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EVALUATION OF OCCUPATIONAL SAFETY AND HEALTH AMONGST WORKERS IN FILLING STATIONS/ FUEL DEPOTS IN YAOUNDE AND CHARACTERIZATION OF THE ASSOCIATED FAMILY HEALTH RISK

Dissertation presented in partial fulfillment of the requirements for the award of a Professional Master of Science Degree in Biochemistry.
Option : Public Health Biotechnology

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Academic Year 2023-2024

DECLARATION

I ANDIN Josephine WAMBANG, declare that this dissertation is my original work, conducted under the supervision of Dr. Wilfred ANGIE ABIA, and that it has not been previously submitted, in whole or in part, for any academic degree program. All sources used have been duly cited in text and acknowledged by complete references.

ANDIN Josephine WAMBANG

DEDICATION

This piece of work is dedicated to the **HOLY SPIRIT**

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

ACGIH: American Conference of Governmental Industrial Hygienists

ATEX: Explosive atmosphere

BTEX: Benzene, Toluene, Ethylbenzene, Xylene

CNS: Central Nervous System

EPA: Environmental Protection Agency

FSW/FDW: Filling Station Workers/Fuel Depot Workers

GC: Gas Chromatography

GC-MS: Gas Chromatography-Mass Spectrometry

IARC: International Agency for Research on Cancer

ILO: International Labor Organization

LOD: Limit of Detection

NIOSH: National Institute of Occupational Safety and Health

OEL: Occupational Exposure Limits

OSH: Occupational Safety and Health

OSHA: Occupational Safety and Health Administration

PEL: Permissive Exposure Limits

PPE: Personal Protective Equipment

REL: Recommended Exposure Limit

SOPs: Standard Operating Procedures

TLV: Threshold Limit Values

TLV-TWA: TLV-Time Weighted Average

TLV-STEL: TLV-Short Term Exposure Limit

TLV-C: TLV-Ceiling

USEPA: United States Environmental Protection Agency

VOCs: Volatile Organic Compounds

WHO: World Health Organization!

WRDs: Work-Related Diseases

ABSTRACT

Workers around the world are faced with various kinds of workplace hazards including but not limited to psychosocial, biological, physical, and chemical agents. Occupational safety and health is a critical issue in the workplace, particularly in industries that involve hazardous materials or processes. Filling stations and fuel depots are one of such industries where workers may be exposed to various occupational hazards. Therefore, the objective of this research is to evaluate occupational safety and health (OSH) of workers in the various filling stations/fuel depots in Yaounde involved in the manipulation of petrochemical agents and to characterize the associated family health risk. To achieve this, Structured questionnaires were developed and administered on-site to collect data on demographic characteristics, hazard exposure, safety practices, and health outcomes from 130 workers with or without direct exposure to volatile organic compounds (VOC) specifically the benzene, toluene, ethylbenzene and xylene (BTEX) group of compounds. Additionally, 520 air samples from ATEX zones and offices were collected (by whole air sampling) from 25 filling stations and a fuel depot (the worst-case scenario) and at various distances (0.5m,1m,1.5m, and 2m) from the refuelling pump every day for two weeks by a portable pump gas detector and analysed on-site. Risk assessment was performed for each of the selected filling stations and fuel depots using document 252274895/Risk Assessments for Petrol Filling Station guidance's template. Results showed that most of the survey participants were married (77/130; 59.2%); age range: 31-58 years old, and mainly males (94/130; 72.3%). The survey findings revealed the most prevalent symptoms of BTEX exposure including fatigue (100%), headache (96.2%), cough/hoarseness (73.1%), burning eyes (73.1%), and dizziness (57.7%). Moderate symptoms such as burning nose/congestion (42.3%), sleeplessness (42.3%), and muscle weakness (53.8%), and less frequent but concerning symptoms like tight chest (15.4%), tachycardia (19.2%), anemia (7.7%), and unconsciousness (7.7%). In addition, 23(17.7%) of the study population testified of miscarriage and the analysis of air samples revealed high levels of BTEX, average benzene levels ranged from 7.63 ppm to 14.21 ppm, with peaks up to 19.64 ppm, toluene and xylene concentrations also varied significantly, with maximum values reaching 19.71 ppm and 31.70 ppm, respectively. In summary, the findings of this research indicate a high prevalence of adverse health symptoms among workers, including fatigue, headaches, respiratory irritation, and dizziness, with severe effects such as tachycardia, anemia, and miscarriages being reported. The elevated BTEX concentrations in air samples, often exceeding safety thresholds, reinforce the direct link between occupational exposure and the observed health outcomes.

Keywords: Occupational exposure, Safety, Health, Filling points/fuel depots, family health risk, volatile organic compounds.

RÉSUMÉ

Les travailleurs du monde entier sont confrontés à différents types de risques sur le lieu de travail, notamment des agents psychosociaux, biologiques, physiques et chimiques. La sécurité et la santé au travail sont des questions cruciales sur le lieu de travail, en particulier dans les industries qui utilisent des matériaux ou des processus dangereux. Les stations-service et les dépôts de carburant sont l'une de ces industries où les travailleurs peuvent être exposés à divers risques professionnels. L'objectif de cette recherche est donc d'évaluer la sécurité et la santé au travail (SST) des travailleurs des différentes stations-service/dépôts de carburant de Yaoundé impliqués dans la manipulation d'agents pétrochimiques et de caractériser les risques pour la santé des familles qui y sont associés. Pour ce faire, des questionnaires structurés ont été élaborés et administrés sur place afin de recueillir des données sur les caractéristiques démographiques, l'exposition aux dangers, les pratiques de sécurité et les effets sur la santé de 130 travailleurs directement exposés ou non aux composés organiques volatils (COV), en particulier au groupe de composés benzène, toluène, éthylbenzène et xylène (BTEX). En outre, 520 échantillons d'air provenant de zones ATEX et de bureaux ont été prélevés (par échantillonnage de l'air entier) dans 25 stations-service et un dépôt de carburant (le scénario le plus défavorable) et à différentes distances (0,5 m, 1 m, 1,5 m et 2 m) de la pompe de ravitaillement, tous les jours pendant deux semaines, à l'aide d'un détecteur de gaz portable pour pompe, et analysés sur place. Une évaluation des risques a été réalisée pour chacune des stations-service et des dépôts de carburant sélectionnés à l'aide du modèle du document 252274895/Risk Assessments for Petrol Filling Station guidance. Les résultats ont montré que la plupart des participants à l'enquête étaient mariés (77/130 ; 59,2 %) ; la tranche d'âge était de 31 à 58 ans : 31-58 ans, et principalement des hommes (94/130 ; 72,3 %). Les résultats de l'enquête ont révélé que les symptômes les plus fréquents de l'exposition aux BTEX étaient la fatigue (100 %), les maux de tête (96,2 %), la toux et l'enrouement (73,1 %), les yeux brûlants (73,1 %) et les vertiges (57,7 %). Des symptômes modérés tels que nez brûlant/congestion (42,3 %), insomnie (42,3 %) et faiblesse musculaire (53,8 %), et des symptômes moins fréquents mais préoccupants tels qu'oppression thoracique (15,4 %), tachycardie (19,2 %), anémie (7,7 %) et perte de conscience (7,7 %). En outre, 23 (17,7 %) de la population étudiée ont témoigné d'une fausse couche et l'analyse des échantillons d'air a révélé des niveaux élevés de BTEX, les niveaux moyens de benzène allant de 7,63 ppm à 14,21 ppm, avec des pics allant jusqu'à 19,64 ppm, les concentrations de toluène et de xylène variant également de manière significative, avec des valeurs maximales atteignant 19,71 ppm et 31,70 ppm, respectivement. En résumé, les résultats de cette recherche indiquent une forte prévalence de symptômes néfastes pour la santé chez les travailleurs, notamment la fatigue, les maux de tête, l'irritation des voies respiratoires et les vertiges, avec des effets graves tels que la tachycardie, l'anémie et les fausses couches. Les concentrations élevées de BTEX dans les échantillons d'air, qui dépassent souvent les seuils de sécurité, renforcent le lien direct entre l'exposition professionnelle et les effets observés sur la santé.

Mots-clés : Exposition professionnelle, sécurité, santé, points de remplissage/dépôts de carburant, risque pour la santé des familles, composés organiques volatils.

GENERAL INTRODUCTION

BACKGROUND

Workers around the world are faced with various kinds of workplace hazards including but not limited to psychosocial, biological, physical, and chemical agents (Ekpenyong and Asuquo, 2017). Occupational safety and health (OSH) is a critical issue in the workplace, particularly in industries that involve hazardous materials or processes. Filling stations and fuel depots are one of such industry where workers may be exposed to various occupational hazards (Chijioke *et al*., 2020; Anigilaje *et al*., 2024). These stations and depots play a critical role in the transportation and distribution of fuels, serving as essential nodes in the energy supply chain. These facilities, however, may present inherent OSH risks to the workers involved in their daily operations. The well-being of these workers is crucial not only for their individual health and safety but also for the overall functioning and sustainability of the fuel industry (Chijioke *et al*., 2020).

Furthermore, exposure to petrochemical industries such as filling stations and fuel depots increases the vulnerability of the front-line workers due to its integration of highly toxic compounds (Qafisheh *et al*., 2021). Based on limited lung cancer evidence studies, the International Agency for Research on Cancer (IARC) has classified diesel exhaust as carcinogenic to humans (Group 1) and gasoline exhaust as a possible carcinogen (Group2B) (IARC, 2012; Qafisheh *et al*., 2021). Exposure to chemical hazards in the workplace is affected by public policy, regulation, mechanical controls, and administrative and behavioral measures like systems of work, supervision, and training. Good Occupational, Social, Health and Safety (OSHS) practices should be used by the employers and employees to control risk, minimize exposure and protect the health of workers and non-workers, who are at risk of exposure (Kuranchie *et al*., 2019).

Understanding the OSH challenges faced by workers in filling stations and fuel depots is vital for implementing appropriate interventions and promoting a healthier work environment. Furthermore, considering the potential long-term impact on the workers and the associated family risk, it is essential to explore the intergenerational health risks associated with their occupational exposures.

By conducting a thorough evaluation of the OSH conditions of filling stations and fuel depots in Yaounde, this research aims to fill the existing knowledge gap and shed light on the associated family health risks. The study will encompass a broad range of factors, including physical hazards, chemical exposures, ergonomic considerations, and psychological factors. Additionally, it will investigate the potential intergenerational effects by examining the health history of workers' first and second generations.

PROBLEM STATEMENT

Over the years, there has been a global increase in petrochemical firms, including the emergence of many gasoline stations, to meet the increasing demands of a fast-growing population and because of globalization, urbanization, and accelerated economic development (Ekpenyong and Asuquo, 2017). In Cameroon, the increase in the number of petrochemical firms in its political capital has been exponential (Kidmo *et a*l., 2021). The World Health Organization (WHO) estimates that only 20-50% of workers in industrial countries, and fewer than 10% of workers in developing countries, have access to occupational health services (WHO,1995). According to the WHO and International Labor Organization (ILO), at least 2 million of the estimated 2.7 billion workers die every year from work-related ill health and injuries, about 160 million people suffer from work-related diseases (WRDs), and approximately 270 million fatal and non-fatal work-related accidents occur each year (Ekpenyong and Asuquo, 2017; WHO/ILO, 2021). Work-related ill health caused by exposure to chemical agents has become a major concern in the workplace. Furthermore, exposure to petrochemical industries such as fuel stations increases the vulnerability of the front-line workers due to its integration of highly toxic compounds (Qafisheh *et al*., 2021) such as petrol and petrol engine exhaust reported to be carcinogenic to humans (IARC, 2012; Qafisheh *et al*., 2021).

Quantifying BTEX exposures and the health risks among FSWs/FDWs have been of research interest in Asia, Europe, Canada, North America and Nigeria (Correa *et al*., 2012; Kitwattanavong *et al*., 2013). The results of these studies indicated that FSWs/FDWs were at a higher risk of adverse cancer and non-cancer health risks (Kitwattanavong *et al*., 2013; Cruz *et al*., 2017). Assessment of BTEX exposure among FSWs/FDWs is a rare research focus in Cameroon despite prevailing conditions that expose FSWs/FDWs in Cameroon to a high volume of BTEX. For example, the dispensing pumps at Cameroons filling stations and fuel depots have no mechanism for vapor recovery and some of these FSWs/FDWs work for long hours daily ranging from 10 to more than 12 hours.

The absence of a comprehensive understanding of the OSH challenges within these workplaces hampers the development and implementation of effective preventive measures. The potential consequences of inadequate safety practices and the associated health risks for workers in filling stations and fuel depots are concerns and demand urgent attention.

Moreover, there is a dearth of research exploring the intergenerational health effects associated with occupational exposures in this industry. Understanding the potential long-term impact on the first and second generations of workers in filling stations and fuel depots is crucial for safeguarding the health and well-being of future workers in this sector.

Therefore, the problem at hand is twofold: first, the need for a comprehensive evaluation of the OSH conditions within filling stations and fuel depots in Yaounde; and second, the necessity to characterize the associated family health risks, including potential intergenerational effects on the workers' first and second generations.

Addressing these research gaps is paramount for the formulation of evidence-based policies, guidelines, and interventions aimed at improving the OSH practices within filling stations and fuel depots. By understanding the specific risks and health consequences faced by workers in this industry, stakeholders can implement targeted measures to protect the well-being of workers and promote sustainable practices in the fuel sector.

RESEARCH HYPOTHESIS

There is a significant association between occupational exposure to hazardous substances at filling stations/fuel depots and adverse health outcomes among workers

RESEARCH QUESTION

1. What are the common health issues reported by workers in filling stations/fuel depots, and how are these linked to benzene, toluene, ethylbenzene and xylene (BTEX) occupational exposure.
2. How does the occupational health status of filling station workers affect the health of their family members?
3. What possible recommendations based on the data generated in addressing the above-mentioned research questions can be made to maintain good safety practices thereby, reducing worker’s exposure and associated health effects?

RESEARCH OBJECTIVES

Overall Objective

The overall objective of this study was to evaluate the occupational safety and health (OSH) of workers in various filling stations/fuel depots in Yaounde involved in the manipulation of petrochemical agents and attempt to characterize the associated family health risk.

Specific Objectives

1. To determine the levels of benzene, toluene, ethylbenzene and xylene (BTEX) exposures through air from explosive atmosphere (ATEX) zones in the various filling stations and fuel depots in Yaounde and its association to common health risk reported by workers.
2. Perform risk assessment of filling stations/fuel depots to identify potential hazards, available mitigation measures, and to Characterize the associated family health risk of benzene, toluene, ethylbenzene and xylene (BTEX) exposure.
3. To produce a series of Standard Operating Procedures (SOPs) to improve occupational safety and health practices within filling stations and fuel depots in Yaounde.

CHAPTER ONE: LITERATURE REVIEW

1.1 OVERVIEW

Workers in filling stations/fuel depots are often exposed to hazardous substances like gasoline, diesel, dual purpose kerosene, liquefied petroleum gas and other chemicals, which can lead to acute and chronic health issues. These substances contain volatile organic compounds (VOC) which can get in to the human organism through inhalation, ingestion or direct contact with these hazardous substances. This review focuses on BTEX, the most toxic VOCs found in the filling stations/fuel depots environment. Whereas BTEX has been found to be potentially hazardous to environmental and human health, this study pays attention to workers' health and the associated family health risk. Occupational health and safety principles, laws and regulations governing occupational health in Cameroon, health risk in filling stations/fuel depots, health outcomes associated with occupational exposure, family health risk, preventive measures and best practices will be discussed.

1.2 INTRODUCTION TO OCCUPATIONAL SAFETY AND HEALTH

Occupational safety and health (OSH) is the science of anticipation, recognition, evaluation, and control of hazards arising in or from the place of work that could impair the health and well-being of workers (Alli, 2008). According to the UK government health and safety executive (HSE), an important part of occupational health is concerned with how work and the work environment can impact on workers' health, both physical and mental. It also includes how worker's health can affect their ability to do their job. A safe and healthy working environment is one where risks are eliminated or when all reasonably practicable actions have been taken to reduce risks to an acceptable level where prevention has been integrated as part of the organizations culture. Employers are not the only ones involved in securing safety and health in the work place. Workers and their representatives should cooperate with employers by taking reasonable care of their own safety, complying with the instructions given regarding safety and health, using protective equipment correctly and reporting any hazardous conditions or events and accidents (ILO, 2020). Organizations must invest rigorous interest in ascertaining the required safety knowledge and its association with specific hazards for employees (Liu *et al.,* 2023), this is achieved by subjecting workers to training leading up to their employment. According to Zin (2012), health and safety training significantly improves knowledge and behaviors related to workplace safety. Workers get to know the layout of the workplace and how to use the necessary equipment and how to safely use any personal protective equipment (PPE) such as gloves, safety footwear, and goggles (Mutungi, 2020).

1.3 COMMON HAZARDS IN FILLING STATIONS AND FUEL DEPOTS

The various hazards encountered in these industries include;

1.3.1 Physical Hazards:

Physical hazards in OSH refer to the potential risk that can cause physical harm or injury to workers due to physical agents, factors or conditions present in the work place (Amponsah-Tawiah *et al*., 2013). Filling stations involve various physical hazards that workers may encounter during their tasks. These hazards include slips, trips, and falls due to uneven surfaces or working at heights, spills, or inadequate lighting, noise and vibration from machines (ILO, 1977; ILO,1981). Workers are also exposed to potential injuries from moving vehicles, handling heavy equipment, and operating machinery. More workers are injured each year by falling than any other environmental or physical hazard. Deadly falls from elevated surfaces and common slips or trips can both cause major injuries (Stout *et al*., 2011). Confined spaces can be particularly deadly. A cramped area like the inside of a storage tank, an excavation or a trench could cause a structural failure or present an asphyxiation risk. Working in the sun or on a hot factory floor can lead to life-threatening heat stress. Winter work or a refrigerated warehouse can induce cold stress. Environmental Hazard Examples: Eye damage from metal shavings or unprotected welding, Fractures or sprains from falling from a ladder, repeat stress from poor posture or other ergonomic failures, Concussions suffered from falling tools or debris, Lacerations or amputations caused by missing or improper machine guarding (Karwowski, 2006). Ionizing radiation is a devastating threat to human health. Most people will never experience acute radiation syndrome, but small, repeated radiation in industrial settings can lead to chronic health complications. That includes frequent exposure to excessive ultraviolet (UV) radiation — the non-ionizing radiation in sunlight. Radiation Hazard Examples: Thermal damage induced by microwave or radiofrequency machinery, Overexposure to X-ray or computed tomography (CT) equipment, Melanoma or other cancers caused by sunburns, Blindness resulting from looking directly into lasers. Electricity represents a significant danger to human tissue. An electrical shock occurs when a live current pass through the body, which can sear flesh or even stop a heart. Electrocution (a fatal shock) is a serious threat when lockout/tag out standards or other crucial electrical safety procedures are ignored. Arc flashes are even more hazardous and can strike seemingly without warning. Electrical Hazard Examples: Contact with exposed wiring leading to electric shock, Fatal electrocution caused by completing an unguarded high-voltage circuit, Injuries sustained following a sudden arc flash, Smoke inhalation and lung irritation, Fatal asphyxiation or immolation (ILO,1977). Loud noise at work can damage workers hearing. This usually occurs over longer periods of time because of prolonged exposure to high noise levels. Hearing loss may be only temporary after short periods of exposure to noise, but if workers continue to be exposed to high noise levels they will suffer permanent damage to their hearing or other diseases such as tinnitus. Permanent damage can also be caused immediately by sudden, extremely loud noises. High noise levels can interfere with communication and making warnings harder to hear, and they can also increase worker fatigue, cause stress, irritability and sleep disorders, reducing performance (ILO,1977). Exposure of workers to hazardous vibration mainly comprises: whole-body vibration (when the body is supported on a surface that is vibrating, such as in vehicles or when working near vibrating industrial machinery; or hand–arm vibration (which enters the body through the hands and is caused by various processes in which vibrating tools or work pieces are grasped or pushed by the hands or fingers). Short duration exposure to whole-body vibration or to hand– arm vibration may result in temporary disability, but prolonged or repeated exposure leads to permanent damage.

Figure 1: Exposure to physical hazards (SafetyCulture, 2024)

1.3.2 Chemical Exposures:

A chemical hazard refers to any substance that can cause harm to human health or the environment through its physical or toxic properties. These hazards can result from exposure to chemicals in the solid, liquid or gaseous forms and can pose risks through inhalation, ingestion, skin contact, or absorption. Chemical hazards can lead to short term injuries like burns, or long-term health effects including respiratory conditions, cancer or organ damage (Safety education, 2024). Workers in filling stations are exposed to various hazardous chemicals, including fuels, lubricants, and cleaning agents. These substances can lead to respiratory problems, skin irritations, and long-term health issues. Proper ventilation, safe handling procedures, and the use of appropriate PPE, such as gloves and masks, are crucial in minimizing chemical exposures and their associated health risks (Fosa *et al*., 2022).

