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FACULTY OF MINERAL RESOURCES AND TECHNOLOGY
DEPARTMENT OF ENVIRONMENTAL AND SAFETY ENGINEERING

A THESIS REPORT ENTITLED

MONITORING AMBIENT VOLATILE ORGANIC COMPOUND CONCENTRATIONS AT SELECTED SITES WITHIN THE TARKWA MUNICIPALITY

BY
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SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF BACHELOR OF SCIENCE IN ENVIRONMENTAL AND SAFETY ENGINEERING

PROJECT SUPERVISOR

……………………………………

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TARKWA, GHANA

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DECLARATION

I, Nawaf Alhassan, declare that this project work is my work. It is being submitted for the B.Sc. in Environmental and Safety Engineering at the University of Mines and Technology (UMaT), Tarkwa. It has not been submitted for any degree or examination at any other university.

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ABSTRACT

A study was conducted in the Tarkwa municipality to measure the concentration of aromatic compounds, such as benzene, toluene, ethylbenzene, and xylene, as well as the total volatile organic compounds in ambient air. The study aimed to monitor the release of VOCs in urban areas. Four designated urban sites, including residential, commercial, and industrial areas, were studied to achieve this goal. On July 1, 2021, samples were collected at the light-duty vehicle workshop, the Goil fuel station, the Tarkwa station, and the Total fuel station. The MINIRAE Lite VOC monitor, mounted on a two-meter platform, and the Draeger Accuro tube pump, manually operated, were used to measure ambient concentrations. The results confirmed the presence of VOC emissions at all sampling sites. The ACGIH TWA permissible exposure limit for benzene was found to be significantly exceeded at the Goil and Total fuel stations. Toluene also exceeded the permissible exposure limit, with a concentration of 21.89 ppm at the Goil fuel station. Nevertheless, the recorded concentrations of ethylbenzene and xylene were below the allowable exposure limit.

I dedicate this research to my family and friends.

ACKNOWLEDGEMENT

My heartfelt appreciation goes to my family, including my father, mother, and siblings, for their support throughout my academic journey. I extend my thanks to my supervisor, Assoc. Prof. Samuel Ndur, thank you for your invaluable contributions to the successful completion of this project. Finally, I sincerely thank the Senior Lab Technician, Mr. Kwofie Augustine, for his exceptional expertise and guidance.

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INTRODUCTION

1.1 Problem Definition

Large quantities of volatile organic compounds (VOCs) are emitted from anthropogenic and natural sources into the atmosphere (Koppmann, 2008). VOCs are of interest because they participate in atmospheric photochemical reactions that contribute to ozone formation (Yang et al., 2020)

VOCs are carbon-containing compounds that quickly evaporate into the atmosphere once emitted. They typically contain hydrogen, oxygen, fluorine, chlorine, bromine, sulfur, or nitrogen and are primarily released from burning fuels such as gasoline, wood, coal, or natural gas (He *et al.*, 2015). Additional release sources are paints, glue, and other products used and stored at home and work (He *et al.*, 2015).

Several of these compounds potentially impact climate due to their properties as greenhouse gases and ability to form aerosol particles on oxidation. The development of gaseous and particulate secondary products caused by the oxidation of VOCs is one of the essential unknowns in predicting the earth's climate on a regional and global basis and understanding local air quality (Koppmann, 2008).

Exposure to VOC can cause both short-term and long-term health effects. Gasoline, benzene, formaldehyde, toluene, xylene, and styrene(or tetrachloroethylene used in dry cleaning) are also rich sources of VOCs (He *et al.*, 2015). Irritation to skin and eye, central nervous system effects, carcinogenicity, and liver and kidney effects have been reported in experimental animals and humans (He *et al.*, 2015).

Tarkwa is an industrial and commercial town with a projected population figure of about 198290 people in 2021. The nature of such area licenses the movement of vehicles, operations of fuel stations and mechanical shops, and manufacturing of consumer and commercial products. This study selected four sites based on their different land use categories, populations, and traffic densities. Sampling sites include the Goil fuel station, Total filling station, Bogoso junction mechanical shops, and Tarkwa Station.

1.2 Objective

The project's objective is to monitor Volatile Organic Compounds (VOCs) levels in four different locations.

1.3 Methods Used

Methods to be used include:

- Review of relevant literature.
- Consultation with the project supervisor and other lecturers.
- Field data collection

1.4 Expected Outcome

An assessment of the local air quality within the case study areas is expected to be conducted.

1.5 Facilities Used

The facilities required for this project include:

- Personal computer
- UMaT library
- Internet facilities and online database

1.6 Work Organization

The project has five chapters. Chapter 1 covers the problem definition, project objectives, methods, facilities used, and project organization. Chapter 2 focuses on reviewing relevant literature. Chapter 3 discusses the research methodology employed. Chapter 4 presents the analysis and discussions. Chapter 5 concludes with the conclusions and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of prominent researchers' studies and explains terms related to volatile organic compounds. It gives a concise overview of the problem's history and current status.

2.2 Definitions of Volatile Organic Compounds

There are several definitions of VOC.

1. The European Union defines a VOC as "any organic compound having an initial boiling point less than or equal to 250 °C (482 °F) measured at a standard atmospheric pressure of 101.3 kPa" (Atif *et al.*).
2. The definition of VOC by WHO based on boiling points states, "Any compound that has Carbon, Hydrogen, and its boiling point is in the range of 0 °C to 50 °C called a very volatile organic compound. Any organic compound with a boiling point in the range of 50-100 °C to 240-260 °C is called a Volatile organic compound" (Atif et al.; Adamová *et al.*, 2020).
3. VOC are those compounds that have "originated from automobiles, industrial production, burning of all types of fuels, storage, and transportation of oils, fitment finish, coating for furniture and machines, cooking oil fume and fine particles (PM 2.5)" and similar sources according to The People's Republic of China (Sewerniak and Wojciechowski, 2013).
4. Volatile organic compounds, or VOCs, are organic chemical compounds whose composition makes it possible to evaporate under average indoor atmospheric temperature and pressure conditions (Epa, 2016).

