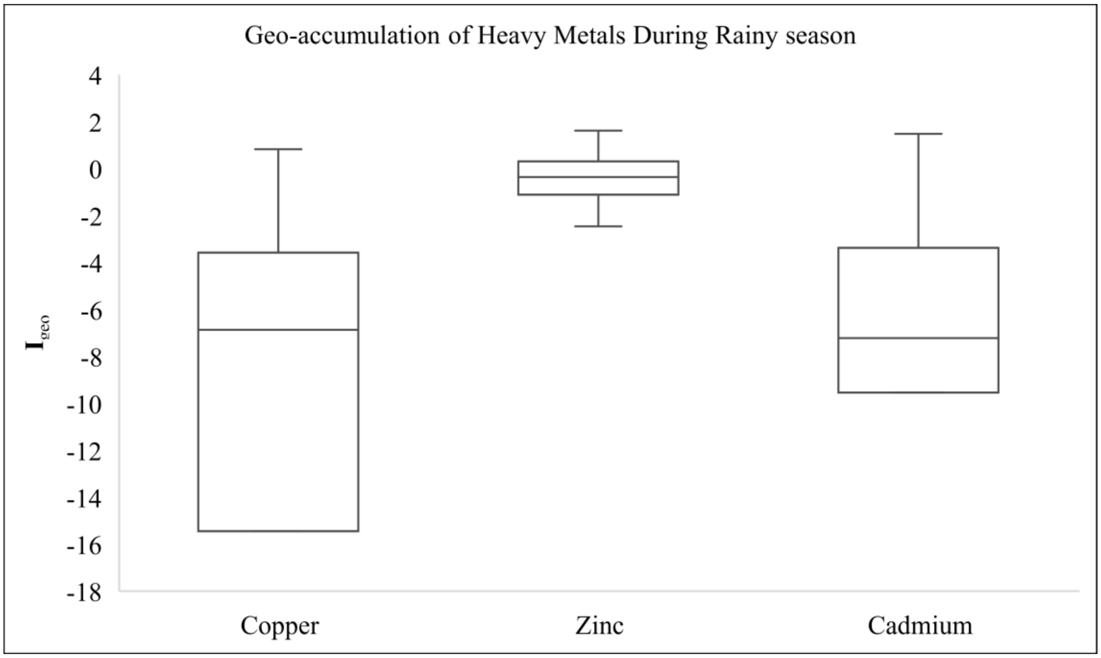


Figure 44. Risk assessment (I_{geo}) results of heavy metals by the study area during rainy season

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The current study covered the determination of concentration levels of air quality (CO, TSP, $PM_{2.5}$, PM_{10}), heavy metals (cadmium, zinc, and copper) and noise levels from sites in industrial areas (Makata, Limbe, Maselema, Chirimba and Maone), examination of the pollutant sources as well as determination of movement pattern of the air pollutants using trajectory models from National Oceanic and Atmospheric Administration (NOAA). The study found that the concentrations of heavy metals in soil were 87% below the England standards except for those from two sites namely Chirimba AP and Makata LF. In the rainy season 93 % of TSP values were within the Malawi Standard while 7 % (Chirimba AP) were above. In the dry season 100 % of the TSP values were within the allowable Malawi Standard. In the dry season 13 % (Limbe MP) of PM_{10} values were above WHO standards. In the rainy season 7 % of $PM_{2.5}$ values were above Malawian standards and 27 % (Limbe MP) were above WHO Standards while in the dry season 7% were above Malawian standard and 60 % were above the WHO standard. In terms of the Canada standards, heavy metals in soil were 27 % below the maximum permissible levels and these were from Maone MH, Chirimba VZ, Makata AP and Makata CM sites. These values were attributed to atmospheric deposition, waste disposal and surface run-off from metal processing industries. Additionally, it was observed that the overall pattern indicated a higher distribution of elevated heavy metal values in soil samples, with 20 % recorded during the dry season and 7 % during the rainy season. Noise levels were found to be within the maximum allowable standard of Malawi and WHO.

Air quality has an influence on noise pollution and can be used as an indicator for heavy metal pollution. It was also seen that the physical and chemical parameters of soil can be utilized as indicators of heavy metal pollution. Plastic manufacturing industries as well as metal processing and manufacturing industries have the highest influence on heavy metals and air quality parameters accumulation as compared to the others. Soils were highly contaminated with Zn and Cd during both rainy and dry seasons at some sites posing a pollution and health risk.