Types of Chemical Hazards (Safety Education, 2024).

Chemical hazards can be classified into various types based on their physical and health-related risks. Here are the primary types of chemical hazards:

1. **Flammable Hazards**

Definition: Flammable chemical hazards include any substance that can ignite and burn easily.

Examples: Gasoline, alcohol, acetone, and methane are examples of flammable chemicals commonly used in industries.

Risks: These substances pose a significant fire risk, especially in areas with high temperatures, open flames, or inadequate ventilation.

2. **Explosive Hazards**

Definition: Explosive hazards refer to chemicals that can react violently, releasing energy in the form of an explosion.

Examples: TNT (trinitrotoluene), ammonium nitrate, and certain peroxides.

Risks: Explosions can result in significant property damage and pose serious risks to human life, often requiring strict handling and storage protocols.

3. **Toxic Hazards**

Definition: Toxic chemical hazards involve substances that are harmful or lethal to humans when ingested, inhaled, or absorbed.

Examples: Lead, mercury, carbon monoxide, and cyanide.

Risks: These chemicals can cause severe health effects, including poisoning, respiratory issues, and long-term organ damage. Even low exposure levels over extended periods can lead to chronic health conditions.

4. Corrosive Hazards

Definition: Corrosive hazards are chemicals that can destroy or irreversibly damage other substances, including living tissues, upon contact.

Examples: Sulfuric acid, hydrochloric acid, sodium hydroxide (lye), and bleach.

Risks: Corrosive substances can cause severe skin burns, eye damage, and respiratory problems if inhaled. They also pose risks to materials and equipment, leading to corrosion and deterioration.

5. Reactive Hazards

Definition: Reactive hazards involve chemicals that can undergo violent reactions when exposed to certain conditions, such as temperature, pressure, or other chemicals.

Examples: Hydrogen peroxide, sodium, potassium, and chlorine.

Risks: Reactive chemicals can produce harmful gases, intense heat, or explosions if improperly stored or handled, making them a critical hazard in industrial settings.

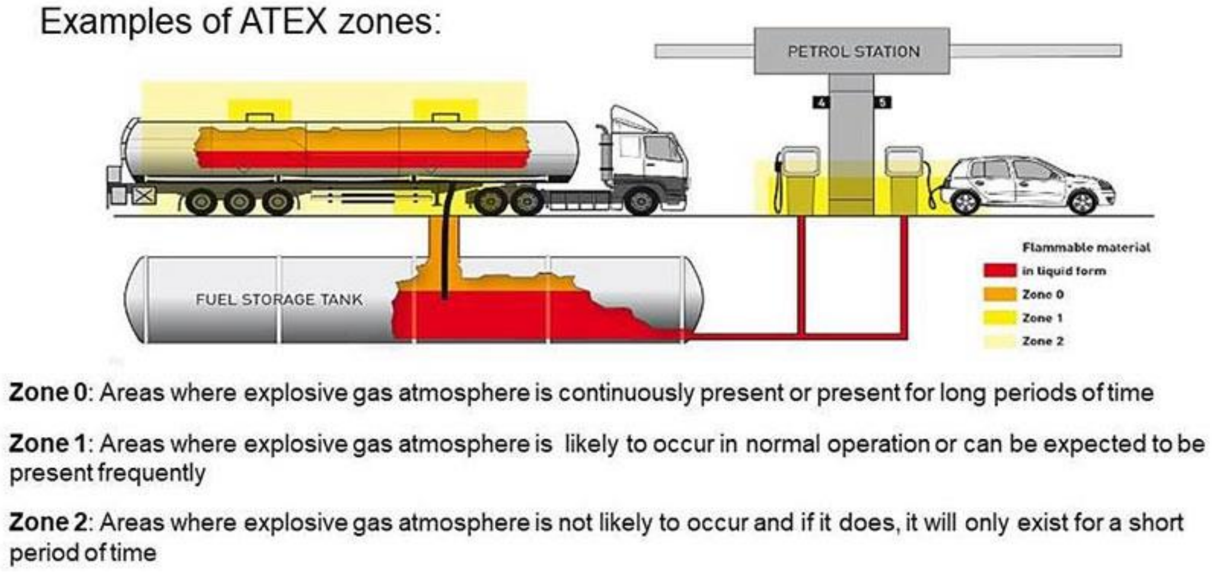
6. Carcinogenic Hazards

Definition: Carcinogenic hazards include chemicals that are known or suspected to cause cancer in humans.

Examples: Asbestos, benzene, formaldehyde, and certain pesticides.

Risks: Long-term exposure to carcinogenic substances can increase the risk of cancer, often necessitating strict regulations and protective measures for workers.

Figure 2: Explosive atmosphere zones (SenConsulting, 2020)

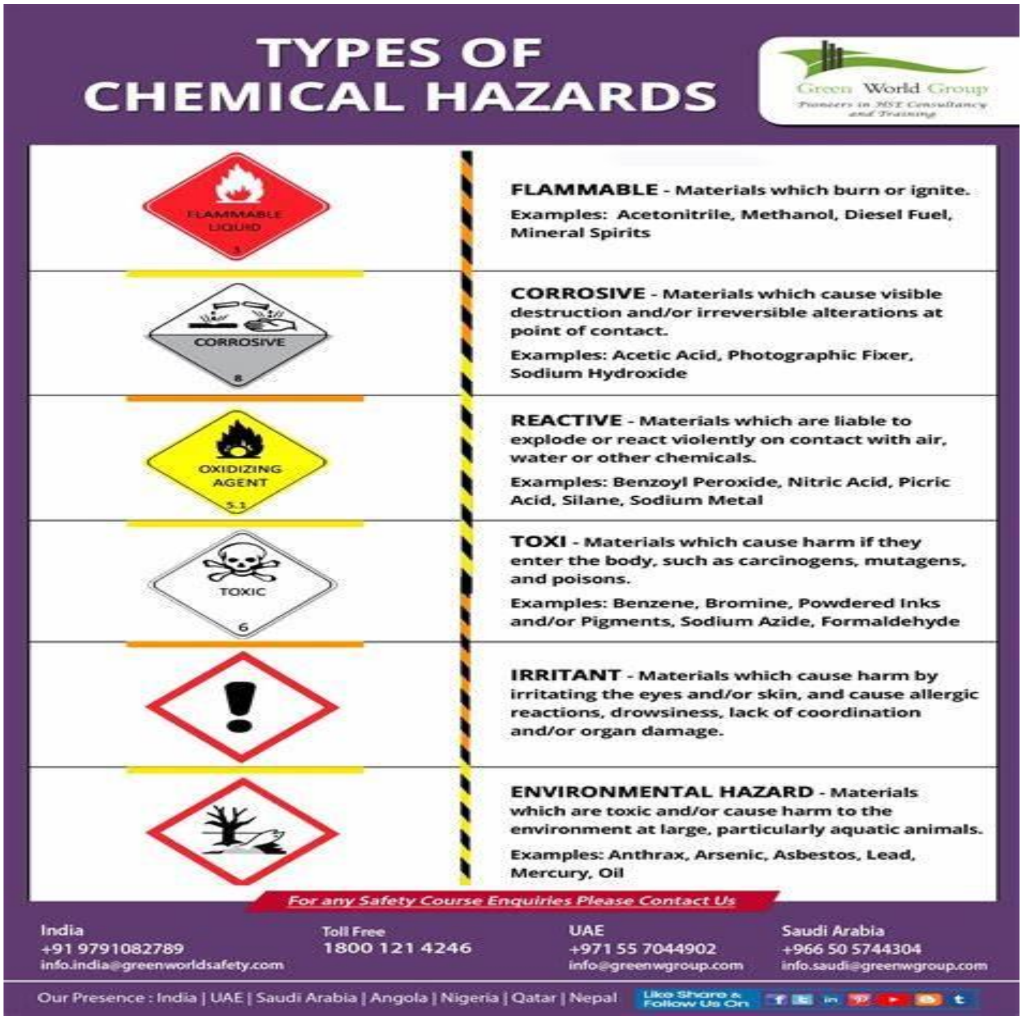


Zone 0: Areas where explosive gas atmosphere is continuously present or present for long periods of time

Zone 1: Areas where explosive gas atmosphere is likely to occur in normal operation or can be expected to be present frequently

Zone 2: Areas where explosive gas atmosphere is not likely to occur and if it does, it will only exist for a short period of time

Figure 3: Types of Chemical Hazards



TYPES OF CHEMICAL HAZARDS

FLAMMABLE - Materials which burn or ignite.
Examples: Acetonitrile, Methanol, Diesel Fuel, Mineral Spirits

CORROSIVE - Materials which cause visible destruction and/or irreversible alterations at point of contact.
Examples: Acetic Acid, Photographic Fixer, Sodium Hydroxide

REACTIVE - Materials which are liable to explode or react violently on contact with air, water or other chemicals.
Examples: Benzoyl Peroxide, Nitric Acid, Picric Acid, Silane, Sodium Metal

TOXI - Materials which cause harm if they enter the body, such as carcinogens, mutagens, and poisons.
Examples: Benzene, Bromine, Powdered Inks and/or Pigments, Sodium Azide, Formaldehyde

IRRITANT - Materials which cause harm by irritating the eyes and/or skin, and cause allergic reactions, drowsiness, lack of coordination and/or organ damage.

ENVIRONMENTAL HAZARD - Materials which are toxic and/or cause harm to the environment at large, particularly aquatic animals.
Examples: Anthrax, Arsenic, Asbestos, Lead, Mercury, Oil

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To minimize the risks associated with chemical hazards, workplaces should adopt rigorous safety practices and preventive measures. Here are some key strategies:

- Use of Personal Protective Equipment (PPE): Provide and enforce the use of appropriate PPE, such as gloves, goggles, face masks, and respirators, depending on the type of chemical hazard.
- Proper Ventilation: Ensure adequate ventilation to minimize the concentration of airborne chemicals, particularly in areas with toxic fumes or vapors.
- Chemical Storage and Labeling: Store chemicals in appropriate containers with clear labels, and follow guidelines for safe storage, especially for flammable and reactive substances.
- Regular Training: Conduct regular training sessions on chemical hazard awareness, safe handling procedures, and emergency response for employees.
- Spill and Leak Management: Develop and maintain protocols for dealing with chemical spills and leaks, including immediate containment, cleanup procedures, and disposal.

- Monitoring and Exposure Limits: Implement exposure monitoring programs, particularly for toxic and carcinogenic chemicals, and ensure compliance with established occupational exposure limits.
- Emergency Preparedness: Establish and practice emergency response procedures in case of accidents involving chemical spills, fires, or explosions (Safety education, 2024).

Figure 4: Personal Protective Equipment (Safetyculture, 2024).

NIOSH N95 respirator.

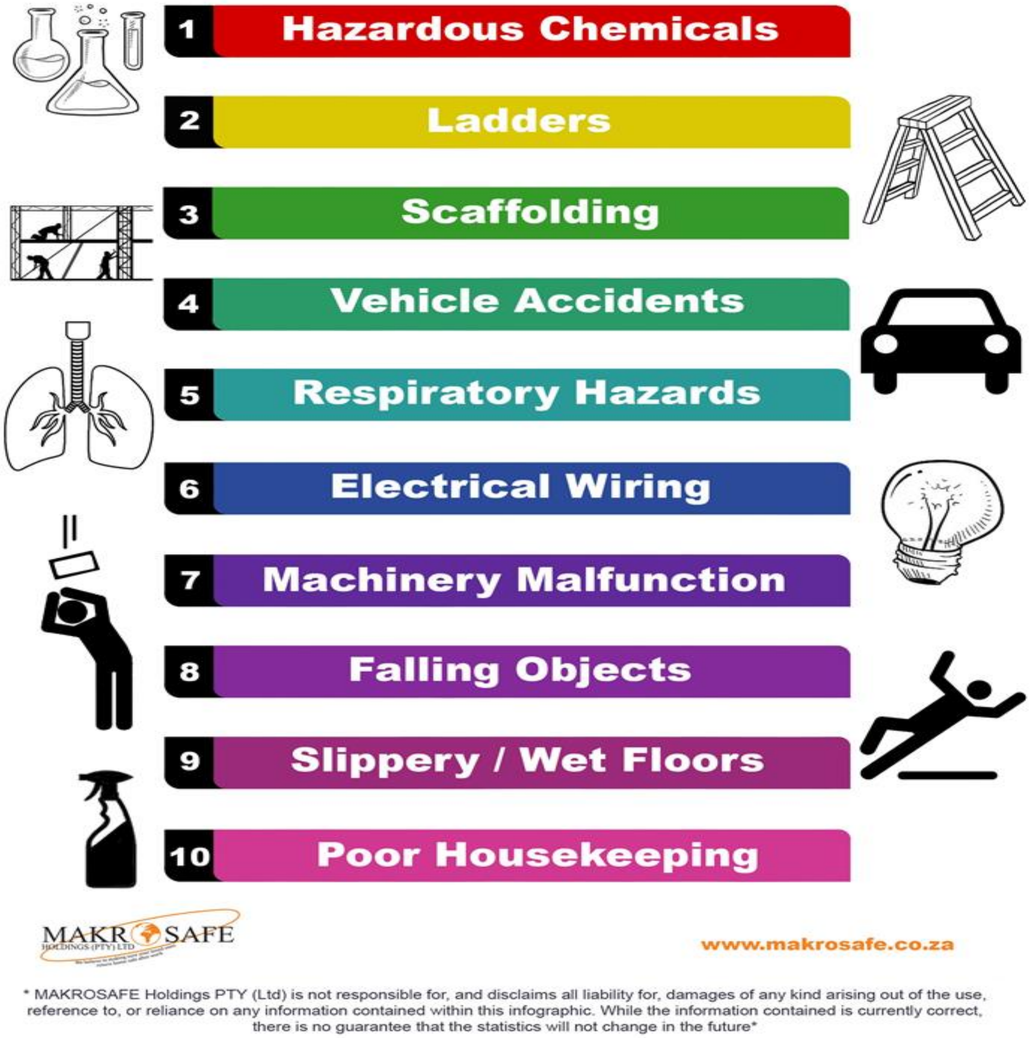
1.3.3 Fire and Explosion Hazards:

Filling stations are at risk of fire and explosion incidents due to the presence of flammable fuels and vapors. Workers need to be trained in fire safety protocols, including emergency response procedures, fire extinguisher usage, and evacuation plans. Regular inspections and maintenance of fire safety equipment, such as fire extinguishers and fire suppression systems, are necessary to minimize the potential for accidents (Fosa *et al*., 2022).

1.3.4 Psychological Factors:

Working in filling stations can also present psychological challenges for employees. High-stress levels, customer interactions, and working in potentially dangerous environments can impact mental health and job satisfaction. Promoting a positive work culture, providing stress management resources, and ensuring adequate training and support can help mitigate these psychological risks (Johnson *et al*., 2018).

Figure 5: Top 10 Most Common Hazards In The Workplace



1.4 PREVIOUS STUDIES ON OCCUPATIONAL HEALTH AND SAFETY

Hazard Identification and Risk Assessment: Several studies have focused on identifying and assessing the hazards present in filling stations. These hazards typically include chemical exposures, fire and explosion risks, physical hazards, and ergonomic challenges. The studies often employ risk assessment methods to quantify the level of risk associated with each hazard and identify control measures to mitigate those risks. Periyasamy *et al* carried out a study in 2017 on the identification and assessment of risk in filling stations in Abu Dhabi, UAE. In Slovak Republic a similar research was carried out by Mäkká *et al*. in 2021.

Chemical Exposures and Health Effects: Research has investigated the occupational health risks related to chemical exposures in filling stations. Studies have explored the presence of hazardous substances, such as benzene and volatile organic compounds (VOCs), and their impact on workers' health. Health effects examined include respiratory disorders, dermatological conditions, and the potential for long-term diseases, such as cancer. Generally, the acronym of BTEX (benzene, toluene, ethylbenzene and the isomers of xylene) highlight the naturally occurring compounds in petrol which are hazardous. The individual exposure to BTEX has been indicated by several studies such as Kuranchie *et al*. (2019) in Ghana, Johnson and Umoren in Nigeria.

Safety Practices and Compliance: Some studies have focused on assessing the compliance of filling stations with safety regulations and guidelines. These studies have examined the implementation of safety measures, such as the use of personal protective equipment (PPE), proper storage and handling of fuels, and the presence of safety signage. They have also identified gaps in compliance and areas where safety practices can be improved. Ndoh *et al.* (2021) conducted such studies in the city of Douala, Cameroon.

Ergonomics and Musculoskeletal Disorders: Occupational ergonomics has been a subject of investigation in filling points/ fuel depots (Fan *et al.,* 2024). Studies have explored the ergonomic challenges faced by workers during tasks like heavy lifting, manual handling, and repetitive movements. The focus has been on identifying risk factors for musculoskeletal disorders and proposing ergonomic interventions to improve worker well-being. A study was carried out amongst heavy load carriers in Yaoundé city by William *et al*., 2022.

Training and Education: Research has examined the effectiveness of training programs in filling points. These studies have evaluated the impact of safety training on workers' knowledge, attitudes, and behavior towards occupational health and safety. They have also assessed the long-term retention of training content and identified areas for improvement in training delivery (Robson *et al.,* 2012)

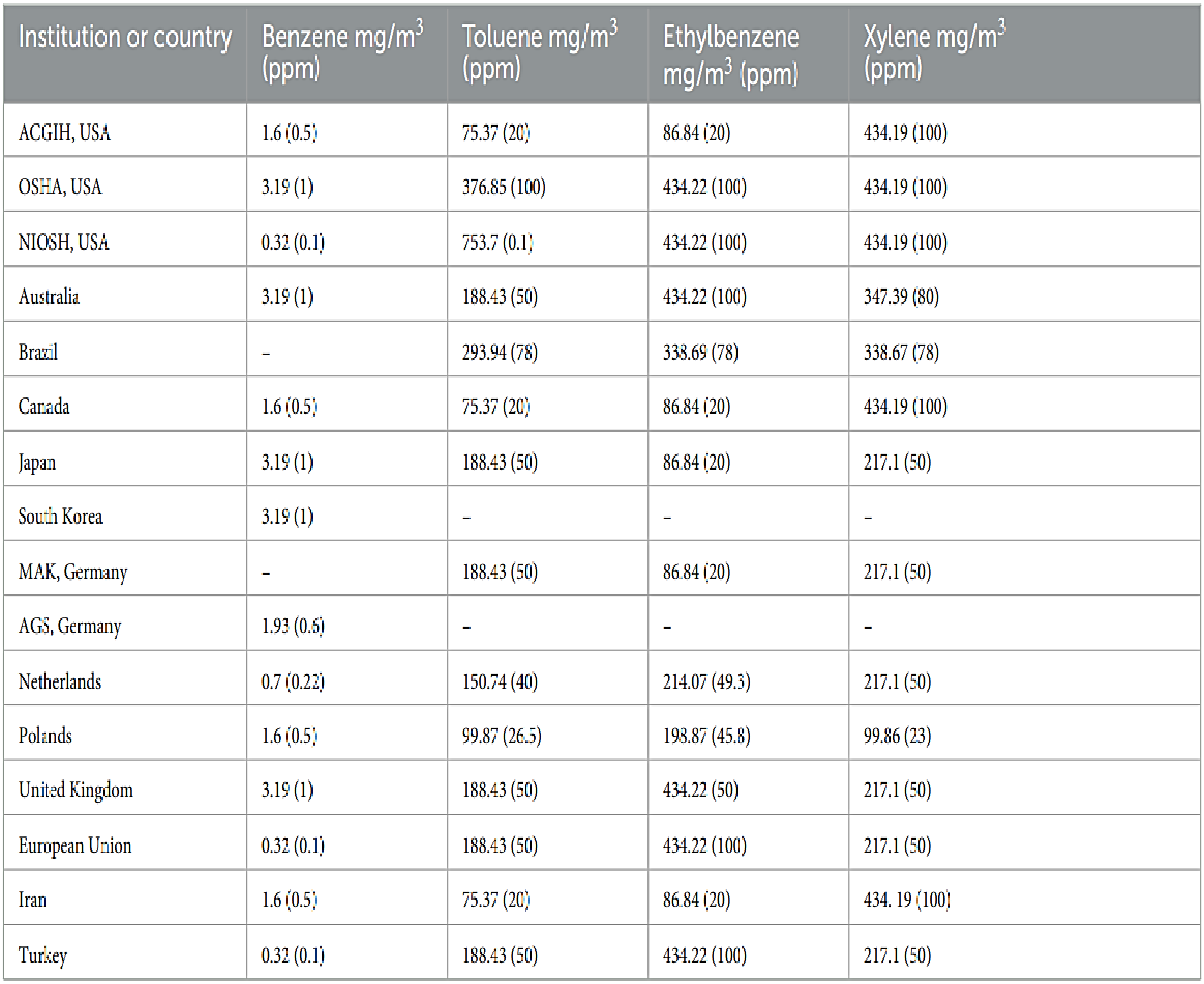
Occupational Stress and Psychosocial Factors: Some studies have examined the psychosocial aspects of work in filling stations, including occupational stress, job satisfaction, and work-related psychological disorders. These studies have explored the sources of stress, such as customer interactions, time pressures, and demanding work environments, and their effects on workers' mental health and job performance (Qafisheh *et al.,* 2021).