2.3 Classification of Volatile Organic Compounds

VOCs are classified into various types based on their boiling points and sources. This categorization helps in understanding their environmental and health impacts more effectively.

2.3.1 Based on their Boiling Points

Organic compounds can be classified into three categories: very volatile organic compounds (VVOCs), volatile organic compounds (VOCs), and semi-volatile organic compounds (SVOCs).

i. VVOCs are extremely volatile and are primarily found in the atmosphere rather than on surfaces or materials. These compounds have boiling points ranging from 0 to 50-100 °C. Examples of VVOCs include methyl chloride, propane, and others (Atif et al.).
ii. VOCs are organic compounds with a boiling point of less than 250 °C at a pressure of 101.3 kPa. Examples of VOCs are acetone, ethanol, and toluene (Atif et al.).
iii. SVOCs have a higher boiling point than water (240-400 °C) and are vaporized in the air at room temperature. Examples of SVOCs include polynuclear aromatic hydrides, phenol, and others (Atif et al.).

Table 2.1 shows the categories of VOC.

Table 2.1 Classification of Inorganic Pollutants (Adapted from WHO)

Description	**Abbreviation**	**Boiling Point Range (°C)**	**Examples Compounds**
Very volatile organic compounds	VVOC	<0 to 50-100	Propane, butane, methyl chloride
Volatile organic compounds	VOC	50-100 to 240-260	Formaldehyde, d-limonene, toluene, acetone, ethanol (ethyl alcohol), 2-propanol (iso hexanal
Semi volatile organic compounds	SVOC	240-260 to 380-400	Pesticides (DDT, chlordane, plasticizers, fire retardants (PCBs, PBB))

(Epa, 2016)

2.3.2 Based on their Sources

Naturally Occurring VOCs

These substances are a vital component of life. Bacteria emit organic matter, carbon dioxide, and methane during biodegradation and oxidation. Conifers, deciduous trees, flower perfumes, and our respiration also contribute to gaseous emissions. At a biological level, isoprene, terpenes, molds, microbes, and fungi are all critical VOCs found in significant quantities.

Biogenic volatile organic compounds (BVOCs) are VOCs that are released by plants, animals, or microbes and encompass a broad range of molecules, with terpenoids, alcohols, and carbonyls being the most prevalent (methane and carbon monoxide are excluded) (Kesselmeier and Staudt, 1999). While highly diverse, they are most commonly terpenoids, alcohols, and carbonyls (methane and carbon monoxide are generally not considered) (Kesselmeier and Staudt, 1999). Most VOCs are produced by plants, with isoprene being the primary compound. Animals and microbes, on the other hand, have only small quantities of VOCs (Terra *et al.*, 2018).

Human-made or anthropogenic VOC

Anthropogenic sources release around 142 teragrams (1.42 1011 kg) of carbon per year as VOCs (Goldstein and Galbally, 2007).

The major contributors of human-made VOCs are petroleum and natural gas extraction, petrochemical activities, and the combustion of fossil fuels in factories, residences, and transportation sources such as automobiles, trucks, buses, motorcycles, ships, and airplanes. Other sources include chemical and industrial operations (paint, lubricants, adhesives, oil derivatives), mining, commercial activities, gas leaks from stoves and home water heaters, boilers, and agricultural pesticide use (Bolden *et al.*, 2015).

2.4 Major VOCs

2.4.1 Aromatic Compounds

Some aromatic compounds are naturally present in petroleum products such as gasoline and fuels derived from crude oil, such as benzene, toluene, and ethylbenzene. When liquid fuels are incompletely combusted in vehicles, significant amounts of aromatic compounds are released into the atmosphere. These compounds are used in various products and formulations, such as petrochemicals, medicine, paint, and detergents (Özçelik *et al.*, 2009).

Aromatic compounds are toxic and can potentially cause severe damage to the ozone layer, produce smog, and pose mutagenic hazards (Kim and Shim, 2010). Many aromatic solvents in paints, thinners, gums, adhesives, lacquers, and printing inks are considered priority pollutants (Shahna *et al.*, 2010). Even at low levels of exposure, aromatic VOCs can cause fatigue, headaches, nausea, loss of appetite, memory loss, and loss of sight.

2.4.2 Halogenated VOCs

VOCs are hazardous compounds due to their strong bioaccumulation potential, acute toxicity, and resistance to degradation (Tyler *et al.*, 2002). (Aranzabal *et al.*, 2014) they highlighted that industries use these compounds in formulating and processing chemical extractants, paints, adhesives, drugs, polymers, solvents for chemical reactions, and cleaning agents. These compounds are highly volatile and often have long atmospheric lifetimes (Aranzabal et al., 2014). (Huang *et al.*, 2014) reported that halogenated VOCs expose humans through drinking water, inhalation, and absorption during swimming. Halogenated VOCs significantly impact the destruction of the ozone layer and act as a source of radicals that contribute to the greenhouse gas effects. The 100-year global warming potential (GWP) of halogenated VOCs ranges from 10 to 1800, much higher than that of CO2 with a GWP of only one (Abedi *et al.*, 2015).

2.4.3 Aldehydes

Aldehydes are among the most significant components of the total reactive VOCs in the atmosphere. Formaldehyde and acetaldehyde are two of the most commonly encountered aldehyde VOCs. These belong to one group that acts as a source of new radicals that control ozone formation. The most important source of formaldehyde is the degradation of VOCs (alcohols and other hydrocarbons) in multiple-step oxidations (Ivanova *et al.*, 2013). Aldehydes are released from many industrial products, such as treated wood resins, cosmetics, plastic adhesives, construction materials, cleaning agents, disinfectants, particleboard, medium-density fiberboard, plywood, carpeting, cigarette smoke, and fabrics (Li *et al.*, 2014).