5.2 Recommendations

The following are recommendations made from the results reported in this study:

a) Periodic monitoring of air, noise and soil needs to be done around the industrial sites to observe the seasonal pollution trends.

b) Blantyre city Assembly and other environmental regulatory bodies such as Malawi Environmental Protection Authority (MEPA), should be more stringent and proactive in environmental monitoring, assessment and enforcement of environmental laws and regulations specifically on emission release from metal processing sites as well as plastic, cement and food manufacturing industries.

c) The government should target the industrial sites such Chirimba AP and Limbe MP whose air parameters surpassed the maximum allowable permissible levels by subjecting them to tax. They could implement this by using a formulated tax rate per unit of emissions. To ensure further emission reductions, the tax rate will need to be amended frequently for inflation effects, income increase as well as change in technology among other aspects.

d) For soils contaminated with cadmium, copper, and zinc mainly at Chimba AP, Makata LF and Maone NM, there is a need to ensure emission control through capture of emissions using pollution control scrubbers and filters. The scrubbers and filters work by using the process of adsorption which in turn prevents release of emissions beyond the allowable limits into the environment.

e) The metal processing and plastic manufacturing industries use fossil fuels for production purposes which lead to increased emission and pollution levels. As such, alternative cleaner fuels such as biomass can substitute fossil fuels and introduction of waste energy recovery systems would also be efficient. This is advantageous because biofuels are carbon neutral, renewable resources, and aid in reduction of industrial carbon footprint. This in turn reduces emissions being released into the environment.

5.3 Areas for further research

a) Research should further be done to analyze the manufacturing processes being utilized by the industries as well as emission control initiatives being employed to correlate with the parameter levels.

b) Further research should explore the specific sources and mechanisms contributing to the observed correlations, considering seasonal variations and potential implications for public health and environmental sustainability.

c) Future assessments may need to be done to include other parameters such as Chromium (Cr), Lead (Pb), Iron (Fe), Nitrogen dioxide (NO2), Sulfur dioxide (SO2), and Volatile Organic Carbons (VOCs) which are also important and may be of concern to the health of people but were not included due to the current study interest.

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APPENDICES

Appendix A: Coordinates for sampling points

SAMPLING POINTS	GPS COORDINATES (Latitude, Longitude)	UTM COORDINATES (Latitude, Longitude)
	MAONE INDUSTRIAL AREA	
Maone OF	-15.79248, 35.07676	722465.48, 8252921.50
Maone MH	-15.78429, 35.07958	722776.63, 8253824.17
Maone NM	-15.78332, 35.07571	722362.96, 8253936.39
	MAKATA INDUSTRIAL AREA	
Makata LF	-15.79132, 35.02744	717182.33, 8253101.41
Makata AP	-15.79029, 35.02339	716748.68, 8253219.58
Makata CM	-15.78641, 35.03355	717841.57, 8253638.50
	CHIRIMBA INDUSTRIAL AREA	
Chirimba AP	-15.73752, 35.03059	717577.34, 8259052.29
Chirimba BC	-15.74260, 35.03074	717587.15, 8258489.82
Chirimba VZ	-15.74120, 35.02713	717201.70; 8258647.93
	LIMBE INDUSTRIAL AREA	
Limbe AZ	-15.80686, 35.06551	721243.21, 8251341.22
Limbe MP	-15.80755, 35.06737	721442.83, 8251262.55
Limbe PC	-15.80511, 35.06359	721442.83, 8251536.57
	MASELEMA INDUSTRIAL AREA	
Maselema PP	-15.80506, 35.05091	719681.90, 8251556.40
Maselema RP	-15.80405, 35.05219	719820.04, 8251666.62
Maselema BP	-15.80644, 35.05758	720395.01, 8251396.02

Appendix B: Seasonal variation of parameters using paired t test

Variable		**Mean difference**	**Confidence interval**		**t**	**df**	**stderr**	**p-value**
			lower	**upper**				**(α=0.05)**
	CO	-0.824	-1.491	-0.158	-2.494	44	0.3306125	**0.01647**
Air	**TSP**	-9.507	-49.941	30.928	-0.474	44	20.06316	0.638
	PM_{10}	-10.418	-15.950	-4.885	-3.795	44	2.745143	**0.0004478**
	$PM_{2.5}$	-7.262	-11.612	-2.912	-3.3644	44	2.158538	**0.001599**
Noise		-4.493	-7.075	-1.912	-3.508	44	1.280761	**0.001053**
pH		-0.334	-0.563	-0.105	-2.944	44	0.114	**0.005158**
EC		-162.96	-337.14	11.208	-1.886	44	86.422	0.06595
Heavy metals	**Copper**	-1.862	-12.444	8.72006	-0.355	44	5.250662	0.7246
	Zinc	10.860	-72.037	93.756	0.26401	44	41.132	0.793
	Cadmium	-0.115	-0.223	-0.007	-2.147	44	0.054	**0.03739**