1.5 BTEX STANDARDS AND REGULATIONS

Monitoring of these compounds has been legislated in many countries and air quality standards have been established (Alyami, 2016). Most countries now have occupational exposure limits (OEL) for BTEX at the workplace. In the United States, 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). TLV-Time Weighted Average (TLV-TWA), TLV-Short Term Exposure Limit (TLV-STEL) and TLV-Ceiling (TLV-C) are in common use in North America and Europe. In the European Union, the ambient air quality standard for benzene is 5-μg/m^3 annual-based time-weighted average (Badjagbo *et al*., 2010).

In occupational settings, the ACGIH recommends threshold limit values (TLVs)-TWA of 0.5 ppm. (1.6 mg/m^3) for benzene, 20 ppm. (75 mg/m^3) for toluene, and 100 ppm. (434 mg/m^3) for ethylbenzene and xylenes, respectively. The current 8-h TWA regulatory values for the workplace in the Province of Quebec, Canada, are 1 ppm. (3 mg/m^3) for benzene, 50 ppm. (188 mg/m^3) for toluene, and 100 ppm. (434 mg/m^3) for ethylbenzene and xylenes (Badjagbo *et al*., _2010). According to OSHA (OSHA, 2002; Rosenthal *et al*., 1992), PEL for short-term exposure (STEL) to benzene is 5 ppm (16 mg/m3) for any 15-min period whilst the 8-h TLV-TWA is pegged at 1ppm. The National Institute of Occupational Safety and Health (NIOSH) has even lower exposure limit of just 1ppm over a 15-min period (STEL) and 0.1ppm over 8 h (TWA) (Rosenthal *et al*., 1992). The Action Level (AL) for benzene, which indicates concentration that requires medical surveillance, increased industrial hygiene monitoring, or biological monitoring, is just 0.5ppm as an 8-h time-weighted average. The Recommended Exposure Limit (REL) for the National Institute for Occupational Safety and Health (NIOSH) is 0.1ppm TWA, and 1ppm STEL. The severity of health effects depends on the duration, dose and frequency of exposure, as well as the general health of the individual. In 2014, WHO identified benzene as a major health concern in Africa, especially in occupational environments (Marc Guéniat *et al.,* 2016). Correa and co-workers (Correa *et al.,* 2012) reported that BTEX concentrations were appreciably higher in filling stations than what is found in locations with high vehicular flux. In north Africa, Kerchich and Kerbachi found higher than normal ambient air levels of BTEX compounds in the city of Algiers (Kerchich & Kerbachi, 2012). Correa and colleagues reported that BTEX exposure directly increases with increasing temperature due to stronger fuel evaporation, which is the situation in most African nations (Correa *et al*., 2012). An effective way to control exposure to BTEX compounds is through regulating their limits in consumer products (Guéniat *et al*., 2016). In Europe and the USA, benzene in gasoline is restricted to 1%. In many African countries, limits do not exist, and where they do, they can be as high as 5% (Guéniat *et al.,* 2016).

Table 1: Occupational limits of benzene, toluene, ethylbenzene and xylene of some professional institutions and countries (Rahimpoor *et al*., 2022)



Institution or country	Benzene mg/m^3 (ppm)	Toluene mg/m^3 (ppm)	Ethylbenzene mg/m^3 (ppm)	Xylene mg/m^3 (ppm)
ACGIH, USA	1.6 (0.5)	75.37 (20)	86.84 (20)	434.19 (100)
OSHA, USA	3.19 (1)	376.85 (100)	434.22 (100)	434.19 (100)
NIOSH, USA	0.32 (0.1)	753.7 (0.1)	434.22 (100)	434.19 (100)
Australia	3.19 (1)	188.43 (50)	434.22 (100)	347.39 (80)
Brazil	–	293.94 (78)	338.69 (78)	338.67 (78)
Canada	1.6 (0.5)	75.37 (20)	86.84 (20)	434.19 (100)
Japan	3.19 (1)	188.43 (50)	86.84 (20)	217.1 (50)
South Korea	3.19 (1)	–	–	–
MAK, Germany	–	188.43 (50)	86.84 (20)	217.1 (50)
AGS, Germany	1.93 (0.6)	–	–	–
Netherlands	0.7 (0.22)	150.74 (40)	214.07 (49.3)	217.1 (50)
Polands	1.6 (0.5)	99.87 (26.5)	198.87 (45.8)	99.86 (23)
United Kingdom	3.19 (1)	188.43 (50)	434.22 (50)	217.1 (50)
European Union	0.32 (0.1)	188.43 (50)	434.22 (100)	217.1 (50)
Iran	1.6 (0.5)	75.37 (20)	86.84 (20)	434. 19 (100)
Turkey	0.32 (0.1)	188.43 (50)	434.22 (100)	217.1 (50)

ACGIH, American Conference of Governmental Industrial Hygienists; AGS, German Committee on Hazardous Substances (Ausschuss für Gefahrstoffe); MAK, German maximum workplace concentrations; NIOSH, National Institute for Occupational Safety and Health; OSHA, Occupational Safety and Health Administration; ppm, part per million.

1.6 OSH REGULATIONS IN CAMEROON

Regulatory frameworks and OSH regulations in Yaounde, Cameroon, play a critical role in ensuring the protection and well-being of workers in filling stations and fuel depots. Occupational health and safety compliance in Cameroon instruct employers whose activities are of a nature to affect the safety and health of employees to insure their workers. This obligation is done in strict adherence to workplace compliance, the health and safety for industries legislation in Cameroon (Kima et al., 2019), this legislation classify filling stations and fuel depots into category C implying that they are high risk companies. According to the International Labor Organization Cameroon 2014, Safety and health at work is essentially governed by Title VI of the Labor Code entitled "Safety and Health at Work". The main OSH regulation besides Title VI of the Labor Code is the " decree n°039 /MTPS/IMT of November 26, 1984, laying down general health and safety measures in the workplace " which contains: the regulations of the respective obligations of employers and workers, the composition of the hygiene and safety committees, the setting of general conditions of hygiene relating to, amongst other things, construction, ventilation, temperature and lighting, the determination of safety measures and transportation, the definition of hazardous substances and rules of prevention and firefighting, the establishment of the means of control and sanctions.

Under the Labour Code, decisions and decrees are taken concerning health and safety at work:

- Decree no. 93/210/PM of March 3, 1993 establishing the organization and operation of the National Occupational Health and Safety Commission;
- Order no. 038/MTPS/IMT of November 26, 1984 supplementing the list of compensable occupational illnesses, the periods during which the insurer or employer remains liable, and the conditions for declaring work processes likely to cause them, set by Order no. 005/TLS/SS of March 9, 1962;
- Law no. 77-11 of July 27, 1977 on compensation and prevention of occupational accidents and diseases;
- " Order of 15 October 1979 on the organization and operation of occupational medical services".
- Decree no. 79-96 of March 21, 1979 setting out the procedures for the practice of occupational medicine.

The health and safety compliance in Cameroon legislation has imposed on employers to provide individual and collective protective material to workers. According to the nature of work, appropriate working tools shall include the following; Respiratory mask, where the industry disposes impurities such as vapors, dust and gases. Googles against solid, liquid or gaseous projectiles that can wound the workers (Kima *et al*., 2019).

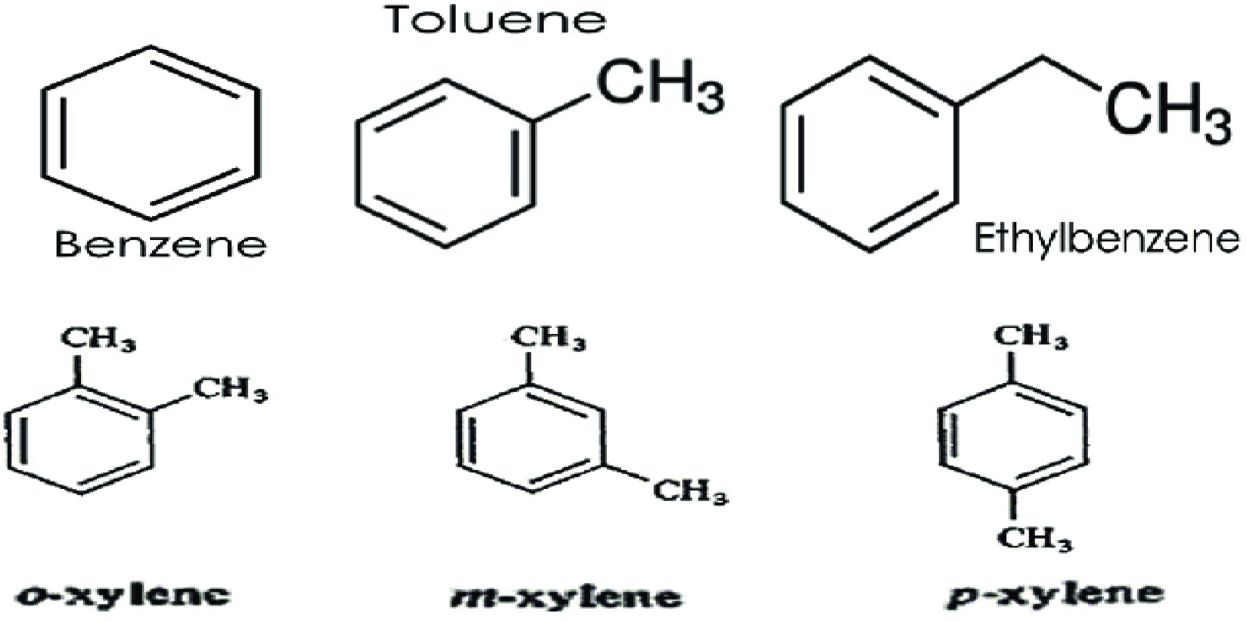
1.7 VOLATILE ORGANIC COMPOUNDS

1.7.1 An overview of BTEX compounds

BTEX compounds are a group of volatile organic compounds (VOCs) that include benzene, toluene, ethylbenzene, and xylenes (Aeroqual, 2016). These compounds are commonly found in gasoline and other petroleum products and can be released into the environment through activities such as fuel combustion, spills and leaks. Each compound possesses distinct chemical properties and poses different health risks. The structural characteristics of these compounds are illustrated below:

- Benzene: C6H6, is a clear colorless flammable liquid with a sweet petrol-like smell.it is found in ambient air as a result of burning fuels, such as coal, petrol or wood. Benzene concentration in fuel were once as high as 20% but are now reduced to <1% in many countries, due to harmful health impacts (Aeroqual, 2016; Pope & Rall, 1995)). it is a known human carcinogen and exposure to high levels can cause leukemia and impacts red and white blood cells. The world health organization (WHO) and the international agency for research on cancer (IARC) classify benzene as a group one carcinogen (IARC, 2012). WHO states that there is no safe level of exposure, hence no standard concentration in ambient air (WHO 2010). Many countries use an average standard of 3.6microgramper meters cube. Benzene is used in the production of various chemicals and is a component of gasoline.
- Toluene: C7H8, also known as methylbenzene is a colorless water-insoluble liquid with a distinctive smell.it is commonly used as a solvent in paints, coatings, adhesives, and other products. toluene is found in petrol as an octane booster and exposure can cause neurological effects and respiratory irritation with prolonged exposure (Aeroqual, 2016).
- Ethylbenzene: C8H10, is a colorless liquid with a gasoline-like odor. It is used in the production of styrene, which is used to make plastics, resins, and synthetic rubber. Ethylbenzene exposure can cause respiratory irritation and central nervous system effects. it is a suspected carcinogen (Aeroqual, 2016).

Figure 6: Structural representation of BTEX compounds (Fayemiwo et al., 2017)



1.7.2 BTEX Sources in filling stations/fuel depots and health impact

Volatile organic compounds (VOCs) ranges from carbon six to carbon ten compounds (C6 -C10), have strong relationship with meteorological parameters and decreasing contributions of VOCs cause increase in turbulence (Xiang *et al*., 2012). VOCs are released from underground tanks, refueling of cars, loading of transport vessels at refineries and storage companies (Hassan *et al*., 2010). Each compound has different behavior to environmental conditions (temperature). VOCs concentration is mostly high in spring to summer (Baudic *et al*., 2016). Major pollutants in urban air pollution are VOCs, oxides of nitrogen, oxides of Sulphur and particulate matter and cause severe threats to human health and atmospheric environment. Method for their control depends on their emission sources and nature (Jeek *et al*., 2017). Xylene and benzene are most abundant. Benzene above international occupational exposure limits with respect to other and occupational air quality at the refueling bay is a health matter (Moolla *et al*., 2015). VOCs concentration increases with increase in temperature especially toluene shows great increase i.e., the temperature increased from 25 °C to 50 °C at 50% of humidity and the concentration of toluene is increased by 1.07-fold (Yang *et al*., 2017). Risks of cancer increases in electrochemical workers. This shows the importance of use of abatement technologies for reduction of VOCs levels and to mitigate their impact in the health of workers (Lerner *et al*., 2012). Filling workers at petrol stations are also affected due to evaporative losses during filling. Benzene (air borne organic compound) have been recorded near petrol stations above the average level for urban areas (Correa *et al*., 2012). Based on temperature and wind, concentrations of VOCs may increase or decrease with time. Flow of the wind accelerates the dispersion of the vapor and decreases the concentration around the pumps (Kountouriotis *et al*., 2014). VOCs are neurotoxin, cause neuronal death and decrease the cell viability (Fournier *et al., 2017).* VOCs are not only produced at filling stations during filling petrol but it can also be produced in friction processes like braking in automobiles (Placha *et al*., 2017). The health risk assessment in Vastra Gotaland region studies relates preterm deaths and asthma due to volatile organic compounds emission (Fridell *et al*., 2014). There is a strong relationship between direct exposure to VOCs and cardiovascular physiology. VOCs effect cardiovascular system of human rapidly (Shin *et al*., 2015).

Table 2: The acute and chronic effects of BTEX in human (Emmanuel *et al.,* 2024)

CHEMICAL	ROUTES OF EXPOSURE	ACUTE	CHRONIC	IARC CARCINOGENICITY CLASS
Benzene	Inhalation, ingestion, skin, and eye contact. Exposure is mainly by inhalation.	Symptoms include drowsiness, dizziness, headaches, skin irritation, respiratory tract, and, at high levels, unconsciousness.	Reduced red blood cells and aplastic anemia in occupational settings. High levels of exposure to inhalation can affect reproductive function in women.	Carcinogenic to humans, Group 1: Acute myeloid leukemia and acute non-lymphocytic leukemia are caused by it. All routes of exposure are carcinogenic.
Toluene	Despite its potential for skin absorption, toluene is primarily absorbed through inhalation and ingestion.	It mainly affects the central nervous system (CNS) in humans. CNS dysfunction and narcosis, including fatigue, sleepiness, headaches, and nausea	High level exposures cause CNS depression. Others are irritation of the upper respiratory tract and eyes, sore throat, dizziness, and headache. Newborns of pregnant women exposed to high inhalation levels can have problems with attention and mild abnormalities of the head, face, and limbs.	Group 3: Not classifiable as to its carcinogenicity to human
Ethylbenzene	Inhalation, ingestion, skin, and eye contact. Exposure is mainly by inhalation.	Low acute toxicity to humans. Irritation of the eyes and throat, chest tightness, dizziness, and vertigo.	An increase in the mean number of lymphocytes and a decrease in hemoglobin levels	Group 2B: Possibly carcinogenic to humans
xylene	Inhalation, ingestion, skin, and eye contact. Exposure is mainly by inhalation.	Irritation of the eyes, nose, and throat, vomiting and diarrhea, and neurological effect	CNS symptoms include headache, dizziness, fatigue, tremors, and in-coordination. Also affect the respiratory, cardiovascular, and renal systems	Group 3: Not classifiable as to its carcinogenicity to humans

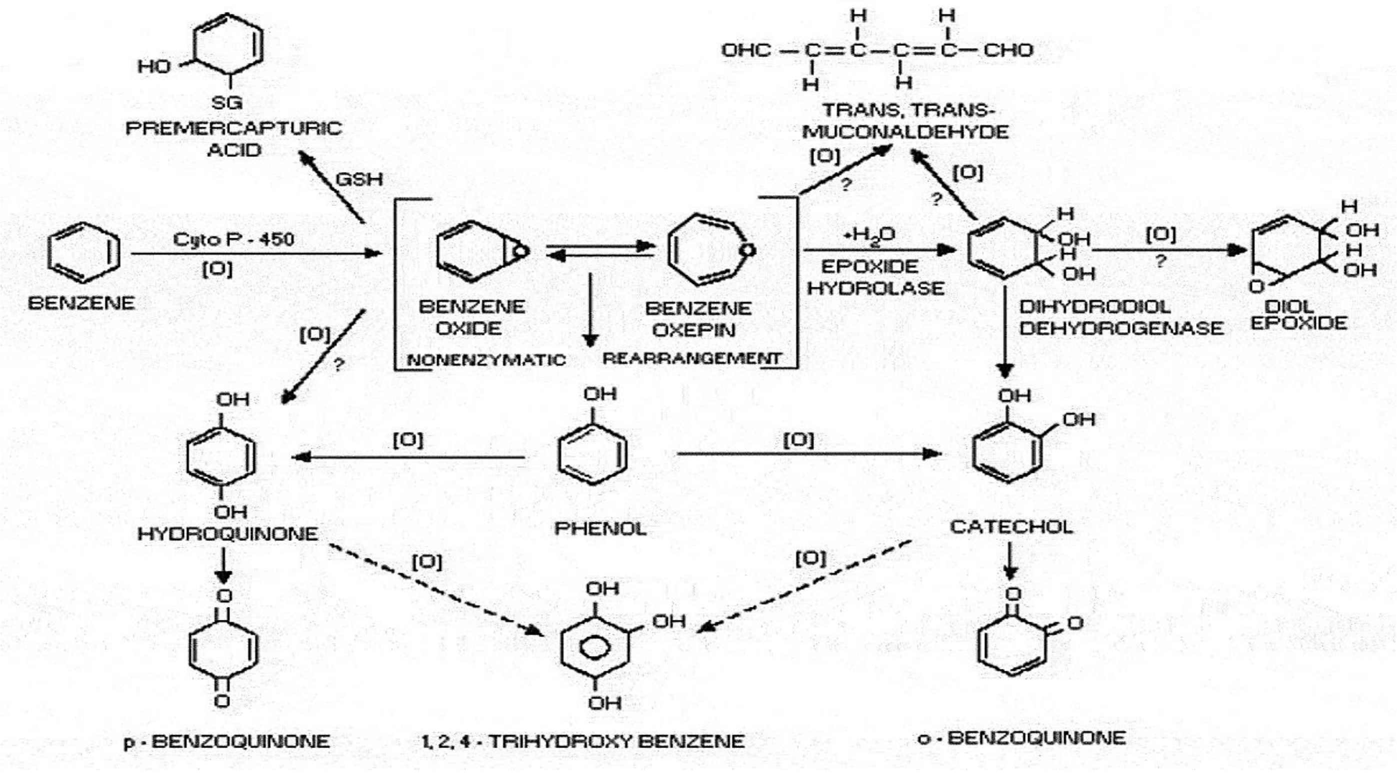
1.7.3 Contamination routes and metabolism

1.7.3.1 Benzene

Benzene is absorbed through inhalation, ingestion and/or dermal absorption and then converted to toxic metabolites by mixed-function oxidases (MFO) in the liver and bone marrow (Philip *et al.,* 2006; Pope & Rall, 1995). The metabolites may bind covalently to cellular macromolecules, causing disruption of cell growth and replication. The various pathways and metabolites are presented below in Figure 8. Alcohol may increase the rate at which toxic metabolites of benzene are formed (Pope & Rall, 1995).

Benzene has been implicated in both acute and chronic poisoning with varying latency periods (Verma & Des Tombe, 2002). It is regarded as the most hazardous compound of the BTEX group and targets the CNS and haematopoietic systems (Pope & Rall, 1995). IARC and USEPA have independently classified benzene as a Group A and Class 1 human carcinogen, respectively, based on sufficient evidence of carcinogenicity from human studies (Edokpolo *et a*l., 2014, 2015b). Acute myeloid leukaemia (Chinwenwa, 2012) in individuals exposed to benzene above action levels (Ntp, 2009). Non-cancerous toxicity of reproductive, immune, nervous, endocrine, cardiovascular and respiratory systems has also been reported in some studies (Bahadar *et al*., 2014; Moro *et al*., 2017, 2015). Myalgia has been reported as a symptom of exposure to benzene vapors. Benzene may also affect the renal system (Collins, 2000), as kidney congestion has been found following fatal inhalational exposure. Benzene appears to affect the immune system, where workers have been shown to have decreased levels of leukocytes and circulating antibodies (OSHA, 2002).