2.4.4 Alcohols and Ketones

Alcohols and ketones are commonly used in cosmetics and personal care products such as nail polish, nail polish removers, colognes, perfumes, rubbing alcohol, and hair spray. Ketones are also found in aerosols, varnishes, window cleaners, paint thinners, and adhesives (Santos *et al.*, 2011). Common alcohol-based VOCs include ethyl alcohol, isopropyl alcohol, benzyl alcohol, while acetone, methacrylate (methyl or ethyl), and methyl ethyl ketone are ketone-based VOCs

Alcohol (mainly ethanol) increases aldehydes' formation by secondary reactions that cause throat irritation, shortness of breath, eye irritation, and chest tightness (Zhu & Wu, 2015). Long-term exposure to short-chain alcohols (ethanol, isopropanol, and n-butanol) may cause central nervous system depression (U.S. Department of Health and Human Services).

2.4.5 Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAH) are a family of VOCs, and they are mainly released by combustion processes (Varela-Gandía *et al.*, 2013). These compounds contain several benzene rings in their structure. Some typical examples of PAH are naphthalene (two rings), phenanthrene (three rings), and pyrene (four rings). The primary sources of PAH are incomplete fuel combustion, asphalt transformation plants, and coal power plants (Diehl *et al.*, 2010)

2.5 Common Examples of VOCs

To maintain optimal IAQ, one must familiarize oneself with and avoid the prevalent VOCs. Regularly assessing the levels of VOC emissions in one's living space is also imperative to maintain adequate air quality and reduce the risk of overexposure.

Table 2.2 Some Common Examples of VOCs

Compound	Atmospheric lifetime(approx.)	Characteristic source
Ethane	1.5 months	Natural gas, biomass burning
Propane	11 days	Liquified petroleum gas, natural gas
Benzene	10 days	Industrial and vehicle emissions, biomass burning
Ethanol	4 days	Plants, biofuel
Toluene	2 days	Solvents, vehicle emissions
Formaldehyde	1 day	VOC oxidation, biomass burning
Isoprene	3 hours	Plants

Source: Environmental Health Perspectives

2.6 Effects of Volatile Organic Compounds

2.6.1 Harmful Health Effects on Humans

It is important to note that certain aromatic compounds can have harmful effects on human health over time. Compounds such as HCHO, CH3CHO, benzene, toluene, and xylene have been linked to cancer in the human body and are therefore considered human carcinogens (Soni et al., 2018). These compounds are particularly concerning when present in the air, as long-term exposure to high levels of VOCs can lead to respiratory irritation and decreased lung function. It is crucial to investigate the biological impact of these compounds on human health, as many air pollutants have been identified as potential sources of cancer by the International Agency for Research on Cancer (Soni et al., 2018)

Short-Term Health Effect

Newly constructed buildings are reported to cause headaches, sickness, atopic dermatitis, dizziness, sleepiness, and irritation of the skin and eyes. These are the short-term effects of contaminated indoor air, which can lead to asthma and severe lung infection (Samet, 1990).

(Unwin *et al.*, 2006) have identified several short-term effects of high exposure to PAHs, including eye irritation, confusion, nausea, and vomiting. However, the specific compound responsible for these symptoms remains unknown. The IPCS (International Programme on Chemical Safety) has reported on the effects of specific PAH compounds, such as benzo(a)pyrene and naphthalene (Organization, 1998), which are known to be inflammatory and irritating. Benzo(a)pyrene, anthracene, and naphthalene are direct skin irritants and can cause skin allergies in humans and animals.

Long-Term Health Effect

The long-term health effects of these pollutants may be life-threatening diseases like nasal tumours, leukaemia, asthma, nasopharyngeal cancer, and reduced pulmonary function. Tracheal, bronchus and lung cancer ranked second globally by the number of incident cases in both sexes in the 50 most populous countries as per the Global Burden of Cancer Report—2013. Singh et al. have termed aromatic compounds and they are subsequently carcinogenic, toxic, and mutagenic (Singh & Chauhan, 2016). They have specified that there is tropospheric ozone formation due to benzene, xylene, and toluene emission. This tropospheric ozone creation depends on the concentration of unregulated emission and their structure. Diesel exhaust emissions have several components which pose severe health problems. All diesel exhaust is recognised as a human carcinogen as per the IARC (Organization, 1989). Emmelin et al. observed that diesel emission is a significant topic in epidemiological studies due to the possibility of lung cancer (Emmelin *et al.*, 1993).

2.6.2 Harmful Effects of VOCs on the Environment

Formation of ozone

Typically, ozone or O_3 is naturally formed in the atmosphere (stratosphere) when O_2 molecules split into individual oxygen particles. These free oxygen particles collide with other O_2 molecules to become ozone (Anon., 2021). In the form of ozone, they absorb UV rays. Here is an example of how ozone forms;

$O + O_2 = O_3$

VOC emissions also contribute to ozone and particulate matter formation, leading to ground-level smog. Aside from the adverse health implications to humans and animals, the effects of ozone on the Environment can include increased chances of plants developing diseases, an inability to fight off pests and environmental stress, reduced growth and survival of tree seedlings, and reduced agricultural yields. (Anon., 2021)

When VOCs and nitrogen oxides react with sunshine, they produce ozone. Here is an example of how nitrogen dioxide can result in ozone formation:

NO_2 + Sunlight (UV rays) = $NO + O$

The extent to which a VOC contributes to the generation of ozone depends on:

- the total mass of the VOC emitted
- the molecular mass of the VOC
- reactivity of the hydrocarbon with O.H. radicals
- the VOC chemical structure