Appendix C: Ethical approval

NATIONAL COMMISSION FOR SCIENCE & TECHNOLOGY
Lingadzi House
Robert Mugabe Crescent
P/Bag B303
City Centre
Lilongwe

Tel: +265 1 771 550
+265 1 774 189
+265 1 774 869
Fax: +265 1772 431
Email:directorgeneral@ncst.mw
Website:http://www.ncst.mw

NATIONAL COMMITTEE ON RESEARCH IN THE SOCIAL SCIENCES AND HUMANITIES

Ref No: NCST/RTT/2/6 **18th January 2023**

Ms Constance Utsale,
P.O. Box 51925,
Limbe.
Email: constancewishesutsale@gmail.com

Dear Ms Utsale,

RESEARCH ETHICS AND REGULATORY APPROVAL AND PERMIT FOR PROTOCOL NO. P.01/23/712: ASSESSMENT OF AIR QUALITY IN INDUSTRIAL AREAS OF BLANTYRE CITY, MALAWI

Having satisfied all the relevant ethical and regulatory requirements, I am pleased to inform you that the above referred research protocol has officially been approved. You are now permitted to proceed with its implementation. Should there be any amendments to the approved protocol in the course of implementing it, you shall be required to seek approval of such amendments before implementation of the same.

This approval is valid for one year from the date of issuance of this approval. If the study goes beyond one year, an annual approval for continuation shall be required to be sought from the National Committee on Research in the Social Sciences and Humanities (NCRSH) in a format that is available at the Secretariat. Once the study is finalised, you are required to furnish the Committee and the Commission with a final report of the study. The committee reserves the right to carry out compliance

Committee Address:
Secretariat, National Committee on Research in the Social Sciences and Humanities, National Commission for Science and Technology, Lingadzi House, City Centre, P/Bag B303, Capital City, Lilongwe3, Malawi. Telephone Nos: +265 771 550/774 869; E-mail address: ncrsh@ncst.mw

inspection of this approved protocol at any time as may be deemed by it. As such, you are expected to properly maintain all study documents including consent forms.