Figure 7: Urinary metabolites of Benzene (INCHEM, 1993).



Exposure to benzene may play a role in infertility in men, as workers have increased incidence of chromosomally defective sperm, which can lead to spontaneous abortions, mental retardation, and inherited defects in their children. An association may exist between mothers exposed to benzene and children with spina bifida (ATSDR, 2007).

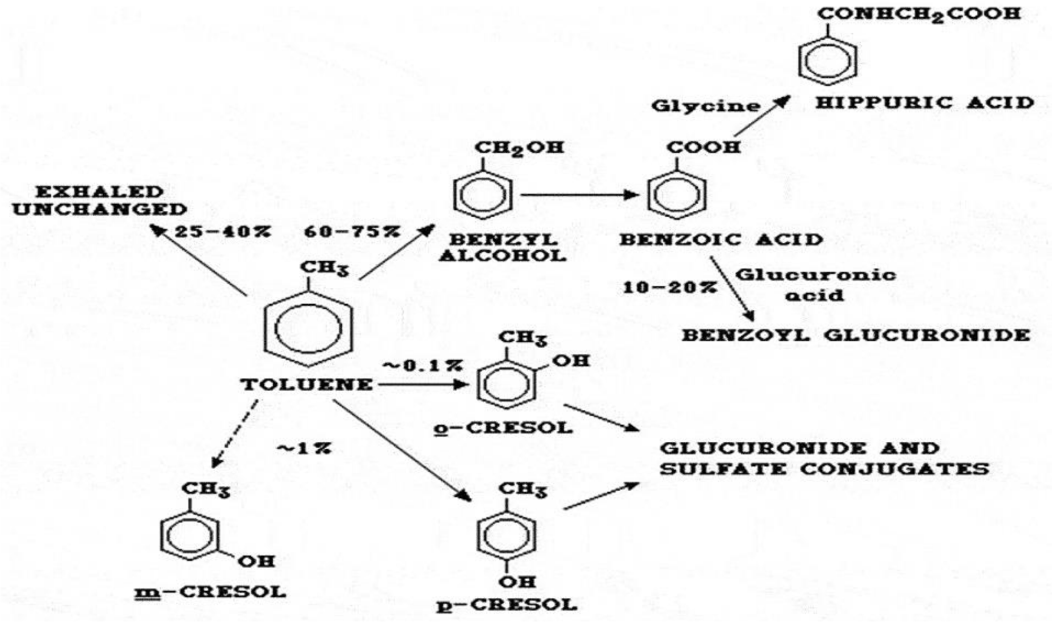
Benzene exposure can be as high as 349 µg/m3 in industrial centers with heavy traffic, and 10 µg/m3 at fuel pump stations. OSHA determined a Permissible Exposure Limit (PEL) of 3mg/l (1ppm) using toxicity studies (Lv *et al.,* 2014). Major routes of exposure are oral and inhalation with a higher rate of retention in women than men and in tissues with high lipid content or placental materials (INCHEM,1993).

1.7.3.2 Toluene

The principal source of exposure to toluene in the general population is gasoline (Pope & Rall, 1995). Toluene is a toxic skin/eye irritant and a CNS depressant. OSHA reports mental confusion, loss of coordination, and unconsciousness above the STEL threshold (OSHA,1998). Exposures above 200 ppm for 8 h causes fatigue, weakness, confusion, headache, dizziness and insomnia (ATSDR, 2015)

Toluene is converted to benzoic acid in the body, which is then conjugated with glycine in the liver to form hippuric acid. The hippuric acid is then excreted in urine. (ATSDR, 2004; INCHEM,1985).

Figure 8: Metabolism of Toluene in Human beings and animals (INCHEM,1985).

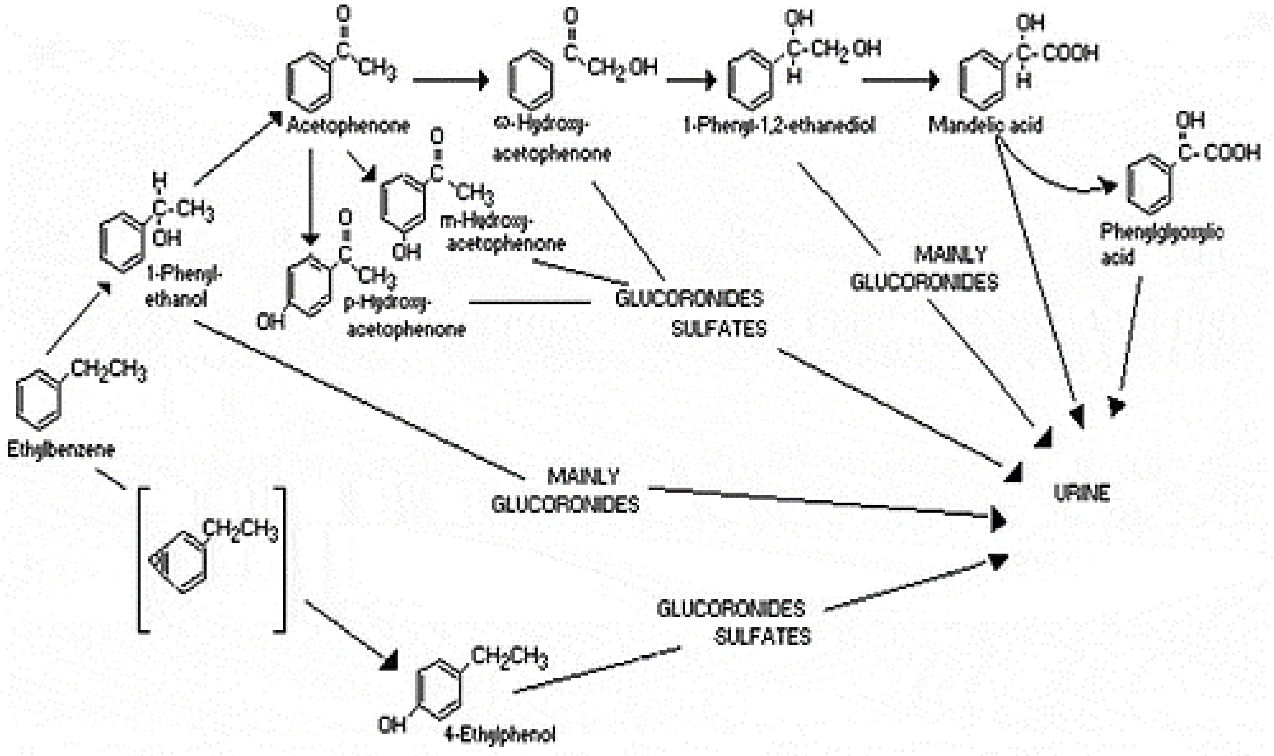


1.7.3.3 Ethylbenzene

Ethylbenzene is a flammable liquid that is totally soluble in organic solvents. Ethylbenzene is almost exclusively as a precursor for the manufacture of styrene and commercial xylenes (INCHEM, 1996; Phoslab, 2016).

It is well absorbed by the skin, lungs and gastrointestinal tract, and metabolized by hydroxylation of the two carbons of the side-chain (ATSDR, 2007b), followed by oxidation to mandelic acid, phenyl glyoxylic acid and a range of minor metabolites that are excreted principally in the urine (INCHEM, 1996)._It occurs naturally in crude oil but exposure can originate from anthropogenic refined products and the incomplete combustion of natural materials including forest fires and cigar smoke (INCHEM, 1996). Ethylbenzene is a skin and mucous membrane irritant. It has acute and chronic central nervous system effects that include vertigo, unconsciousness, tremors, and changes in respiration (OSHA, 1999). IARC has determined that long-term exposure to ethylbenzene may cause cancer in humans (ATSDR, 2007b). Ethylbenzene is mainly excreted in the urine as glucuronides.

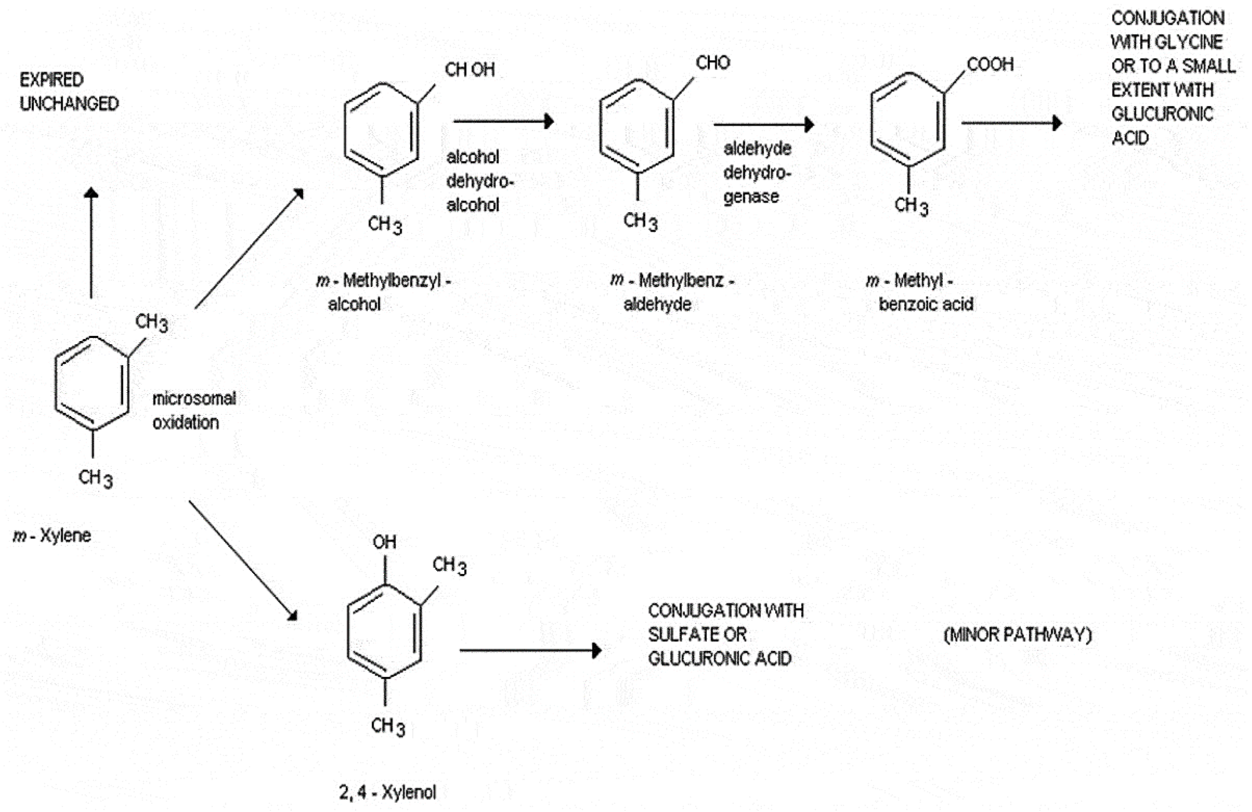
Figure 9: Metabolic pathways of Ethylbenzene (INCHEM, 1996).



1.7.3.4 Xylenes

Xylene isomers of *m, o*, and *p* differ only in the placement of the two methyl groups on the benzene ring. Xylenes are soluble in alcohol and ether but insoluble in water. They each have clear, colorless organoleptic properties at room temperature, however, *p*-xylene forms crystals at a relatively high temperature (Philip et al., 2006). Most mixed xylenes are used as additives in gasoline blends and as the raw material in the coating industry (OSHA, 1999). Xylenes are eye, skin, and mucous membrane irritants and can cause respiratory, gastrointestinal, musculoskeletal, and nervous problems (Phoslab, 2016). Xylenes can also cause liver and kidney damage. Long-term risk of carcinogenicity has not been reported in experimental animals (OSHA, 1999). The ACGIH TLV-TWA was set at 100 ppm, and the STEL at 150 ppm, for mixed xylene isomers and for individual isomers. The main metabolites of the xylenes are the corresponding isomers of toluic acid (m-methyl benzoic acid) which is then conjugated with glucuronic acid and excreted in urine.

Figure 10: Biotransformation of m-xylene (INCHEM, 1997).



1.7.4 Methods of BTEX testing

There are several methods of testing for BTEX compounds, including gas chromatography (GC) or photo-ionization detector. Samples can come from air, water, or soil **(**Aeroqual, 2016).

1.7.4.1 Sample pretreatment methods

Sample pretreatment is an essential step prior to qualitative and quantitative analysis, directly influencing the method’s accuracy, precision, reproducibility and limit of detection (LOD). Proper sample pretreatment methods remove potential interferences that could mask trace objects or enrich target analytes from complex matrices to obtain the compounds of interest and adapt to the needs of detection methods.

1.7.4.1.1 Passive sampling methods and headspace methods

Sample pretreatment methods can take different forms depending on the nature of the matrix. In gaseous samples, such as atmospheric air, diffusive sampling is commonly used to collect BTEX. The low cost, easy operability, and high spatial resolution make diffusive sampling ideal for air pollution monitoring. P. Baltrenas *et al*., 2011 and Scheepers *et al*., 2010 determined children’s exposure to BTX by personal air sampling using diffusive samplers and analysis of end-exhaled air. This study did not require complicated pretreatment, and the sampling process was pollution-free. Because it does not require electricity, passive sampling provides a convenient way to sample BTEX in air, increasing the acceptance of research participants. The advantages of passive sampling are that it's cheap and straightforward, but data resolution is limited. Common methods are 3M badges or sorbent tubes. The U.S. EPA uses standard methodology for these techniques, published as Compendium Method TO-17 (McGlenny, W. A.*et al*., 1991).

In liquid samples, such as water, headspace (HS) extraction is commonly employed in BTEX extraction. Fakhari *et al*., 2012 developed a simple and rapid HS extraction method for the pretreatment of BTEX compounds in wastewater and water samples. In addition, HS extraction has been used for the pretreatment of solid samples. Zhou *et al*., 2013 applied HS sampling for field analysis of BTEX in soils. However, there are some challenges in using HS to analyze VOCs in soil, as this method relies on a balanced distribution of the target components in the sample and the gas phase.

1.7.4.1.2 SPE-based approaches

1.7.4.1.2.1 Solid-phase extraction (SPE):

It is a common technique in the pretreatment of environmental samples. It has the advantage of effective preconcentration, low intrinsic costs, and high recovery. In addition, the emergence of microtechnology, alternative sorbents, and new ideas have led to developments in SPE. Typically, the SPE procedure consists of pretreatment of adsorbent in cartridges where the analyte is retained as the samples flow through it. After that, an appropriate solvent is used to elute and recover the analyte for further determination. Based on this, Zhang *et al*., 2010 developed a novel method, using SPE and thermal desorption (TD) technology for the extraction of BTEX in a solid–liquid mixing matrix. The intermolecular forces between the adsorbent and solvents are weaker due to nitrogen flow at room temperature. Therefore, by increasing the temperature, the retained BTEX was desorbed from the adsorbent. The SPE-TD technique had better separation quality than traditional direct injection (DI). The sample pretreatment process of the conventional SPE method is complicated, time-consuming, and requires many organic reagents, which is not conducive to real-time on-site detection (Mujahid *et al*., 2016). Therefore, a rapid and solvent-free SPE device with polydimethylsiloxane (PDMS)/divinylbenzene (DVB) sorbent coating on the inner wall of a sample bottle was developed by Liu *et al*., 2016 for real-time on-site detection of BTEX in water samples.

1.7.4.1.2.2 Solid-phase micro extraction

Solid-phase micro extraction (SPME) is a solvent-free extraction technique, which was developed based on SPE. SPME integrates sampling, extraction, concentration, and injection into one step and avoids blocking filler pores shortcomings. The volatility of the sample increases the extraction efficiency of SPME. Fiber coating is one of the most important factors affecting the performance of SPME methods. In general, commercial carboxen (CAR)/ PDMS, DVB/PDMS, and DVB/CAR/PDMS were the three most common SPME fiber coatings. Crom *et al*., 2010 employed an SPME method with CAR/PDMS fiber coatings to analyze BTEX in water samples. Experimental parameters, including sampling time (60 min), adsorption temperature (50 ◦C), and HS/sample volume ratio (1:5 ratio), were optimized to determine the most appropriate sampling conditions. Hosseinzadeh *et al*., 2011 used ion pair of cationic surfactants (cetyltrimethylammonium bromide and tungestosilicic acid) incorporated in a PVC matrix as a highly sensitive SPME fiber for the extraction of BTEX in water. Sarafraz-Yazdi *et al*., 2014 developed new polypyrrole-carbon nanotubes-silicon dioxide (PPyCNT-SiO2) SPME fiber for the preconcentration of BTEX in a water matrix.

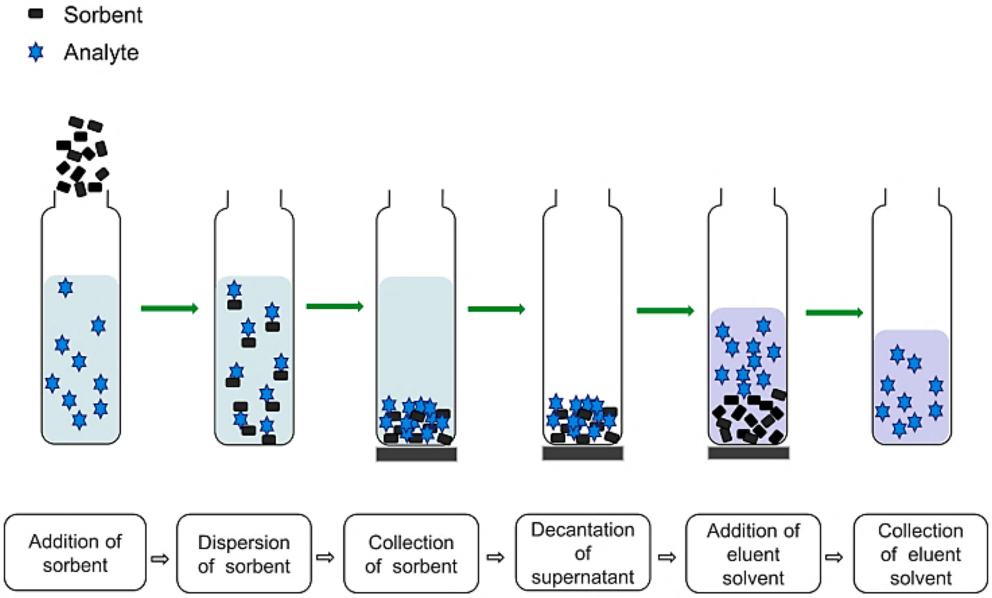
Standard approaches currently used for quantification of BTEX (Baimatova *et al*., 2015; M.I. Khoder, 2007) are primarily based on trapping analytes onto sorbent tubes followed by thermal desorption, cryogenic focusing and analysis by gas chromatography (GC). Despite good reliability, these techniques are quite complex, labor and time intensive, and require additional (often expensive) sampling and sample preparation equipment. This significantly limits the capabilities for air monitoring in many developing countries having serious air quality problems.

Compared to standard methods, solid-phase micro extraction (SPME) (H. Guo *et al*. 2007; C.Y. Moreira dos Santos *et al*., 2004) constitutes an attractive alternative technique for screening and quantification of VOCs in air. SPME is based on passive extraction of VOCs by a thin polymer coating followed by their desorption in a GC injection port. Use of SPME does not require a canister interface or a thermal desorption unit, which are needed for standard methods. Desorption of VOCs from SPME is rapid; it does not require cryogenic focusing and can be automated.

1.7.4.1.2.3 Dispersive micro-solid-phase extraction

Dispersive micro-SPE (D-µ-SPE) is a miniaturized extraction method. It is simple to operate, does not consume solvent, and has a short analytical time. D-µ-SPE can directly trap the target compounds using micro- or nano-sorbents. After sonication, the targets in the solid sorbent are isolated from liquid samples via filtration or by use of an external magnetic field (Frink *et al*., 2014).

Figure 11: Dispersive micro-solid-phase extraction procedure (Frink et al., 2014).



1.7.4.1.2.4 Micro-solid-phase extraction

The SPME technology is simple, fast, and environmentally friendly. However, it has some disadvantages, such as the fibers being easily degraded with multiple uses. Moreover, the carryover phenomenon may occur between extractions. To overcome these disadvantages, Fernandez *et al.*, 2016 used a new micro-solid-phase extraction (μ-SPE) technology for the extraction of BTEX from aqueous solutions. Naing *et al.*,2016 applied a sealed polypropylene envelope housing the microspheres as the μ-SPE device to evaluate BTEX extraction efficiency. Under optimized conditions, this method achieved a satisfactory RSD (between 2 and 3%), with relative recoveries ranging between 59 and 97%.