(Porteous, 2013)

Global warming

Methane, the second most commonly emitted greenhouse gas in the U.S., is frequently discharged into the atmosphere. Greenhouse gases are chemicals that trap heat in the atmosphere, causing global temperatures to rise. According to research conducted by the Environmental Protection Agency (EPA), the industrial sector is responsible for 22% of all greenhouse gas emissions into the atmosphere. (Anon., 2021)

Acid rain

Precipitation with acidic constituents is referred to as acid rain. Rain, snow, fog, hail, or corrosive dust can all fall to the ground as wet or dry. Acid rain primarily results from nitrogen oxides (NOX) and sulfur dioxide (SO2) being emitted into the atmosphere and reacting with water. Acid rain depends on its pH level, which is usually between 4.2 and 4.4, while average rain has an approximate pH level of 5.6 (it is generally slightly acidic due to dissolved carbon dioxide) (Anon., 2021)

The primary sources of acid rain are four:

- Vehicles, such as cars.
- Power stations that burn fossil fuels.
- Oil refineries.
- Manufacturing processes.

(Anon., 2021)

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The chapter covers the study area, data collection methods, monitoring techniques, and instruments to achieve the study's objectives.

3.2 Study Area

Tarkwa, located between Latitudes 400'N and 500 40'N and Longitudes 10 45' W and 20 10'W, is the second largest town in the Western Region. Wassa Amenfi East District borders the town to the north, Ahanta West District to the south, Nzema East Municipal to the west, and Mpohor Wassa East to the east. The Municipality's total land area spans 2354 km2 (Anon.,2021). Tarkwa is renowned for its thriving agricultural and mining industries (Anon., 2014).

3.2.1 Climate

The municipality is located in the South-Western Equatorial Zone, resulting in a fairly consistent temperature that ranges from 26℃ in August to 30℃ in March. Relative humidity remains high throughout the year, typically 70% to 80% during the rainy season. Sunshine is about seven hours daily for most of the year.

3.2.2 Resource

The Tarkwa Gold Mine is located about four kilometres west of Tarkwa. The district is one of the most resourceful ones in Ghana, with gold being its primary natural resource. There is also a manganese mine in Nsuta, a suburb of Tarkwa. In addition, the Tarkwa glass factory, established by Ghana's first president, Kwame Nkrumah, is also located in the district. Furthermore, the district is home to the only public university in the region, the University of Mines and Technology.

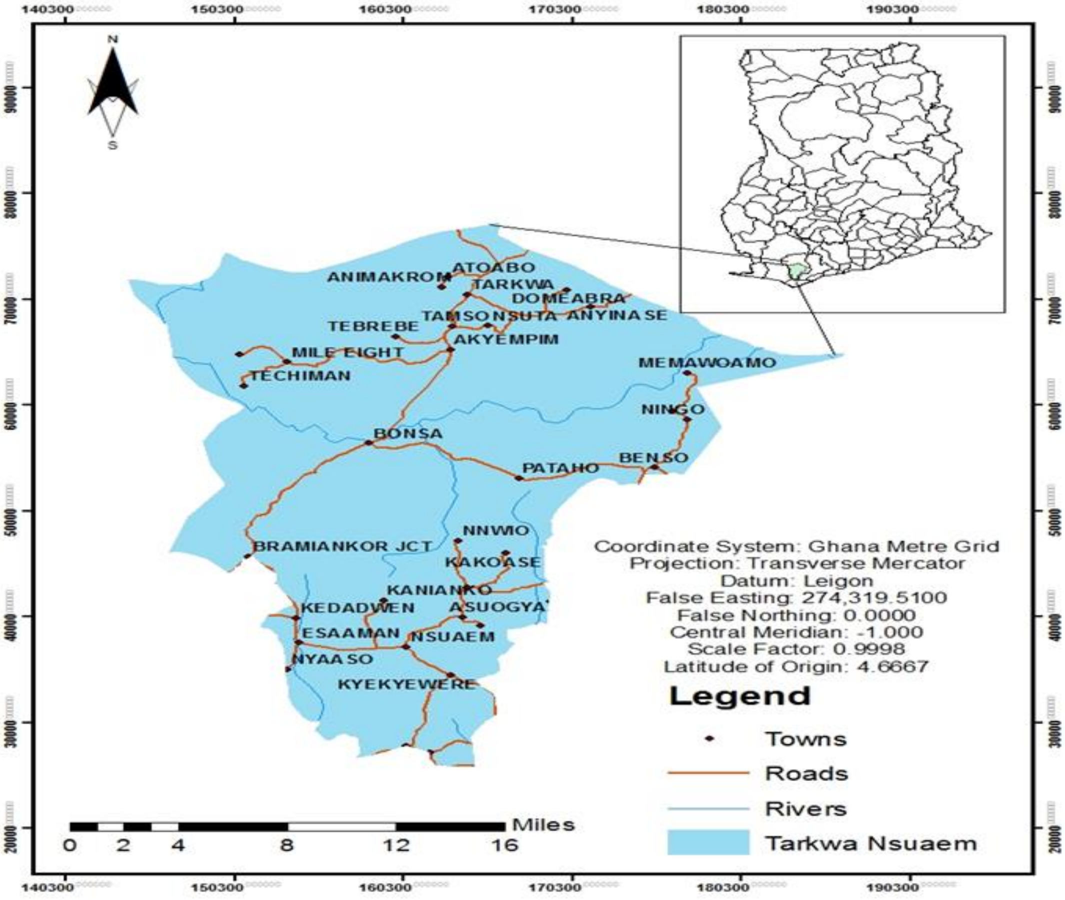

Fig. 3.1 A Map of Ghana showing the location of Tarkwa(Kemausuor *et al.*, 2014)