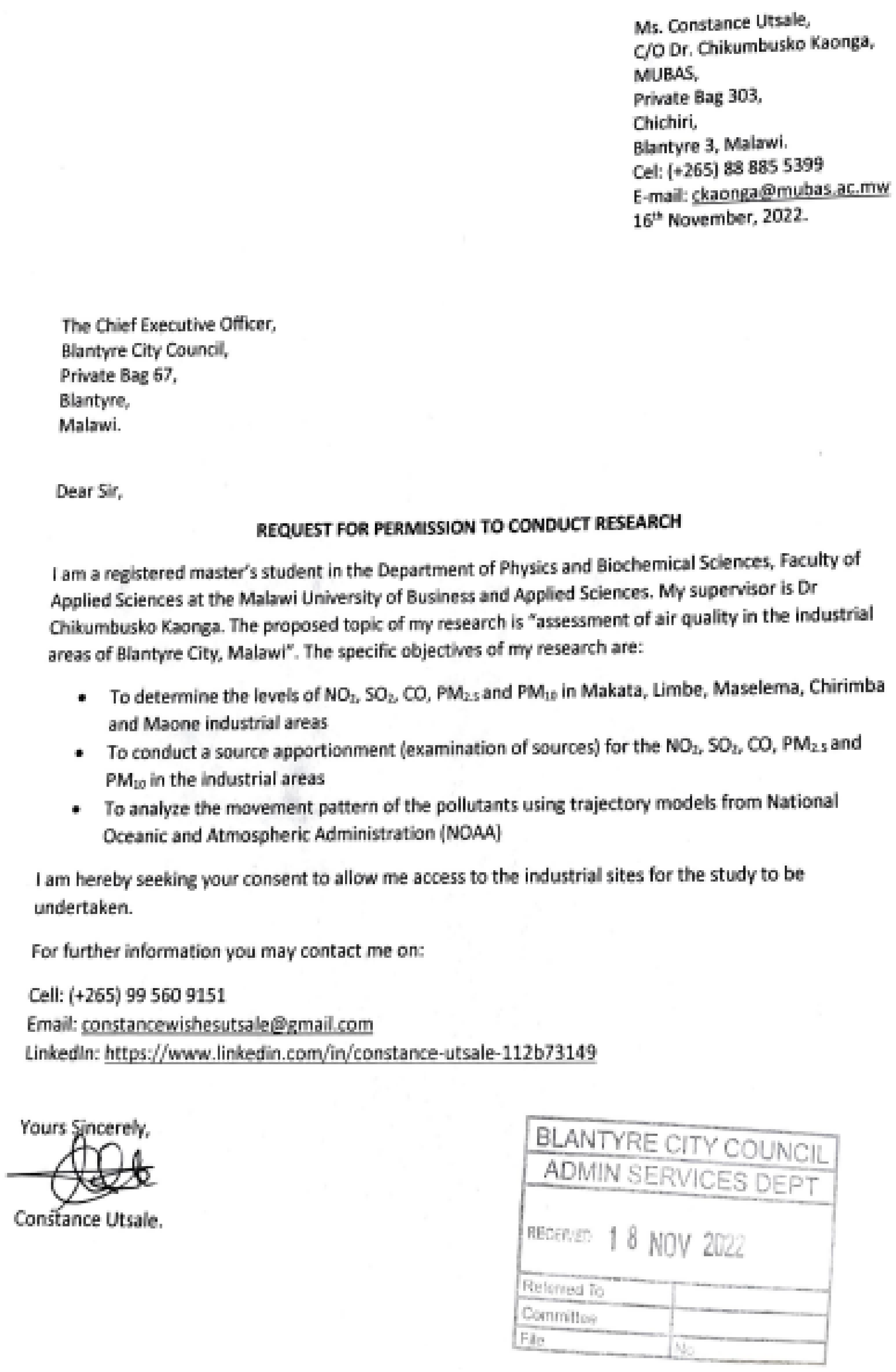
Wishing you a successful implementation of your study.

Yours Sincerely,

Yalonda .J. Mwanza
NCRSH ADMINISTRATOR
HEALTH, SOCIAL SCIENCES AND HUMANITIES DIVISION

For: CHAIRPERSON OF NCRSH

Committee Address:
Secretariat, National Committee on Research in the Social Sciences and Humanities, National Commission for Science and Technology, Lingadzi House, City Centre, P/Bag B303, Capital City, Lilongwe3, Malawi. Telephone Nos: +265 771 550/774 869; E-mail address: ncrsh@ncst.mw



Ms. Constance Utsale,
C/O Dr. Chikumbusko Kaonga,
MUBAS,
Private Bag 303,
Chichiri,
Blantyre 3, Malawi.
Cel: (+265) 88 885 5399
E-mail: ckaonga@mubas.ac.mw
16th November, 2022.

The Chief Executive Officer,
Blantyre City Council,
Private Bag 67,
Blantyre,
Malawi.

Dear Sir,

REQUEST FOR PERMISSION TO CONDUCT RESEARCH

I am a registered master's student in the Department of Physics and Biochemical Sciences, Faculty of Applied Sciences at the Malawi University of Business and Applied Sciences. My supervisor is Dr Chikumbusko Kaonga. The proposed topic of my research is "assessment of air quality in the industrial areas of Blantyre City, Malawi". The specific objectives of my research are:

- To determine the levels of NO_2, SO_2, CO, $PM_{2.5}$ and PM_{10} in Makata, Limbe, Maselema, Chirimba and Maone industrial areas
- To conduct a source apportionment (examination of sources) for the NO_2, SO_2, CO, $PM_{2.5}$ and PM_{10} in the industrial areas
- To analyze the movement pattern of the pollutants using trajectory models from National Oceanic and Atmospheric Administration (NOAA)

I am hereby seeking your consent to allow me access to the industrial sites for the study to be undertaken.

For further information you may contact me on:

Cell: (+265) 99 560 9151
Email: constancewishesutsale@gmail.com
LinkedIn: https://www.linkedin.com/in/constance-utsale-112b73149

Yours Sincerely,

Constance Utsale.

BLANTYRE CITY COUNCIL
ADMIN SERVICES DEPT
RECEIVED 18 NOV 2022
Referred To
Committee
File No.