1.7.4.1.3 Liquid-phase micro extraction

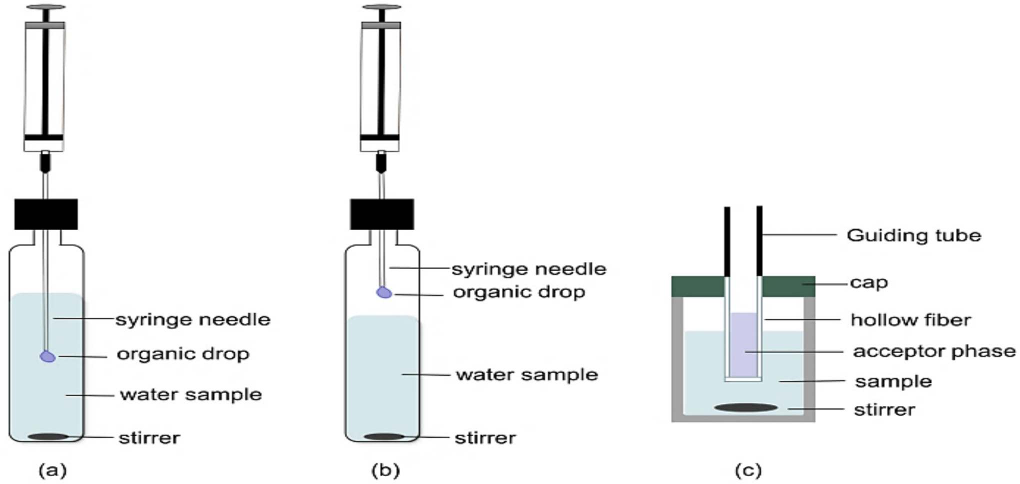
In general, liquid–liquid extraction (LLE) is a simple universal method widely applied in sample pretreatment of aqueous matrices. However, conventional LLE is associated with some disadvantages: it requires a large volume of organic solvents, easy to form an emulsion, time-consuming and labor-intensive. To overcome these disadvantages, miniaturized sample pretreatment technology was developed based on LLE. LPME, a miniaturized format of LLE, is a fast, economic and environmentally friendly sample preparation technology. As a solvent minimized extraction method, LPME combines extraction, concentration, and sample introduction into one step. It can achieve high enrichment without solvent evaporation and reconstitution. In recent years, LPME has become a promising alternative to traditional sample preparation methods. The LPME was classified into several operational modes, like single drop microextraction (SDME), hollow fiber liquid phase micro extraction (HF-LPME), and dispersive liquid–liquid micro extraction (DLLME) (Sarafraz-Yazdi *et al*., 2010).

1.7.4.1.3.1 Single-drop micro extraction

SDME is a straight-forward extraction method. The extraction phase consists of a drop of water-immiscible solvent, suspended in the stirred aqueous solution. SDME is very popular in the extraction and determination of VOCs. The micro extraction method may be directly immerged into sample solution, named DI-SDME (Fig.13a), or suspended sample solution on the headspace, named HS-SDME (Fig. 13b). HS-SDME is a faster and cleaner method, with higher efficiency for VOCs compared with DI-SDME. Sarafraz-Yazdi *et al.,* 2014 did a comparative study of DI-SDME and HS-SDME techniques for BTEX determination in a water matrix. The HS-SDME methods showed higher efficiencies (enrichment factor ranging from 82.8 to 418.3) than DI-SDME (enrichment factor ranging from 43.8 to 64.5). Kaykhaii *et al.,* 2016 compared the HS-SDME and DLLME methods for the extraction of benzene in juice drinks containing vitamin C. The total analytical time, LOD and RSD, in HS-SDME were 30 min, 1.49 µg/L, and 5.03%, respectively, and 10 min, 1.93 µg/L, and 5.56%, respectively in DLLME. The results showed that the DLLME method was simpler and faster. However, the LOD and the repeatability (RSD) of HS-SDME were lower.

Figure 12: Single drop micro extraction procedures (Sarafraz-Yazdi et al., 2014)

(a) The DI-SDME procedure; (b) The HS-SDME procedure; (c) The HF-LPME procedure.



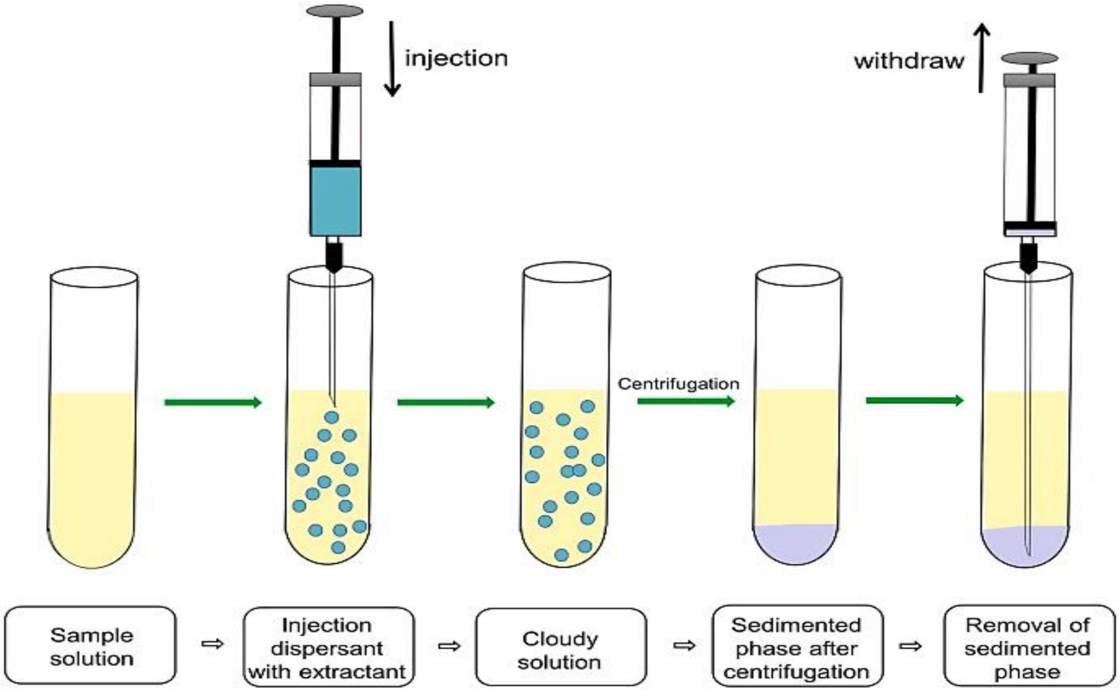
1.7.4.1.3.2 Hollow fiber liquid-phase micro extraction

HF-LPME was introduced to increase robustness and efficiency in extraction of BTEX and overcome poor stability of the droplet in SDME (Fig. c). It uses hydrophobic porous hollow fiber to protect the organic phase. A hollow fiber liquid phase micro extraction using IL (1-butyl-3-methy-limidazolium hexa fluorophosphates ([BMIM] [PF6]) as extractant for pretreatment of BTEX from water sample was introduced by Ma et al., 2011.

1.7.4.1.3.3 Dispersive liquid–liquid micro extraction

DLLME is a pretreatment technique which was developed to save the pretreatment time and improve BTEX extraction efficiency (Fig.14). It is simple, rapid, sensitive, inexpensive and environmentally friendly. Conventional DLLME is based on a solvent system with three components, a sample solution, an extraction solvent and a dispersive solvent. In traditional DLLME, using the dispersive solvent, this extraction solvent can be dispersed as very fine droplets into the water phase to extract targets. After centrifugation, the extraction solvent particles are then removed for analysis. A fast, low-cost and efficient DLLME procedure was developed by Assadi *et al.,* 2010.

Figure 13: The DLLME procedure (Assadi et al., 2010)



1.7.4.1.4 QuECHERS

Quick, easy, cheap, effective, rugged and safe (QuEChERS) is an alternative extraction procedure to achieve satisfactory results without the need for expensive and complex instruments. This technique includes liquid–liquid partitioning, using acetonitrile to extract solid samples in an aqueous environment, followed by dispersive solid-phase extraction (d-SPE) to purify the extract Originally, the QuEChERS method was first developed in 2003 to extract pesticide residues from fruits and vegetables (Anastassiades *et al*., 2003). Recently, due to the introduction of different extraction solvents, salt formulations and buffers in the partitioning step, and the use of various d-SPE adsorbents in the purification step, QuEChERS has been greatly developed. The method has been used to analyze VOCs in different environmental samples omitting some complicated operating procedures, providing a high sample throughput, low solvent consumption and low cost of analysis. A simplified QuECHERS approach was developed by Pinto *et al*., 2011 to determine BTEX in soil. The method used met the requirements of the "green chemistry" and provided reliable results.

1.7.4.1.5 Hybridization of different sample pretreatment methods

To achieve higher recovery and sensitivity, a combination of different sample pretreatment methods is undoubtedly a better choice. In the study of Khajeh *et al*., 2014 d-SPE combined with dispersive LLE (DLLE) has been developed for the extraction of BTEX in water matrix.

1.7.4.2 Analytic methods

Because BTEX are highly toxic volatile organic compounds even at trace levels. It is easily absorbed into human body through the lungs tissue and the skin tissue. It is important to establish highly sensitive, accurate and specific determination methods. In the past ten years, the methods used for quantification of BTEX include GC coupled with various detectors, such as mass spectrometry (MS), flame ionization detectors (FIDs) and barrier ionization discharge detection (BID), LC coupled with diode array detector (DAD) and sensors (Yu *et al*., 2022).

1.7.4.2.1 Gas chromatography

Gas chromatography (GC) is a separation technique in which volatile, thermally stable solutes migrate through a column containing a stationary phase at rates determined by their distribution ratios. In a wide range of mixtures, from the simplest (such as purity tests of individual compounds) to the most complex (such as petrochemical assays of samples consisting of hundreds of individual components), GC provides separation and quantitative analysis for volatile, thermally stable compounds (Jyoti, 2024).

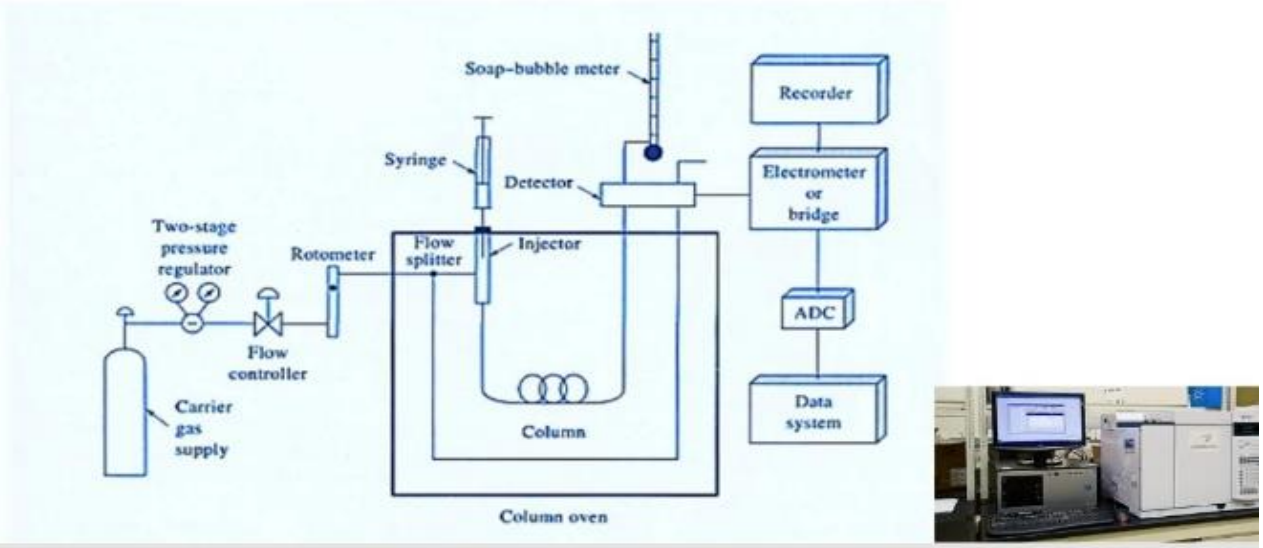
Principle:

It operates on similar principles to column permeation chromatography, where a sample is dissolved in a liquid phase and passed through a porous stationary structure. Compounds are characterized and quantified by the time it takes for them to elute from the permeable, packed column. This factor is determined by multiple characteristics, including molecular weight, hydrodynamic behavior, and concentration in the mobile phase. The differentiating factor between gas chromatography and standard chromatographic methods is using a vapor rather than a fluid as a mobile phase and liquid samples as opposed to a solid for the stationary phase.

An inert gas such as helium (He) or hydrogen (H2) are used as a carrier for vaporized molecules of interest. This gaseous mixture flows through the column of a gas chromatograph, which comprises a microscopic fluidic membrane and an inert, solid substrate. This column partitions vapors based on their mechanical properties and affinity with the stationary fluid. The flow-through rates of the components of a sample can be used for compound detection, identification, quantitation, and purification. The detector's electronic monitoring allows for accurate and precise measurement of the retention time, enabling the identification and characterization of different compounds in the sample. This information can be used to determine the composition of a mixture, identify unknown compounds, or assess the purity of a sample. Overall, the electronic monitoring of elution in gas chromatography plays a crucial role in the analysis and separation of compounds in various fields such as pharmaceuticals, environmental analysis, and forensic science(Environomics, 2018).

GC has superb separation efficiency and does not require organic reagents. It is an effective tool for the qualitative and quantitative determination of VOCs in various sample matrices. In GC, the choice of column for separation is crucial. Different columns have been adopted for the separation of BTEX. Fused silica capillary columns which are coated with a liquid phase were previously the most popular. Usually, a polysiloxane stationary phase is used to combine with different phenyl, cyanopropylphenyl groups and obtain different degrees of polarity (Chary *et al*., 2012). Silicone-based columns such as DB-5, HP-1, OV624 and Rtx-5MS (Criado-Garcia *et al*., 2015; Cavalcante *et al.,* 2017) are frequently used in BTEX separation and all have a 100% poly dimethysiloxane.

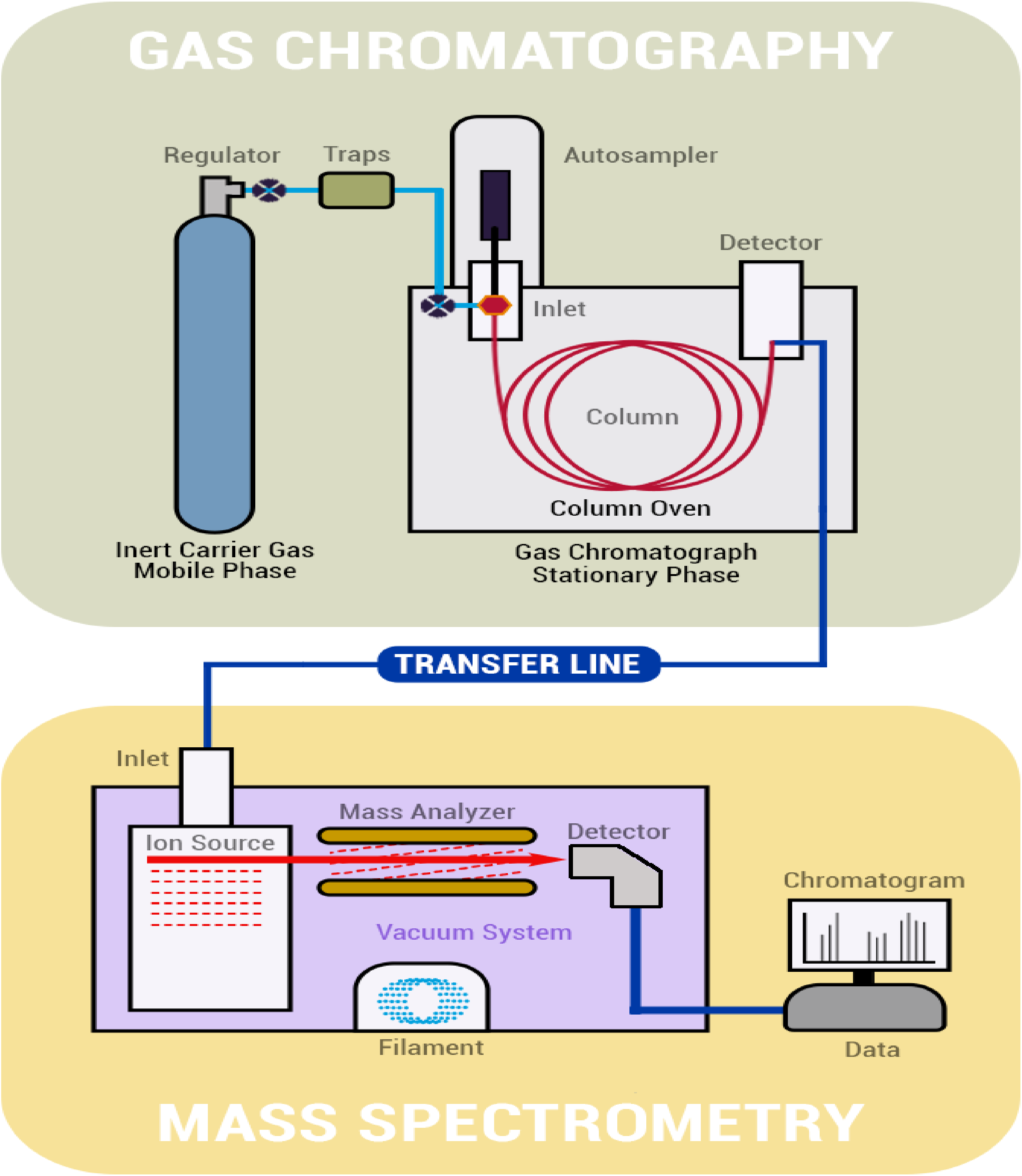
Figure 14: A Gas chromatograph (Jyoti, 2024)



1.7.4.2.2 Gas Chromatography–Mass Spectrometry

Principle: Gas chromatography–mass spectrometry (GC–MS) is composed of two major parts: the gas chromatograph and the mass spectrometer. The gas chromatograph utilizes a capillary column (housed in an oven) with specific dimensions and characteristics as well as the phase properties (e.g., 5% phenyl polysiloxane). To inject the molecule into the gas chromatograph, the temperature is increased, thus the molecule needs to be volatile at the injection temperature. The molecules are eluted sequentially from the gas chromatograph by increasing the oven temperature. The differences in the chemical properties between different molecules in a mixture will separate the molecules as the oven temperature increases and the sample travels through the column. At the exit of the column, the separated compounds enter the ionization chamber of the mass spectrometer. The electron impact (EI) ionization at a fixed energy of 70 eV is the main technique and produces fragment ions directly in the source. The mass analyzer then separates the fragments according to their mass. The resulting chromatogram combines data from the retention time on the column and the ion fragments (the intact molecular ion is usually not or barely detected) (Chevalier *et al*., 2011). After separating the sample on the capillary column, electron ionization (EI) is performed in MS for BTEX. The prerequisite for using this ion source is that the targets must be gasified. The EI source is not suitable for samples that are difficult to volatilize or thermally unstable. EI spectrum provides rich structural information, that is, the fingerprint spectrum of the compound (Bian *et al*., 2010). The sample enters the ionization chamber after vaporization, where it is hit by high-energy electrons and accepts part of the energy transferred by the electrons to form ions into the mass analyzer. *Zhang et al., 2017* developed a GC–MS approach with EI-SIM mode to determine volatile benzene homologues in three different indoor air samples.

Figure 15: GC-MS principle (PerkinElmer, 2022)

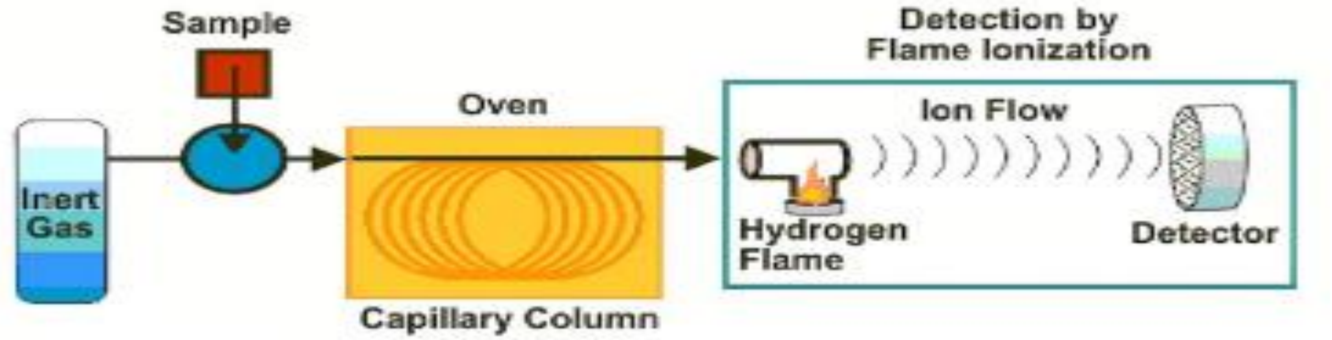


1.7.4.2.3 Gas chromatography (GC) with Flame-Ionization Detection

Principle:

The flame-ionization detector is mass sensitive. Thus, the amount of signal is proportional to the mass of carbon in the sample, not the number of moles. Compounds with more carbon give greater signals. The burning of carbon produces ions which are detected as a current. FID is one of the most sensitive general detectors for GC with a limit of detection in the picogram range. The response is linear over seven orders of magnitude, giving it a large linear range (Jill Venton, 2023).