3.3 Sampling Sites and Descriptions

Four sampling sites were selected to monitor the levels of TVOC and BTEX compounds based on their respective activities and land use. The sampling sites were conveniently labeled as Site 1, Site 2, Site 3, and Site 4. Site 1 and Site 2 are both located on the busy Tarkwa-Bogoso road with heavy traffic, between latitude 50 18.522" N and longitude 10 59.621' W with an elevation of 81m and latitude 50 18.536 N and longitude 10 59.610' W with a height of 81m, respectively. The road condition is deteriorating, resulting in high dust particles. These sites are considered semi-residential areas. Site 3, or Tarkwa station, is situated between latitude 050 18.294’’N and longitude 10 59.725’’W with an elevation of 79m on the Tarkwa highway. It is a commercial area with a high traffic density and many commercial buildings. Site 4, or the total fuel station, is located between latitude 50 15' 18.47' N and longitude 10 59.663' W with an elevation of 80m at Tarkwa railway road adjacent to Ariel to Pentecost Hospital. Site 4 has a favourable environmental setting. All four sites represent urban background areas.

Fig. 3.2 Ariel View of the Four Different Sampling Sites

3.4 Data Collection

A sampling campaign was conducted during the rainy season. The first phase occurred from 8 a.m. to 12 p.m. in the morning. The second sampling phase was conducted in the afternoon from 12:30 p.m. to 4:30 p.m. on July 1st, 2021. The campaign lasted approximately 6 to 8 hours in the field.

3.4.1 Primary Data

Primary data was acquired through site visits and data collection instruments from primary sources.

3.5 Instruments for Data Collection

3.5.1 MiniRAE Lite (VOC monitor)

The MiniRAE Lite, a VOC sampling monitor, accurately measures the concentration of TVOC in real time. Its capabilities extend to hazardous and non-hazardous environments and function as a broadband VOC gas monitor. It features preset limits, triggering a loud buzzer and a red flashing LED if the concentration exceeds thresholds. This immediately alerts you to the alarm status, providing a safe and secure monitoring experience.

3.5.2 TFA Handheld Anemometer

This device is designed to provide essential information about the weather conditions for any outdoor activity. With its 10cm long anemometer, you can easily measure wind speed, wind chill, and temperature. All you have to do is hold it in the air, wait a little, and then observe. You will see the current wind speed and temperature displayed on the screen, along with their maximum and average values. It's the perfect tool for anyone who wants to stay informed about the weather while enjoying outdoor activities.

3.5.3 Draeger Accuro Tube Pump (Handpump)

Colourimetric detector tubes are calibrated glass tubes filled with chemical reagents that undergo a colour change when exposed to specific gases. Hand pumps extract a sample of air, and the ends of the detecting chips are sealed. When ready to take a sample, the end of the chip is broken and inserted into the pump, which is manually operated during the process. The colour of the detection chips indicates the presence of gas in the atmosphere.

3.5.4 Garmin Handheld GPS device

During the fieldwork, a Garmin-sensitive handheld GPS device captured four GPS coordinates. The device operated without any complications and had a navigation accuracy of 3-4 meters.

3.5.5 Wind Rose

The Wind Rose is a graphical chart that displays the direction and speed of wind in various locations. Meteorological factors are recorded on the chart to identify the direction of the wind blowing.

3.6 Method of Monitoring

We used the active grab sample approach with a hand-operated pump, and VOC monitor to collect VOC samples. The pump we used was the Draeger Accuro, which has a gas detection chip explicitly calibrated for each BTEX compound present. This calibration is achieved using known standards to develop response factors and ranges for the method. The targeted BTEX compound is broken off at the tip and inserted into the hand pump, requiring manual effort. During each sampling round, concentration levels were recorded using a book and pen, with the sampling range of values recorded from peak to almost negligible concentrations. Additionally, we monitored temperature and wind speed as part of the environmental monitoring process.

3.7 Validity of Research Instrument

The validity of the research instrument was rigorously assessed. Each instrument component underwent evaluation by being exposed to a calibration gas of known concentration prior to daily use.

3.8 Reliability of the Instrument

The accuracy and consistency of an instrument are key factors in achieving desired outcomes. The MiniRAE Lite's photoionization detection (PID) range of 0 to 5,000ppm and speedy 3-second response time make it a top choice for such applications. Furthermore, the instrument undergoes annual calibration revisions and testing to ensure its continued reliability.

CHAPTER 4

RESULTS AND DISCUSSION

4.0 Introduction

This chapter presents and interprets the data gathered in the study, discussing the contributing factors that result in ambient concentrations.

4.1 Analysis

Analysis during the campaign, there were two instances of air direction changes. The prevailing wind was mainly from the southwest of Site 1, Site 2, and Site 4. The second episode marked wind direction from the south of Site 3. Site 1 recorded the lowest wind speed of 0.6 ms-1, with the maximum TVOC concentration of 87 ppm during this time (Table 4.1). The highest wind speed of 1.6ms-1 was recorded at Site 3, with a maximum TVOC concentration of 10.3 ppm. Site 3 recorded the lowest peak and minimum readings values throughout the campaign.

TVOC concentration increased considerably from 2.6 ppm to 18.5 ppm to 34.4 ppm when fuel spillages refuelled a vehicle at Site 2. Our observations suggest a general increase in TVOC and BTEX concentrations during fuel dispensing. The highest skin irritation was observed at Site 2, followed by Site 4. Both sites distributed fuel, degreasing garages, and a lube bay. The two fueling stations rendered the same services and were located at an equal distance from the roadside. Higher concentrations of TVOC and BTEX were recorded at Site 2 relative to Site 4, as seen in Tables 4.1 and 4.2. The most abundant VOC compounds recorded at the sites were benzene, toluene, ethylbenzene, and xylene. The maximum BETX levels measured at sampling sites were 12.14, 21.89, 9.67, and 14.11, respectively. BTEX compounds were recorded only at the two fuel stations. Site 2 recorded the highest BTEX compound at a temperature of 32.5℃. Toluene was the dominant BTEX measured at the sampling sites.

Table 4.1 Measurement at Sampling Site for Ambient Total Volatile Organic Compounds

ID	S1	S2	S3	S4
Peak Reading of TVOC (ppm)	87	34.4	10.3	13.1
Average Reading of TVOC (ppm)	45.3	18.5	5.2	7.2
Minimum Reading of TVOC (ppm)	3.6	2.6	1.1	1.3
Average Air Temperature (°C)	31.1	32.5	31.8	31.1
Average Wind Speed (ms^{-1})	0.5	0.8	1.6	1.0
Wind direction	SW	SW	S	SW

Table 4.2 Measured BTEX Concentrations at Four Different Sampling Sites

ID	S1	S2	S3	S4
Benzene	0.00	12.14	0.00	8.83
Toluene	0.00	21.89	0.00	17.45
Ethylbenzene	0.00	7.99	0.00	9.67
Xylene	0.00	14.11	0.00	13.33
Average Air Temperature (°C)	31.1	32.5	31.8	31.1

4.3 Discussion

4.3.1 Comparison of TVOC emission at Sampling Sites to European Union Standard

We compared the TVOC emissions at various sampling sites during our discussion to the European Union standard. We found that Site 1, a light-duty vehicle workshop with high industrial activity, including petrochemical processes, storage and distribution of chemicals, combustion processes, maintenance of automobiles, and a high traffic density, recorded the maximum ambient TVOC concentrations. The burning of fossil fuels and vehicular emissions contributed to these high concentrations. However, due to the confined and congested work area with many cars, there was low dispersion and circulation of pollutants, resulting in an exceeded exposure limit for TVOC. On the other hand, TVOC concentrations at Site 1, Site 2, and Site 3 were within the permissible exposure limit. We also observed that during fuel dispensing, relatively high concentrations of TVOCs were measured at Site 2 and Site 4. Furthermore, meteorological factors played a role in the dilution and dispersion of pollutants in the environment. For instance, Site 3 had many vehicular emissions, but relatively high wind speed caused pollutants to disperse, resulting in low VOC concentrations.

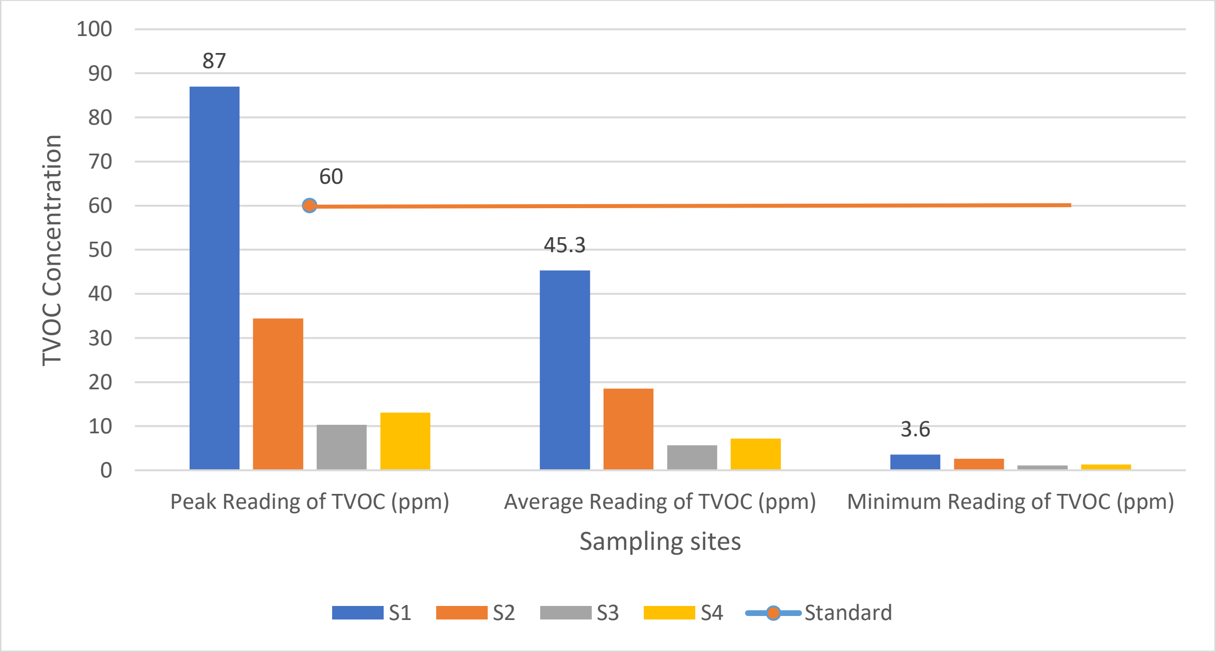

Fig. 4.1 TVOC Concentrations at Four Different Sampling Sites

4.3.2 Comparison of BTEX Compounds to American Conference of Governmental Industrial Hygienists (ACGIH) Standard

Most countries now have occupational exposure limits (OEL) for BTEX at the workplace. The American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV) and the OSHA Permissible Exposure Limit (PEL) standards are the most cited contaminant airborne standards (Cruz et al., 2017).

Table 4.3 Typical Exposure Limits for BTEX according to ACGIH

Compound	ACGIH TWA (ppm)
Benzene	0.5
Toluene	20
Ethylbenzene	20
Xylene	100

According to Speight's (2015) report, BTEX compounds have high vapour pressures and are prone to rapid evaporation, especially at higher temperatures.

The elevated levels of TVOC and BTEX detected at Site 2, as compared to Site 4, could be attributed to the greater number of pumps and nozzles available at Site 2. Furthermore, traffic congestion at Site 2 was relatively higher than at Site 4.