Figure 16: chromatography with FID (chromatographyscience.blogspot.com)



FID is a high sensitivity universal detector with a minimum detection amount of up to 10-12 g. This detector responds to almost all organic matter in a wide linear range of approximately 107. The generated ions from FID, in a hydrogen–oxygen flame migrate in the electric field to form an ion flow. The works of Hashemi *et al.,* 2011 developed an accurate, rapid and sensitive GC-FID method for the determination of BTEX in water samples. Nespeca *et al*., 2019 developed a faster and less costly way with ultra-fast gas chromatography (UFGC) methods with FID to determine BTEX in soil. The UFGC-FID methods showed a short analytical time (5 min), good linearity (R2 > 0.997) and high sensitivity ($\gamma > 0.02$ mg/kg). Therefore, compared with conventional GC technology, UFGC-FID method is a faster, cheaper, and more environmentally friendly process.

1.7.4.2.4 Sensors

The most commonly used technique for the detection and discrimination of BTEX compounds is GC coupled with various detectors. Although the previously mentioned methods have low LOD, high selectivity and good reliability, GC-based methods are difficult to be used on site real-time detection due to complicated operation, bulky instrument, high power consumption and slow speed. Therefore, in the last one decade, a variety of sensors have been introduced to determine BTEX compounds. These sensors include resistive-based gas sensors (Ngaraju *et al*., 2019) quartz crystal microbalance (QCM)- based sensors, porous framework-based sensors, surface acoustic wave sensors and optical sensors (Yu *et al.,* 2022). Different from GCs, sensors are usually portable, consuming less power and operating in a simpler and faster way. Gas sensors have been widely employed in VOCs detection due to low cost, compact size, easy production and field portable and simple measuring electronics. Morphology and structure of sensing materials can affect the performance of sensors because it decides the rate of gas diffusion. Among the various gas sensors available for BTEX detection, resistance-based gas sensors are the most common.

1.7.4.2.4.1 Principles of VOC Gas Sensors

Sensing Mechanism

VOC gas sensors operate based on various sensing mechanisms, including:

Photoionization Detection (PID)

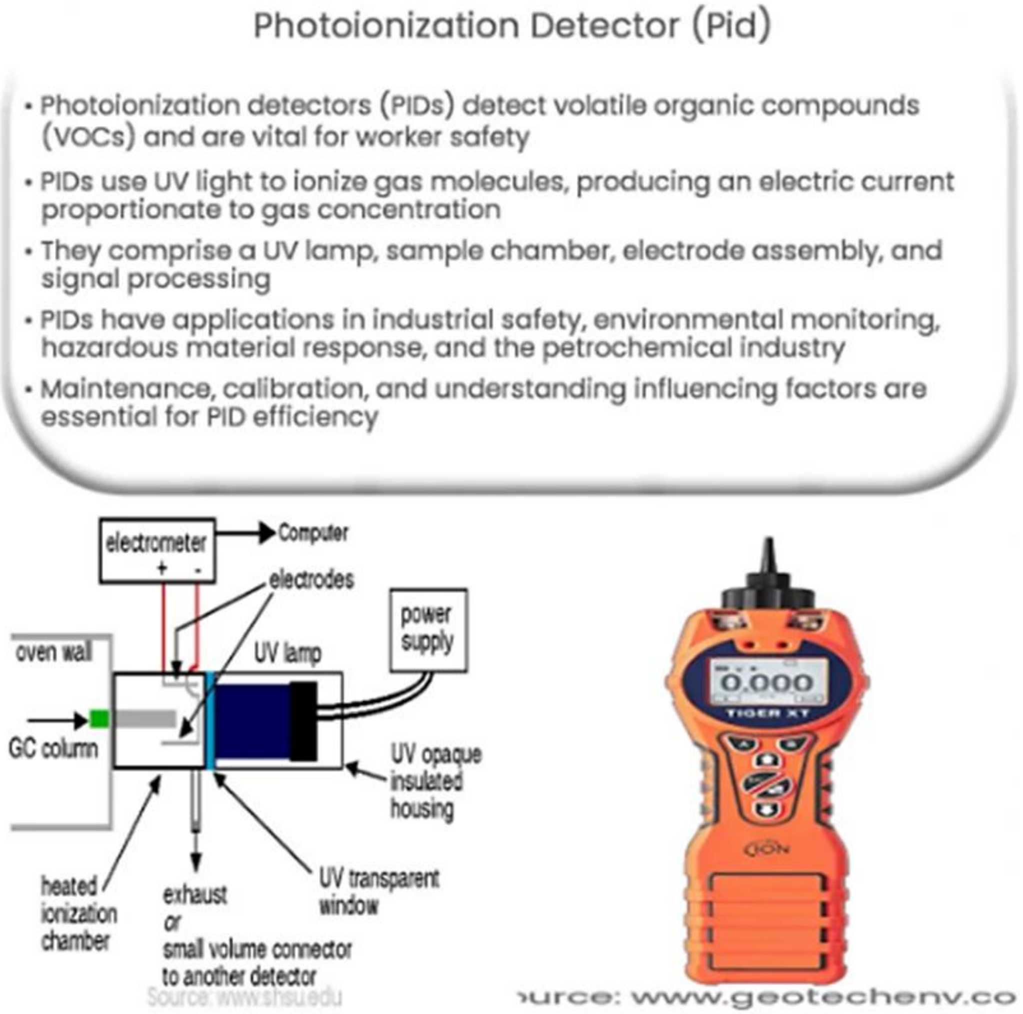
PID sensors utilize ultraviolet light to ionize VOC molecules, generating an electrical current proportional to the concentration of VOCs present. This method offers high sensitivity and real-time detection capabilities, making it suitable for a wide range of applications.

Photoionization Detector (PID) sensors represent an advanced technology for the detection of volatile gases and volatile organic compounds (VOCs). Due to their sensitivity, reliability and versatility, these sensors are widely used in various industrial, environmental and security sectors. PID sensors operate through the principle of photoionization. C F Poole*,* 2019 summarizes their operation in three steps:

- **Ionization**: An ultraviolet (UV) lamp inside the sensor emits light at a specific wavelength. This UV light hits the target gas molecules, providing enough energy to ionize them.
- **Detection**: Ionized molecules produce ions and free electrons. These ions are collected by an electrode, generating an electric current.
- **Measurement**: The intensity of the electric current is proportional to the concentration of the target gas in the air. The sensor converts this current into a measurable signal, which is then interpreted and displayed.

Selective ionization of most organic compounds in the gas phase is possible by absorption of photons with energy either close to or greater than the ionization potential of the compounds. For typical organic compounds this requires photons in the far ultraviolet of about 5–20 eV. The photon source is a compact discharge lamp, containing an inert gas or gas mixture at low pressure, which emits monochromatic light of a specific energy, depending on the choice of fill gases and window material (C F Poole, 2019). Carneiro *et al*., 2014 developed a GC-PID method to determine and quantify BTEX in water and wastewater samples

Figure 17: Photo Ionization Detector (Geotechenv, 2024)



Photoionization Detector (Pid)

- Photoionization detectors (PIDs) detect volatile organic compounds (VOCs) and are vital for worker safety
- PIDs use UV light to ionize gas molecules, producing an electric current proportionate to gas concentration
- They comprise a UV lamp, sample chamber, electrode assembly, and signal processing
- PIDs have applications in industrial safety, environmental monitoring, hazardous material response, and the petrochemical industry
- Maintenance, calibration, and understanding influencing factors are essential for PID efficiency

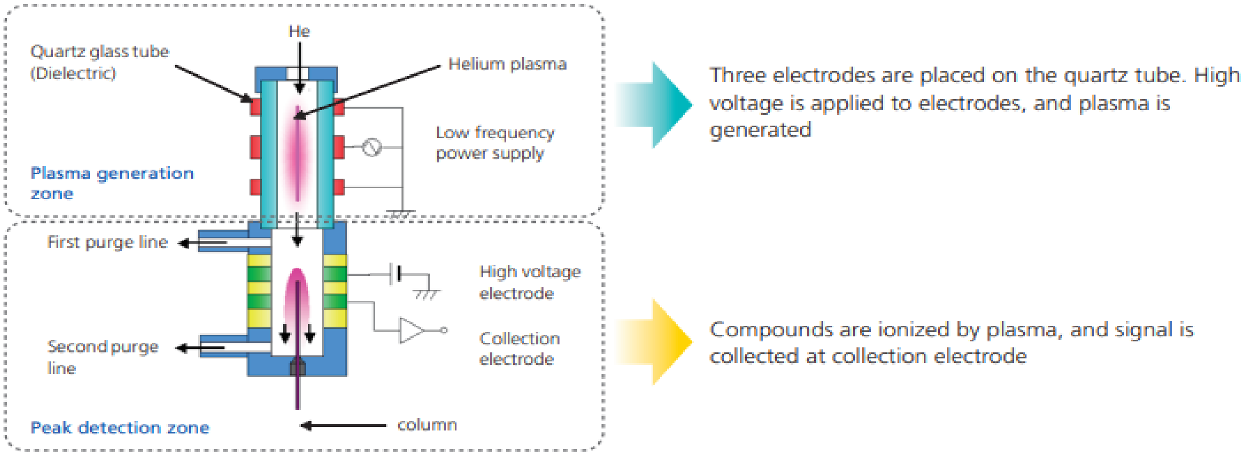
Source: www.shsu.edu

ɔurce: www.geotechenv.co

Barrier ionization discharge (BID) detector

The Barrier Ionization Discharge (BID) detector generates a17.7 eV helium plasma that ionizes almost all compounds except Neon. A newly designed quartz dielectric chamber allows for a lower discharge current and higher operating temperature. The BID is a universal detector with sensitivity greater than 100 times that of a TCD (thermal conductivity detector). It is an ideal detector for trace levels of permanent gas, water, volatile fatty acids and light hydrocarbons. A plasma is generated by applying a high voltage to a quartz dielectric chamber, in the presence of helium. Compounds that elute from the GC column are ionized by this He plasma, then captured with collection electrodes and described as peaks. The photon energy of He is extremely high (17.7 electron volt). Therefore, it makes possible to detect every compound except Ne (neon) and He which is the plasma gas, with high sensitivity (Zhuangzhi *et al*., 2014).

Figure 18: Structure of BID (Teresa, 2020)



Three electrodes are placed on the quartz tube. High voltage is applied to electrodes, and plasma is generated

Compounds are ionized by plasma, and signal is collected at collection electrode

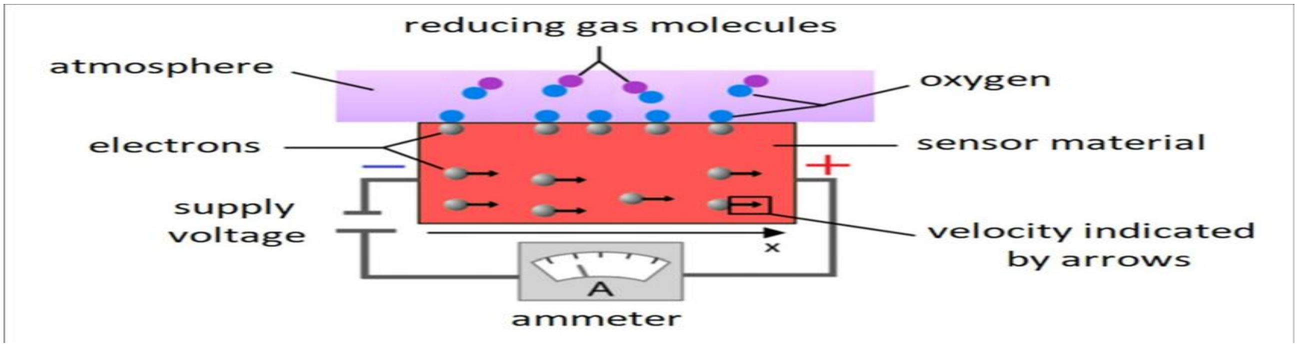
Metal Oxide Semiconductor (MOS)

MOS sensors rely on changes in electrical conductivity when VOC molecules adsorb onto a metal oxide surface. As VOC concentration increases, the conductivity of the sensor changes, allowing for the detection and quantification of VOCs present in the environment.

MOS sensors detect concentration of various types of gases by measuring the resistance change of the metal oxide due to adsorption of gases. Atmospheric oxygen residing on the MOS surface is reduced by the target gases, allowing more electrons in the conduction band of the metal oxide material. This resistance drop is reversible and varies depending on the reactivity of sensing materials, presence of catalyst materials and working temperature of the sensor.

MEMS (microelectronic mechanical systems) have enabled miniaturization of MOS sensor technology to a single die by allowing implementation of heating and sensing elements by thin film fabrication. Deep reactive ion etching provides thermal isolation of the heater and sensor elements. MOS gas sensors offer low power consumption (few 10s of mW in constant operation), wafer-based manufacturing for cost reduction, reproducibility and scalability, as well as high sensitivity. MOS devices are suitable for integration with ASIC (application- specific integrated circuit) electronics and chip scale packages, allowing for higher-level integration and sensor arrays.

Figure 19: Schematic structure of a MOS gas sensors (Sebastian et al., 2021)



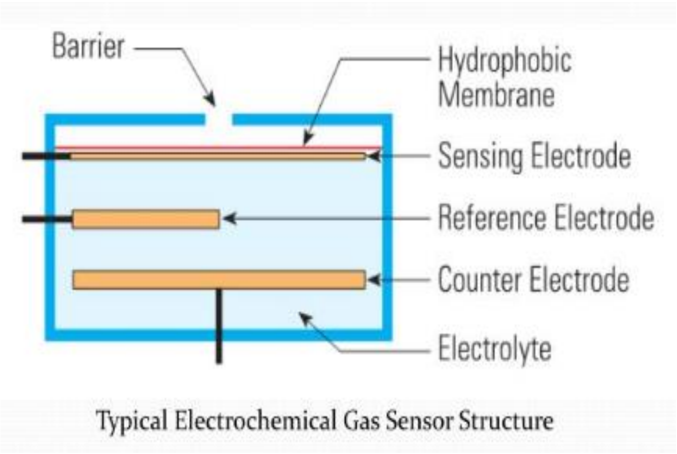
Electrochemical Gas Sensor

It is a sensor that specializes in detecting toxic gas. It has high selectivity and is used for various detection alarms for consumer and industrial use. Due to the operating principle that does not consume power, it consumes less power and can be driven by batteries, has high gas detection accuracy, few mechanically weak parts, it is strong against drops, vibrations, impacts, it is stable for a long time because it is hardly affected by poisoning such as silicon, excellent reproducibility and stability because it is hardly affected by humidity (sensor.nemoto.co)

Basic structure of electrochemical gas sensor (ECGS).

It is made up of; the detection electrode, reference / counter electrode, electrolyte holder / separator, and air vent sheet enclosed in a plastic case together with the electrolyte. Carbon monoxide passes through the capillary to remove miscellaneous gases in the spare chamber with a built-in charcoal filter, diffuses the PTFE sheet, reaches the detection electrode, and is oxidized there. The capillaries are also protected by a special filter that is dustproof and waterproof (sensor.nemoto.co).

Figure: 2020a: structure of ECGS (Slideserve, 2014) 20b: Portable gas detector (Eco-rentalsolutions, 2019)



1.7.4.2.5 Additional methods

Currently, GC is the most widely used method for analysis of VOCs in environmental samples. However, GC has some limitations in the applications where there is high BTEX concentration water samples. This is because its incompatibility with water, leads to the potential detector saturation, thereby causing reduced detection accuracies beyond the 2.0 to 9.5 mM range (Amy Tan *et al*., 2012). Thus, GC-based methods are not suitable for the determination of high BTEX concentrations (0.5 to 2.0 mM). The application limitations of GC-based methods may be resolved by HPLC based methods. High performance liquid chromatography (HPLC) is suitable for the direct analysis of water samples with higher compound concentrations without complex pretreatment process. Moreover, HPLC has high throughput performance and lower capital cost. Therefore, HPLC has become a popular supplementary method of GC for BTEX analysis in water samples (Amy Tan *et al*., 2012). Compared with other analytical techniques like HPLC and GC, capillary electrophoresis (CE) has advantages in terms of speed, cost of analysis and easy automation. Cho *et al.,* 2016 realized the on-line full automation analysis of BTEX with CE as an acceptor phase. Organic receptor plugs such as chloroform in the capillary was used to extract BTEX. Then micellar electro kinetic chromatography (MEKC) was used to analyze the targets enriched in the organic receptor plug. Immunochemical analysis is a simple, fast, low-cost method without complicated pretreatment. Immunological methods reported for BTEX are mainly enzyme-linked immune-sorbent assay (ELISA) (Maiolini *et al.,* 2010) which has specific binding to antibodies to BTEX. Compared to traditional analytical methods, ELISA requires little effort for sample cleanup and the methods are rapid, economical and sensitive. An indirect competitive chemiluminescent (CL)-ELISA was developed by Maiolini *et al*., 2010 for the BTEX determination in water and soil. Using phenyl-alkanoic acids and bovine serum albumin (BSA) and ovalbumin (OVA) as carrier proteins, new coating antigens were synthesized. Due to high volatility of BTEX, considerable efforts were devoted to obtain the optimal ELISA conditions (such as temperature, incubation time and organic solvent). Maziejuk *et al.,* 2016 applied a differential ion mobility spectrometry (DMS) to determine BTX compounds in humid air. Under the test conditions (low concentrations of BTX: 5 to 20 ppm, and air humidity: 0 to12 g/kg), the average concentration error was approximately 1 ppm for three targets. The experimental results were very promising regarding the further application of DMS technique. Allafchian *et al*., 2016 used IMS method to detect xylene and toluene. They achieved wide linear ranges of 1.10 to 32.0 ppb and 16.0 to 112.0 ppb for xylene and toluene, respectively. Another real-time continuous determination technology is direct atmospheric pressure chemical ionization (APCI)-MS/MS system. This technique can determine low-µg/m3 levels of atmospheric BTEX. Fluorescence spectroscopy, as an effective and fast analytical method, can distinguish these isomers with less effort. Khan *et al*., 2018 investigated the structure and spectrum to distinguish xylene isomers with experiment and theory. At the same concentration, the fluorescence excitation/emission wavelength (ex/em) for o-, m-xylene were at 260 nm/285 nm, and for p-xylene was at 265 nm/290 nm. Alharbi et al., 2018 developed transform limited femtosecond pulses for differentiating three xylene isomers. Using circularly polarized light to probe doubly charged parent ions, the yield of o-xylene decreased while p-xylene increased as the laser polarization was changed from linear to circular. Then, the high harmonic generation from randomly oriented xylene isomers were invested under an intense laser field. The research indicated that the position of the methyl group in xylene isomers (o-, p- and m-) will affect the yield of high-order harmonics. The above result was caused by the differences in the ionization strength of the tunnel, as well as the overlap between the ionization peak and photo-recombiis still the most common and classic method among all determination methods that are used to the volatile BTEX. The RaPID assay total BTEX/TPH test kit can be used as a quantitative, semi-quantitative and qualitative enzyme immunoassay (EIA)for the analysis of petroleum hydrocarbons(BTEX)in water. It applies the principle of enzyme linked immunosorbent assay (ELISA) to the determination of BTEX and other compounds.