Benzene

Fig. 4.2 The concentration of benzene at Site 2 and Site 4 was found to be 12.14 ppm and 8.3 ppm, respectively. Benzene is considered to be the most dangerous compound of the BTEX group, as it can negatively impact the CNS and hematopoietic systems(Pope & Rall, 1995).

According to ACGIH standards, S1 and Site 2 exceeded the permissible exposure limit.

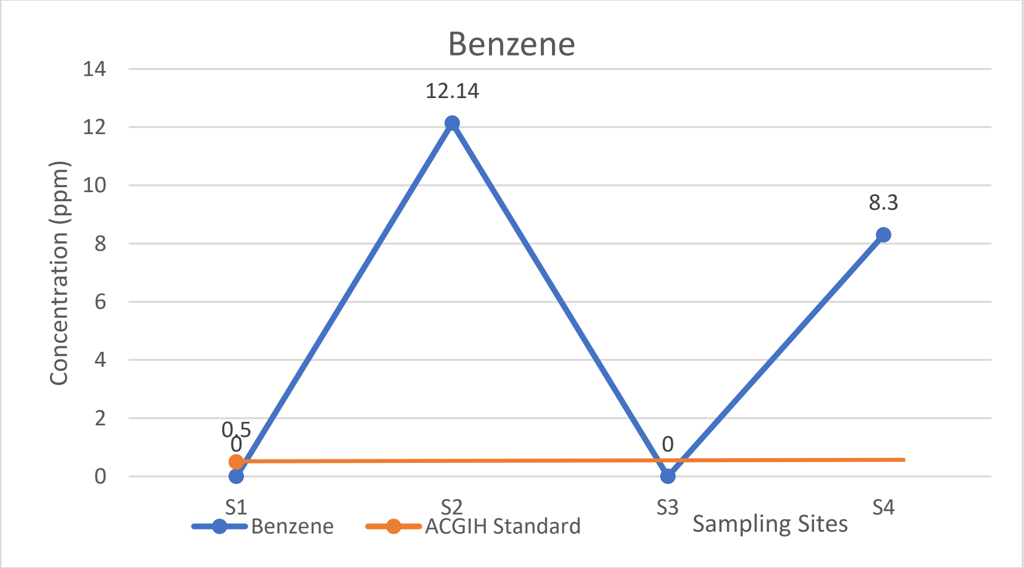

Fig. 4.2 Benzene Concentrations at Four Different Sampling Sites

Toluene

Toluene is a natural component found in gasoline and a gasoline additive (Kuranchie *et al.*, 2019). At Site 2 and Site 4, concentrations of toluene were measured at 2.89 ppm and 17.85 ppm, respectively. The permissible exposure limit was exceeded at Site 2, while at Site 4, the exposure limit was slightly below the permissible limit.

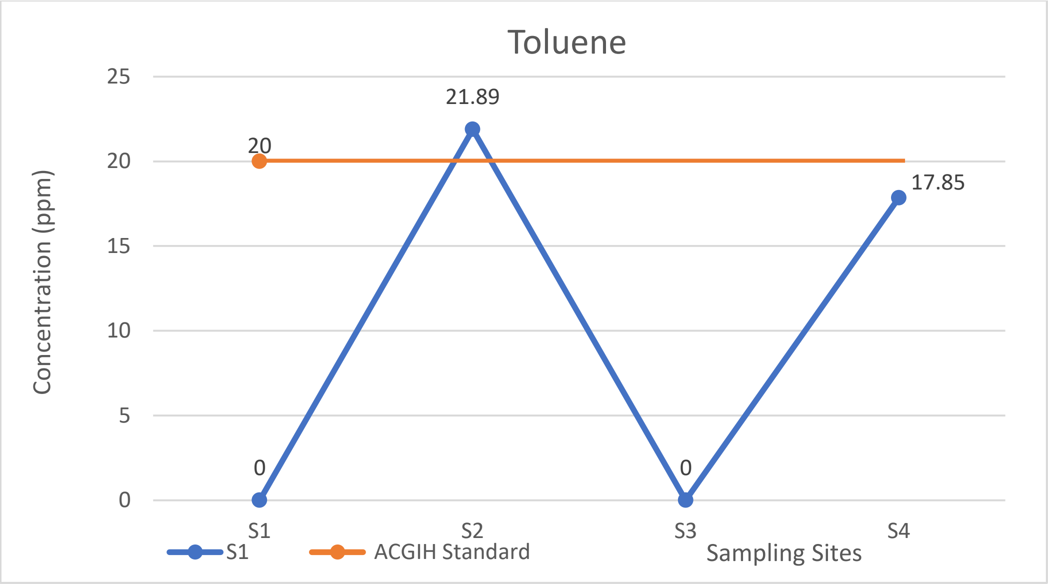

Fig. 4.3 Toluene Concentrations at Four Different Sampling Sites

Ethylbenzene

Ethylbenzene can be found in crude oil, but human activities like refining and incomplete burning of natural materials such as forest fires and cigars can also cause exposure (Inchem, 1996). Although there were some recorded concentrations of ethylbenzene, they did not exceed the permissible exposure limit. Notably, Site 1 and Site 4 had no recorded concentrations.

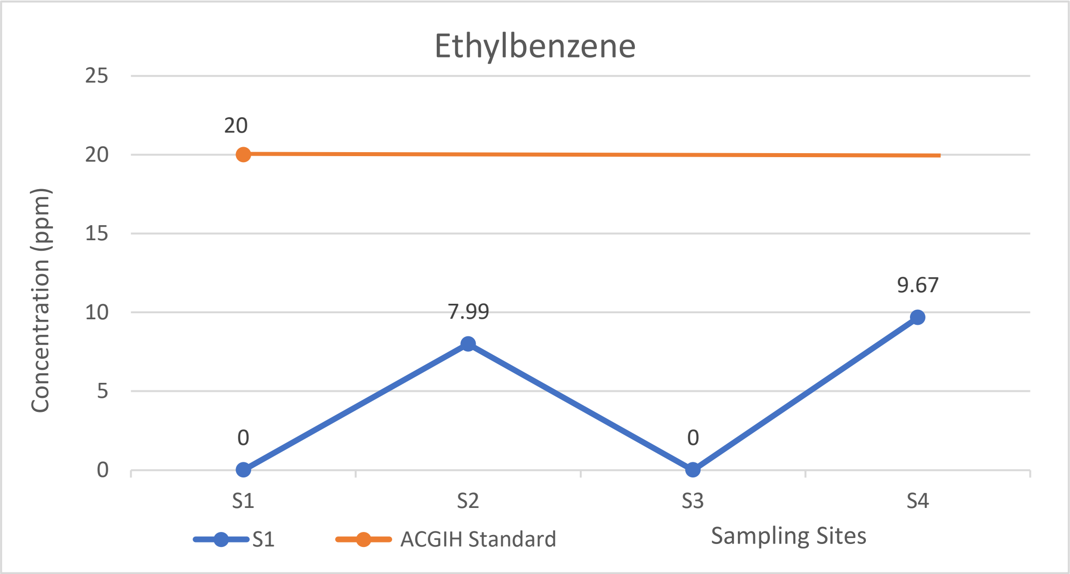

Fig. 4.4 Ethylbenzene concentration at Four Different Sampling Sites

Xylene

Xylene concentrations were recorded at Site 2 and Site 4 and were found to be below the permissible exposure limit based on ACGIH standards.

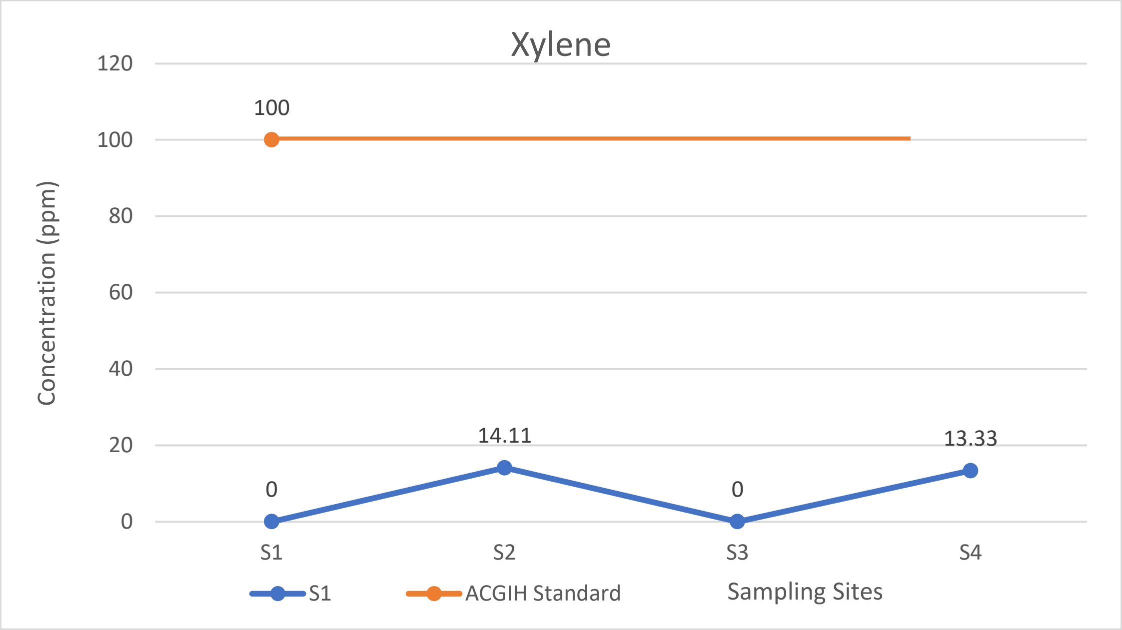

Fig. 4.5 Xylene Concentration at Four Different Sampling Sites

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study aimed to analyze the Volatile Organic Compounds (VOC) levels and identify the factors that affected these levels. The researchers measured VOC levels at four different sites to determine the emission factors that contributed to these levels. The results indicated that industrial sources and traffic in the surrounding area influenced the emission of VOCs.

Toluene was found to be more concentrated at fuel stations than other VOC species. The highest Total Volatile Organic Compound (TVOC) emissions were recorded at Site 1, reaching 87 ppm, while the lowest measurements were taken at Site 3. Interestingly, the commercial location had consistently low levels of TVOCs throughout the study.

The study also revealed that meteorological conditions such as wind speed, temperature, and precipitation significantly affected the dispersion and dilution of VOC concentrations. These findings provide valuable insights into the sources of VOC emissions and the factors contributing to their levels.

5.2 Recommendations

i. It is crucial to take specific actions to keep emissions into the environment below limits set by organizations like the EPA. Implementing environmental monitoring programs in highly polluted urban areas and industrial and petrochemical areas, such as dump sites, polluted rivers, and industrial areas, is an example of such an action. This will help identify and track the pollution level in the area and enable necessary measures to keep it under control.

ii. Additionally, it is essential to ensure adequate ventilation in and out of work areas when dealing with VOCs. When inhaled in large quantities, VOCs can be harmful to the respiratory system and may cause a range of health problems. An adequately ventilated environment will mitigate these risks and prevent any adverse effects.

iii. It is recommended that appropriate personal protective equipment (PPE) be worn when working with VOCs. This ensures that any contact with the compounds is minimized and that individuals handling them are protected from any harm. Proper PPE can include gloves, masks, or other protective gear, depending on the situation.

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