1.8 ASSOCIATED FAMILY HEALTH RISK OF BTEX EXPOSURE

Exposure to BTEX compounds can have potential effects on the health of offspring of individuals exposed to these substances, such as filling station/fuel depot workers. Some potential effects that have been studied include:

- Reproductive health issues: some studies suggest that exposure to BTEX compounds may lead to reproductive health problems, including decreased fertility and increased risk of miscarriage (Webb *et al.,* 2014; Suaidi *et al*., 2020). This can affect the health of offspring if conception occurs during or after exposure.
- Developmental effects: prenatal exposure to BTEX has been associated with various developmental issues in children. This can include: low birth weight, preterm birth, developmental delays or cognitive impairments (Webb *et al.,* 2014).
- Neurodevelopmental disorders: exposure to toluene and other BTEX compounds during pregnancy has been linked to neurodevelopmental disorders in children, including attention-deficit hyperactivity disorder (ADHD) and other behavioral issues (Webb *et al.,* 2018; Kalkbrenner *et al*., 2014).
- Respiratory problems: children born to parents exposed to BTEX may have an increased risk of respiratory problems, such as asthma or other chronic respiratory conditions (Geen, 2014).
- Cancer risks: benzene, one of the BTEX compounds, is a known carcinogen. While direct causation is difficult to establish, there is concern that exposure could increase the risks of certain cancers in offspring later in life (Geen, 2014; Heck *et al*., 2014).
- Endocrine disruption: some studies suggest that exposure to these chemicals may disrupt endocrine function (Reutman *et al*., 2002;), potentially leading to hormonal imbalances that could affect development and health in offspring.
- Genetic effects: there is ongoing research into whether exposure to BTEX compounds could lead to genetic mutations or epigenetic changes that may be passed on to future generations (Spatari *et al*., 2021).

1.9 Risk ASSESSMENT/ANALYSIS AT WORKPLACE

Risk assessment is a vital process that every organization must undertake to ensure the safety and well-being of its employees, customers, and the public. It is the process of identifying, evaluating, and prioritizing potential hazards or risks in a workplace or activity. A risk assessment is crucial because it helps organizations understand the level of risk and take appropriate measures to control or eliminate the identified risks. The basic principles of risk assessment include the identification of hazards, the assessment of risks associated with these hazards, the identification of control measures to mitigate these risks, and the review and monitoring of these control measures (Afnan Tajuddin, 2024).

1.9.1 How to Perform Risk Assessment?

Below are the 5 steps on how to efficiently perform risk assessments:

1. Identify hazards: Survey the workplace and look at what could reasonably be expected to cause harm. Identify common workplace hazards. Check the manufacturer's or suppliers' instructions or data sheets for any obvious hazards. Review previous accident and near-miss reports.

2. Evaluate the risks: Risk evaluation helps determine the probability of a risk and the severity of its potential consequences. To evaluate a hazard's risk, you have to consider how, where, how much, and how long individuals are typically exposed to a potential hazard. Assign a risk rating to your hazards with the help of a risk matrix.

3. Decide on control measures to implement: After assigning a risk rating to an identified hazard, it's time to come up with effective controls to protect workers, properties, civilians, and/or the environment. Follow the hierarchy of controls in prioritizing implementation of controls.

4. Document your findings: It is important to keep a formal record of risk assessments. Documentation may include a detailed description of the process in assessing the risk, an outline of evaluations, and detailed explanations on how conclusions were made. 5. Review your assessment and update if necessary: Follow up with your assessments and see if your recommended controls have been put in place. If the conditions in which your risk assessment was based change significantly, use your best judgment to determine if a new risk assessment is necessary (Afnan Tajuddin, 2024; Jairus, 2024).

Figure 21: Risk Analysis Framework (Jairus, 2024)

1.9.2 Risk assessment in petrol filling stations/ fuel depots (PFS/FD)

Fuel has the potential to create fire accidents. Fuel hazard fire assessment is an important input for fire management plan (Gould & Sullivan, 2004). From 1993 to 2004 approximately 243 incidents related to fire outbreak have been reported at PFS/FD around the world. Electrostatic charges found to be main root cause for fire generation (Ahmed *et al*., 2011). Tank lorries (T/Ls) during their operation and maintenance at PFS/FD possess various kinds of hazards on allied facilities and staff. Apart from fire accidents, automobile refueling is one of the main sources of benzene vapors production. It has severe health effect on workers and nearby staff (Udonwa *et al.,* 2009). Every year in USA alone about 150-200 fires events occurred due to static-electricity-caused ignition of gasoline vapors (Babrauskas *et al.,* 2005). Both contractors and clients have activities that can create major and minor injuries during operation. Hazard identification and risk assessment is an important tool to prioritize hazardous activities. Electrostatic charges have interaction of weather, clothing, and car seat material, getting in and out of the car (Babrauskas *et al*., 2005). Most of the incidents occur under low-humidity conditions; consequently, they are more prevalent in cold weather. A disproportionate fraction of these incidents (55% of the incidents where the ignition details are known) have involved an individual who re-enters and re-exits the vehicle during the fueling operation. Other studies have shown that charging an individual to around 6 kV can suffice to produce an incentive spark. In terms of responsibility of the individual doing the refueling, the American Petroleum Institute issued a widely-publicized press release on February 3, 2000, “Do not get back into your vehicle during refueling." Their press release also emphasized that if for some reason the person does have to re-enter the vehicle, "Discharge the static electricity buildup when you get out by touching the outside metal portion of your vehicle, away from the filling point, before attempting to remove the nozzle". Failures in human behaviors and process are two primarily main causes of hazards occurrences (Ahmed *et al*., 2011).

According to the Dangerous Substances and Explosive Atmospheres Regulations 2002, the conditions attached to petroleum licenses issued under the Petroleum (Consolidation) Act 1928 have been significantly reduced. The onus is now on the employers/responsible person to identify and assess the risks arising from the delivery, keeping and dispensing of petroleum products and other motor fuels (such as liquefied petroleum gas - LPG). The following legislations state out the requirements for risk assessment by the employer; The Petroleum (Consolidation) Act 1928, The Health and Safety at Work Act 1974, The Management of Health and Safety at Work Regulations 1999, The Dangerous Substances and Explosive Atmospheres Regulations 2002, The Regulatory Reform (Fire Safety) Order 2005.

1.9.2.1 What Legislation Requires

The employer/responsible person must:

- Find out what dangerous substances are present in their workplace/premises and what the fire and explosion risks are. (Petroleum spirit and LPG are both "dangerous substances" for this purpose, but there may be others at the premises. If so these should be considered as well).
- Put control measures in place to either remove these risks or, where this is not possible, to control them.
- Put controls in place to reduce the effects of any incidents involving dangerous substances.
- Prepare plans and procedures to deal with accidents, incidents and emergencies involving dangerous substances.
- Make sure that employees are properly informed about and trained to control or deal with the risks from dangerous substances. (This includes providing them with details of the substances and with a copy of the significant findings of the risk assessment).
- Identify and classify areas of the workplace/premises where explosive atmospheres may occur and avoid ignition sources (for example from unprotected equipment) in those areas. Recording these areas is best done by way of a plan.
- Carry out a risk assessment and record the significant findings of that assessment, including the measures that have been or will be taken by the employer/responsible person to control the risk.

- Keep a record of the risk assessment and significant findings available for inspection.
- Review the risk assessment periodically and following any significant changes.

The requirement to assess the risks from the dangerous substances should not be considered in isolation. It should be carried out as part of the overall risk assessment required by Regulation 3 of the Management of Health and Safety Regulations 1999 rather than as a separate exercise.

Appendix D is a suggested format considered as a method of recording the required information. Appendix E lists some of the control measures that may be necessary for each activity. Appendix F details the hazardous zones associated with a petrol filling station forecourt. Following this guidance is not necessarily the only way to comply with the legislation, however, the advice represents best practices.

CHAPTER TWO: MATERIALS AND METHODS

2.1 STUDY SETTING AND POPULATION OF INTEREST

This study was carried out in Yaounde which is one of the largest cities in Cameroon. Yaounde (Latitude: 3°50’ north; longitude:11°29’ East) is the political capital of the country expanding on 180 Km^2 with about 4.5 million inhabitants. The study sites were filling stations/fuel depots belonging to five fuel marketers: **B, D, O, AD, AH, and AM** (a petroleum storage facility).

The target population was made up of adult workers (18-60 years old) both males and females employed in filling stations/fuel depots in Yaounde who were willing to participate in the study.

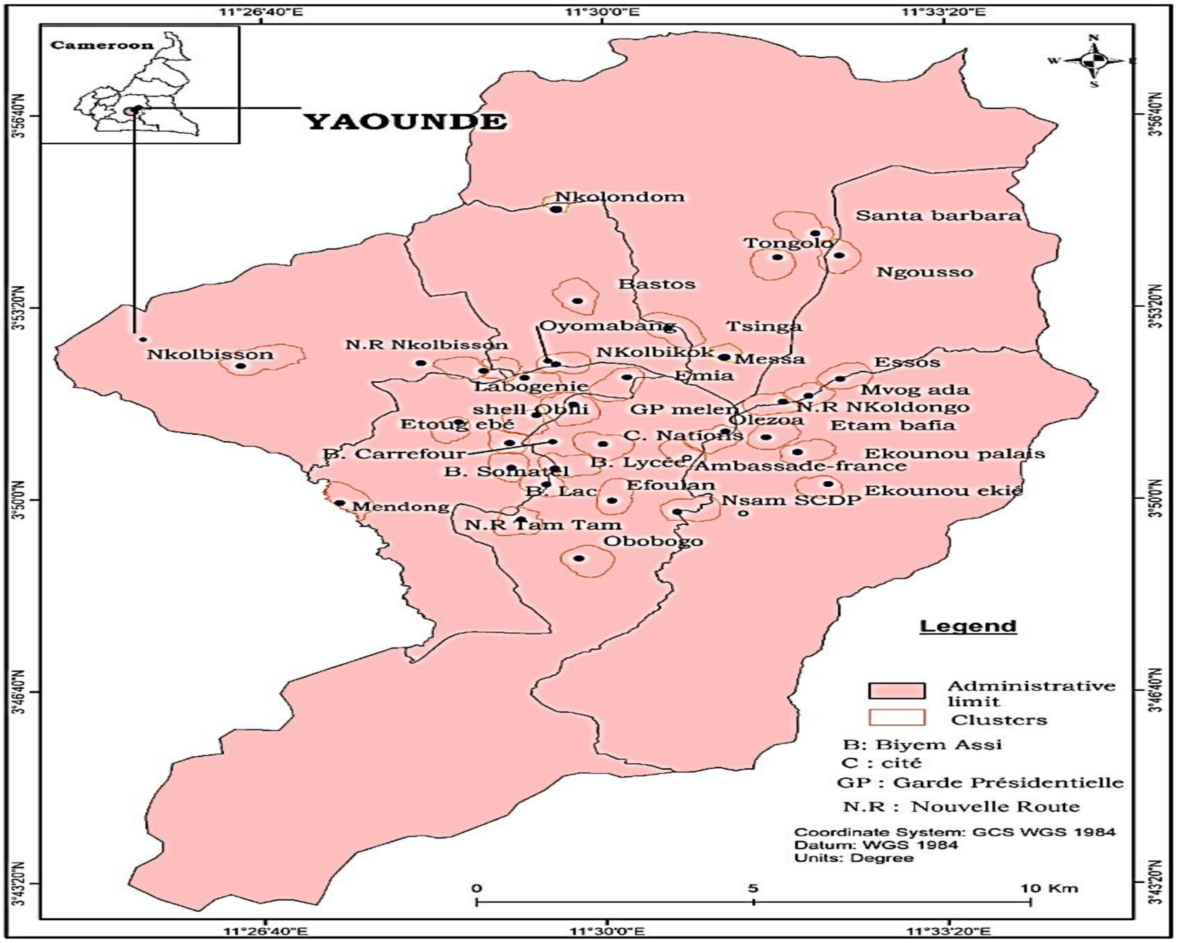


Figure 22: The map of Yaounde indicating the study locations (Sonhafouo-Chiana et al; 2022)

Table 3: Study Sites

Fuel Marketing/ Storage Company	Filling Stations/Fuel Depots
B	BFS1
	BFS2
	BFS3
	BFS4
	BFS5
D	DFS6
	DFS7
	DFS8
	DFS9
	DFS10
O	OFS11
	OFS12
	OFS13
	OFS14
	OFS15
AD	ADFS16
	ADFS17
	ADFS18
	ADFS19
	ADFS20
AH	AHFS21
	AHFS22
	AHFS23
	AHFS24
	AHFS25
AM	AMFS26

2.2 RESEARCH DESIGN

This research adopted a mixed method approach where a descriptive cross-sectional study (part1- survey) and a longitudinal study (part 2- BTEX monitoring) were used to collect qualitative and quantitative data. A simple random sampling technique was employed to select five (5) fuel marketing companies amongst a total of thirty-seven (37) in Yaounde. Each of these companies were assigned an identification code (ID) to produce a sample frame (a list of all the members of the population) and numbers were randomly generated for each element by balloting (between 1 and 37) as shown in table 4 below. The first five random numbers represented the five fuel marketers mentioned above. The only fuel storage company (**AM**) was also included in the study, making the sample population(N) = 38, and Sample size(n) = 6. Furthermore, a purposive sampling technique was employed to select five filling stations from each of the five fuel marketers following their work load per day or the barrels of fuel manipulated per day (the worst-case scenario), statistics obtained from SCDP. This sampling technique was also used for the collection of air samples from ATEX zones for the analysis of VOCs (BTEX). **N.B:** N = Total number of fueling companies in Yaounde.

Table 4: Random numbers generated by balloting

ID	Name
001	A
002	B
003	C
004	D
005	E
006	F
007	G
008	H
009	I
010	J
011	K
012	L
013	M
014	N
015	O
016	P
017	Q
018	R
019	S
020	T
021	U
022	V
023	W
024	X
025	Y
026	Z
027	AB
028	AC
029	AD
030	AE
031	AF
032	AG
033	AH
034	AI
035	AJ
036	AK
037	AL

⇒

ID	Name	Random numbers
001	A	6
002	B	3
003	C	25
004	D	1
005	E	20
006	F	15
007	G	24
008	H	27
009	I	14
010	J	8
011	K	22
012	L	11
013	M	7
014	N	16
015	O	2
016	P	36
017	Q	33
018	R	12
019	S	23
020	T	31
021	U	17
022	V	26
023	W	9
024	X	35
025	Y	21
026	Z	13
027	AB	34
028	AC	37
029	AD	5
030	AE	18
031	AF	28
032	AG	30
033	AH	4
034	AI	32
035	AJ	29
036	AK	10
037	AL	19

2.2.1 Data Collection Methods

Structured questionnaires were developed and administered to collect qualitative data from all workers with or without direct exposure to VOC (BTEX) in filling stations and fuel depots who were willing to participate in the study. The questionnaires covered areas such as demographics, hazard exposure, safety practices, and health outcomes.

The quantitative data was obtained by quantitative assessment of occupational health and safety indicators (BTEX). Air samples were captured directly by the air intake port of the portable gas detector by diffusive sampling. In addition, risk assessment was performed for each of the selected filling stations and fuel depots using document 252274895/Risk Assessments for Petrol Filling Station guidance's template (Appendix D).

2.3 SAMPLE ANALYSIS.

Sample analysis was conducted on-site using the portable pump suction gas sensor which adopts the advanced large-scale integrated circuit technology, the international standard intelligent technology level design technology and the proprietary digital analogue hybrid communication technology design and the fully intelligent gas detector. The detector uses natural diffusion mode to detect gas, and then sensitive element uses high quality gas sensor, which has excellent sensitivity and excellent repeatability, and greatly meets the requirements of industrial site safety monitoring for equipment reliability.

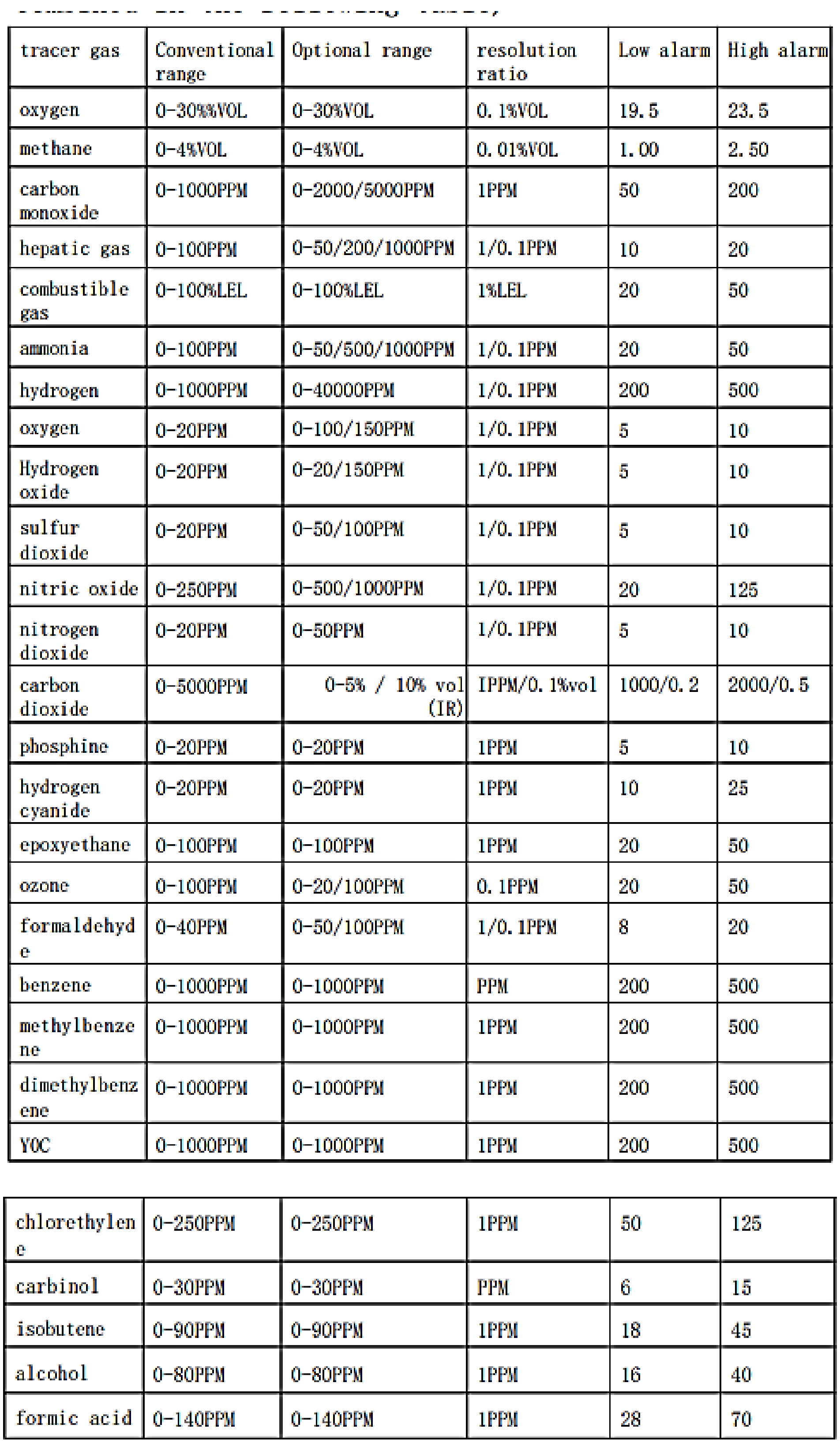
2.3.1 Apparatus

The apparatus used for the analysis of BTEX in air is the portable pump suction gas detector with structural and functional characteristics as shown below (figure 27). it is mainly composed of housing, circuit board, battery, gas sampling pump, display screen, sensor, charger and other components. The working principle is the electrochemical formula and catalytic combustion type of the different gases, and the routine gas detection range is shown in the table below (figure 28).

Figure 23: Structural and functional characteristics of the portable gas detector

1	Gas sampling air intake port	2	LCD
3	ON key	4	Left key
5	Right key	6	Ok key
7	Under key	8	Return key
9	Boot button	10,11	LED alarm indicator
12	The buzzer pronunciation hole	13	Charging port

Figure 24: Routine gas detection range



tracer gas	Conventional range	Optional range	resolution ratio	Low alarm	High alarm
oxygen	0-30%%VOL	0-30%VOL	0.1%VOL	19.5	23.5
methane	0-4%VOL	0-4%VOL	0.01%VOL	1.00	2.50
carbon monoxide	0-1000PPM	0-2000/5000PPM	1PPM	50	200
hepatic gas	0-100PPM	0-50/200/1000PPM	1/0.1PPM	10	20
combustible gas	0-100%LEL	0-100%LEL	1%LEL	20	50
ammonia	0-100PPM	0-50/500/1000PPM	1/0.1PPM	20	50
hydrogen	0-1000PPM	0-40000PPM	1/0.1PPM	200	500
oxygen	0-20PPM	0-100/150PPM	1/0.1PPM	5	10
Hydrogen oxide	0-20PPM	0-20/150PPM	1/0.1PPM	5	10
sulfur dioxide	0-20PPM	0-50/100PPM	1/0.1PPM	5	10
nitric oxide	0-250PPM	0-500/1000PPM	1/0.1PPM	20	125
nitrogen dioxide	0-20PPM	0-50PPM	1/0.1PPM	5	10
carbon dioxide	0-5000PPM	0-5% / 10% vol (IR)	IPPM/0.1%vol	1000/0.2	2000/0.5
phosphine	0-20PPM	0-20PPM	1PPM	5	10
hydrogen cyanide	0-20PPM	0-20PPM	1PPM	10	25
epoxyethane	0-100PPM	0-100PPM	1PPM	20	50
ozone	0-100PPM	0-20/100PPM	0.1PPM	20	50
formaldehyde	0-40PPM	0-50/100PPM	1/0.1PPM	8	20
benzene	0-1000PPM	0-1000PPM	PPM	200	500
methylbenzene	0-1000PPM	0-1000PPM	1PPM	200	500
dimethylbenzene	0-1000PPM	0-1000PPM	1PPM	200	500
YOC	0-1000PPM	0-1000PPM	1PPM	200	500
chlorethylene	0-250PPM	0-250PPM	1PPM	50	125
carbinol	0-30PPM	0-30PPM	PPM	6	15
isobutene	0-90PPM	0-90PPM	1PPM	18	45
alcohol	0-80PPM	0-80PPM	1PPM	16	40
formic acid	0-140PPM	0-140PPM	1PPM	28	70

2.3.2 Principle of the Portable Gas Detector.

The portable gas detector possesses an electrochemical sensor which measures gas concentrations by oxidizing or reducing the gas at an electrode and measuring the resultant current. Electrochemical gas sensors are composed of electrodes (working, counter, and reference) immersed in an electrolyte, usually housed in a compact casing with a gas-permeable membrane. Target gases diffuse through the membrane and undergo a redox reaction at the working electrode, generating a current proportional to the gas concentration. The electrochemical gas sensor monitors the detection electrode where the oxidation (reduction) reaction occurs, the counter electrode where the reduction (oxidation) reaction occurs at the same time, and the potential change that occurs at the detection electrode at this time and keeps the potential of the detection electrode constant. These sensors employ a redox reaction between VOC molecules and an electrolyte to generate a measurable electrical signal. These sensors offer high selectivity and sensitivity, making them ideal for detecting specific VOCs in complex environments. In the case of carbon monoxide detection, the following carbon monoxide oxidation reaction occurs at the detection electrode.

$2CO + 2H2O \rightarrow 2CO2 + 4H+ + 4e-$

Here, when the detection electrode and the counter electrode are connected by an external circuit, electrons flow from the detection electrode toward the counter electrode, hydrogen ions move in the electrolytic solution, receive electrons on the counter electrode side, and react with oxygen to produce water.

In this way, the electrochemical gas sensor detects gas by converting the chemical reaction caused by redox into electrical energy. In such a reaction process, a voltage drop occurs inside the electrolytic solution due to polarization caused by the reaction layer near the electrode and internal resistance that hydrogen ions receive when moving in the electrolytic solution. This voltage drop generally increases as the gas concentration increases and acts as a factor that impairs the linearity of the output characteristics of the electrochemical gas sensor. Here, the effect of the reference electrode is that the potential of the detection electrode is detected, the potential of the detection electrode is kept constant regardless of this voltage drop, and a current proportional to the gas concentration always flows between the detection electrode and the counter electrode. make it possible. An electrochemical gas sensor with such a potential control function using a reference electrode is called a three-electrode method. Such a three-electrode method has been widely adopted in fields such as industrial gas concentration measurement because of its excellent linearity and stability. In contrast to the three-electrode method, the electrochemical gas sensor, which omits the reference electrode and consists of a detection electrode and a counter electrode, is called a two-electrode method. This method has been used for consumer gas alarms, etc., where accuracy is not required so much because of its cost advantage. Although it has the performance that can be used in consumer gas alarms, its linearity and output stability is inferior to those of the three-electrode method (sensor.nemoto.co).

The current generated in an electrochemical cell can be described by Faraday's law:

$I = nF\ d[ox]/dt$

Where:

I = current(A)

n = number of moles of electrons transferred per mole of reactant

F= Faraday's constant (approximately 96485C/mol)

$(d[ox])/dt$ = rate of change of concentration of the oxidized species (mol/m3. s).

The Nernst equation relates the concentration of reactants and products to the potential(voltage) of an electrochemical cell:

$E = E^\circ + RT/nF$

$\ln (([ox]/[Red]))$

Where: E = Cell potential(V)

E° = standard electrode potential(V)

R = universal gas constant (8.314J/(mol-K))

T = Temperature

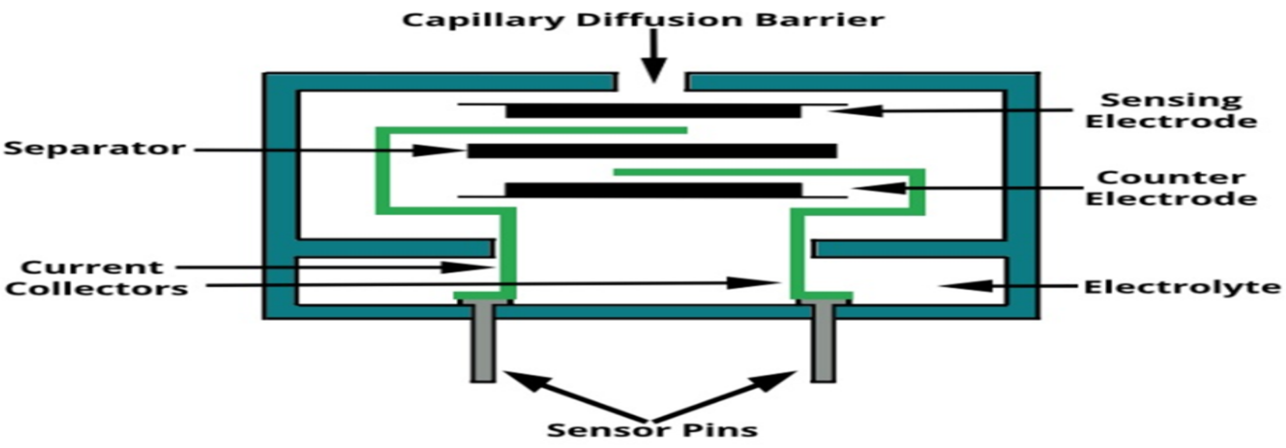
n = number of moles of electrons transferred

$[ox]$ = concentration of oxidized species

$[Red]$ = concentration of reduced species

(Park, 2009)

Figure 25: Working principle of ECDs (Components101, 2024)



2.3.3 Procedure

The detector was powered –on by pressing the power button for about 3 seconds, and the display screen lighted up. The detector entered the startup state, and the screen displayed the system initialization interface. The sound, alarm light, and vibration test were performed respectively, the sensor preheating started and finally displayed preheating completed after which it entered the welcome interface. The sampling tube was installed in the air intake port, the desired maximum and minimum limits were set, and the detection began.

2.4 DATA ANALYSIS

The collected data was analyzed using Statistical Package for the Social Sciences (SPSS) software version 26. The KOLMOGOROV test was used to check the normality of the data while descriptive statistics were generated to summarize the mean concentrations of benzene, toluene, xylene, and total volatile organic compounds in the work environment, as well as the frequency of self-reported symptoms among workers.

To examine the relationship between BTEX exposure and health symptoms, **Pearson correlation analysis** was employed. This statistical method was chosen to identify the strength and direction of linear relationships between the mean concentrations of BTEX compounds and the occurrence of specific symptoms reported by workers. The correlation coefficients (r) were interpreted as follows:

- Weak ($0.1 \leq |r| < 0.3$),
- Moderate ($0.3 \leq |r| < 0.5$),
- Strong ($r \geq 0.5$).

Significance levels were assessed at **$p<0.05$** and **$p<0.0011$** thresholds to determine the statistical reliability of the correlations. Symptoms with positive correlations to BTEX concentrations and statistically significant p-values were highlighted to identify potential health risks associated with exposure.

2.5 ETHICAL CONSIDERATIONS

In conducting this research on the evaluation of occupational safety and health amongst workers in filling stations and fuel depots in Yaoundé, and the characterization of associated family health risks, the following ethical considerations were adhered to, thereby ensuring the protection of participants and the integrity of the study.

1. **Informed Consent** All participants were provided with detailed information regarding the purpose, objectives, and potential implications of the study. They were required to give their voluntary consent before participation. Those who consented to participate in the study were

handed the questionnaire with the assurance that they could withdraw from the study at any time without any consequences.

2. **Confidentiality and Anonymity** The privacy of participants were protected by ensuring that all data collected remains confidential. Personal identifiers such as names, addresses, and specific workplace details were not recorded in any publication or report. Data was anonymized using codes to ensure that individual responses could not be traced back to specific participants.
3. **Non-Maleficence and Risk Minimization** The study was designed to minimize any potential harm to participants. The nature of questions and interactions were kept simple to avoid psychological distress. Additionally, human samples were not collected, and any identified occupational health risks was reported to relevant authorities while maintaining confidentiality.
4. **Beneficence** This research aimed to contribute positively to the well-being of workers and their families by identifying occupational hazards and providing recommendations for improved safety measures. The findings will be shared with relevant stakeholders, including policymakers and occupational health authorities, to facilitate evidence-based interventions.
5. **Voluntary Participation and Right to Withdraw** Participants were informed that their involvement in the study was entirely voluntary. They had the right to decline participation or withdraw at any stage without facing any penalties or negative consequences.
6. **Ethical Approval** Before commencing the study, administrative authorization was obtained from the administrations of the various filling stations, ethical approval will be obtained from the ethics review board of the University of Yaounde 1 to ensure that the research adheres to established ethical guidelines, and modifications will be made in accordance with the board's recommendations before any part of this work is published.
7. **Data Protection and Storage** All collected data were securely stored in a password-protected database, accessible only to authorized researchers. Hard copies of the dissertation did not disclose the identity of the various study sites, in compliance with data protection regulations.

By adhering to these ethical considerations, this study ensured the protection of participants' rights and well-being while contributing valuable knowledge to occupational safety and public health research.

CHAPTER THREE: RESULTS AND DISCUSSION

3.1 SURVEY FINDINGS

3.1.1 Socio - demographic characteristics of the sampled population

This section of the study presents the demographic characteristics of the sampled population. A total of **130** workers from 25 filling stations and fuel depots were assessed, and out of the total number of workers sampled, **94** were male representing **72.3%** of the total sampled, while 77out of the sampled size were married making a total of 59.2%. Their ages ranged from **31 to 58** years, with **50%** of the population aged below **42** years. **50%** of the studied population had finished secondary school. Majority of the employees did not smoke **(87.7%)** while **12.3 %** had stopped smoking; **58.5%** consumed alcohol and **50%** of the population had their body mass index (BMI) below **27.33**, with the BMI ranging from **20.68 to 35.32 kg/m2**.

Table 5: Demographic Characteristics of the Study Population(n=130)

Variables	Categories	N	%
Gender	Male	94	72.3
	Female	36	27.7
Marital status	Married	77	59.2
	Single	40	30.8
	Divorced	4	3.1
	Widow/widower	9	6.9
Level of education	Illiterate	0	0
	Primary	20	15.4
	Secondary	65	50
	University	45	34.6
Age	< 39	57	45.8
	40-50	37	28.5
	50-60	36	27.7
Median(Q1-Q3)[Min-Max]: 42(38-50)[31-58]			
BMI	<18.5	0	0
	18.5-24.9	23	17.7
	25-29.9	71	54.6
	>30	36	27.8
Median(Q1-Q3)[Min-Max]: 27.33(25.1-31.14)[20.68-35.32]			
Smoking status	Smokes	0	0
	Stopped smoking	16	12.3
	Never smoked	114	87.7
Alcohol consumption	Yes	76	58.5
	No	54	41.5
Number of children less than 12 years	0	29	22.3
	1-5	93	71.5
	>5	8	6.2
Number of adult children (18 years and above)	0	90	69.2
	1-5	39	30
	>5	1	0.8
Number of grand children	0	96	73.8
	1-5	16	12.3
	>5	18	13.9

3.1.2 Employment history and occupational exposure of filling station /fuel depot workers to BTEX compounds.

Research findings showed that, the frequency of personal hygiene practices amongst workers in the filling stations/fuel depots was **80%** and **50.8%** of the worker wore complete personal protective equipment (PPE) except for the use of respirator (nose mask) which stood at **9.2%.** Most subjects **(61.5%)** had work experience of 2 years or more, **65%** worked 8- 12 hours per day, and **86.9%** worked ≥ six days per week. These data are shown in table 6

Table 6: Employment history and occupational exposure to BTEX compounds(n=130).

Work history and exposure to BTEX compounds	N	%
Working area		
Loading/dispensing	41	31.5
offloading	27	20.8
laboratory	26	20.0
office	36	27.7
Working hours per day		
8hours	27	20.8
8-12hours	85	65.4
> 12hours	18	13.8
Working days per week		
5days	17	13.1
6days	97	74.6
7days	16	12.3
Working years		
<2	3	2.3
2-10	80	61.5
10-20	33	25.4
> 20	14	10.8
Personal hygiene		
Do not practice	26	20
Practice	74	80
Using personal protective equipment (PPE)		
Do not use/use partially	18	13.8
Do not have	46	35.4
use	66	50.8
Safety googles		
Do not have	66	50.8
Do not use	37	28.5
Use	27	20.8
Respirator use		
Do not have	106	81.5
Do not use	12	9.2
Use	12	9.2
Use of gloves during work		
Do not have	64	49.2
Do not use	14	10.8
Use	46	35.4
Use boots during work		
Do not have	11	8.5
Do not use	15	11.5
use	104	80.0
long –sleeved cotton shirts		
Do not have	11	8.5
Do not use	15	11.5
use	104	80.0
long cotton pants		
Do not have	16	12.3
Do not use	10	7.7
use	104	80.0

3.1.3 Occupational accidents reported by workers

Occupational accidents were reported by **73.1% (95/130)** of the participants (figure 29). The most frequently reported occupational accidents were outpouring of fuel on the workers **(50.8%),** contact between fuel and skin, eye contact with fuel, and fuel leaks, which were reported by **60** workers **(46.1%)** each, followed by fuel inhalation reported by **54** workers **(41.5%).**

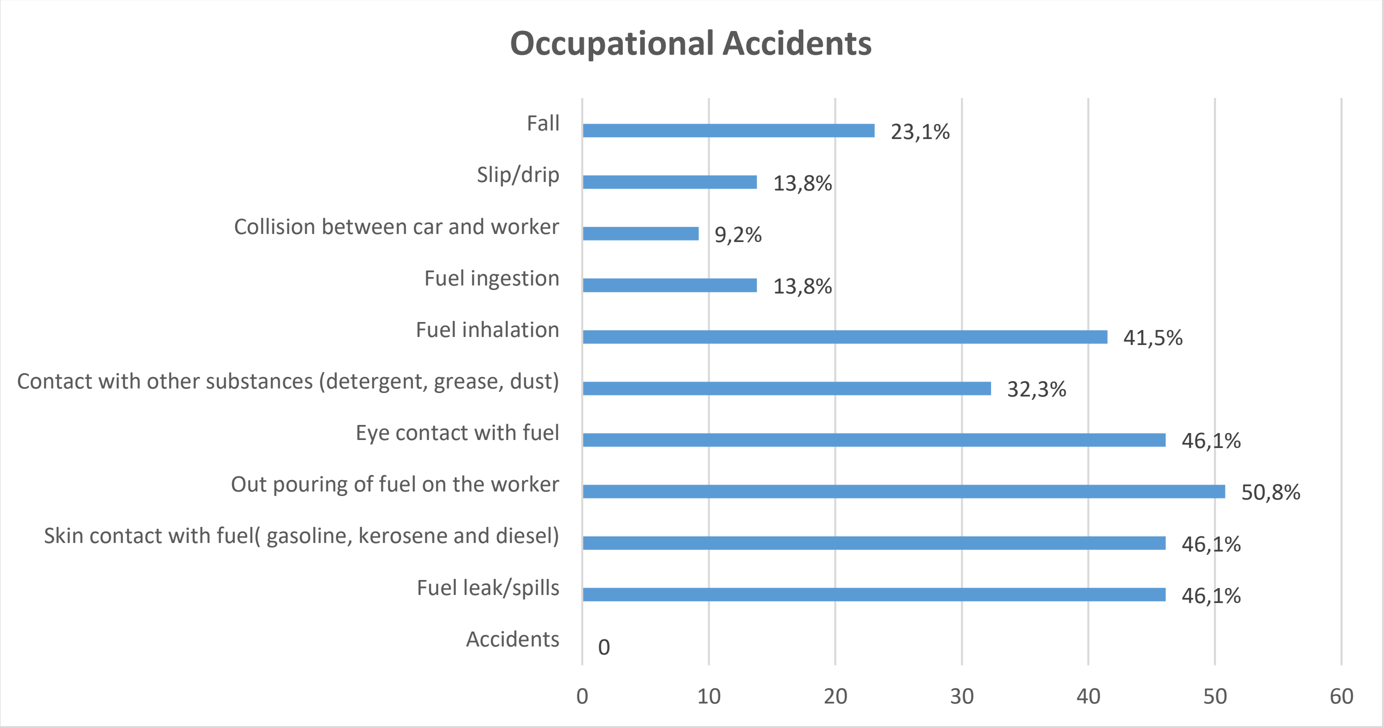


Figure 26: Occupational Accident

3.1.4 Health History reported by workers

The study findings pointed out that, medical examination is a common practice among filling station/fuel depot workers. Out of the 130 workers sampled, **74.6%** of them reported undertaking annual medical examination (Table 7) paid for by the employers. The distribution of signs/symptoms commonly experienced by the filling station/fuel depot workers as the adverse effect of BTEX toxicity were reported as follows; headaches **(96.2%),** fatigue **(100%),** mild symptoms(cough/hoarseness, burning nose/congestion, sore throat, breathlessness, dizziness, sleeplessness, cracked skin, skin rashes, burning sensation, burning eyes, fatigue and numbness)**(18.5%),** moderate symptoms (anorexia, blurred vision, tight chest, vomiting, muscle weakness, cramp, drowsiness, depression, confusion, tremor, scurvy) **(40.8%),** and severe symptoms (petechial, tachycardia, unconsciousness, and anemia)**(25.4%).** This implies that **84.6%** of the study population experienced signs of BTEX toxicity.

3.1.5 Associated family health risk

Out of the 36 females who participated in the survey, **20 (55.5%)** reported to have been pregnant while working in this sector and **23 (17.7%)** of the study population testified of miscarriage either by their wives or themselves. **9 (6.9%)** of the workers testified of having children suffering from a chronic or genetic disease.

Table 7: Health History reported by workers and associated family health risk(n=130).

Health Information	**N**	**%**
Medical check ups		
Monthly	0	0
Every 6 months	12	9.2
Once a year	97	74.6
When I feel sick	21	16.2
I pay the bills	41	31.5
My company pays the bills	89	68.5
You are sick but all routine medical test are negative		
Yes	66	50.8
No	64	49.2
Pregnant while working in this sector		
Yes	20	15.4
No	110	84.6
Have you/your wife ever suffered from any miscarriages		
Yes	23	17.7
No	107	82.3
Have a child with any chronic/genetic disease		
Yes	9	6.9
No	121	93.1
Have a grandchild with any chronic/genetic disease		
Yes	0	0
No	130	100
Do you suffer from any chronic disease		
No	105	80.8
Diabetes	0	0
Hypertension	5	3.8
Chronic respiratory disease	14	10.8
Cancer	0	0
HIV	0	0
Genetic disorder	11	8.5
Adverse health effects related to BTEX toxicity		
No symptom	20	15.4
Mild signs and symptoms	24	18.5
Moderate symptoms	53	40.8
Severe symptoms	33	25.4

Table 8: Frequency of signs and symptoms amongst filling station/fuel depot workers(n=130).

Signs and symptoms	**Frequency of signs and symptoms per work area**				**Total frequency of signs and symptoms across filling stations(n=130)**	
	Loading/ refueling(n=41)	Off-loading(n=27)	Laboratory(n=26)	Office(n=36)		
	N	N	N	N	N	%
Breathlessness	15	15	10	10	50	38.5
Cough/hoarseness	30	25	15	25	95	73.1
Burning nose/congestion	15	15	10	15	55	42.3
Throat irritation	25	15	5	5	50	38.5
Dizziness	30	20	10	15	75	57.7
Headache	41	27	22	35	125	96.2
Sleeplessness	25	15	5	15	55	42.3
Cracked skin	10	15	10	5	40	30.8
Skin rashes	20	5	5	5	35	26.9
Burning sensation	15	10	0	0	25	19.2
Burning eyes	35	25	15	20	95	73.1
Fatigue	41	27	26	36	130	100
Numbness	5	5	0	5	15	11.5
Anorexia	5	0	0	0	5	3.8
Blurred vision	20	15	0	10	45	34.6
Tight chest	10	5	0	5	20	15.4
Vomiting	5	15	0	0	20	15.4
Muscle weakness	25	20	10	15	70	53.8
Cramp	10	20	0	5	35	26.9
Drowsiness	30	20	0	0	50	38.5
Depression	10	20	0	0	30	23.1
Confusion	10	10	0	0	20	15.4
Unusual tiredness	30	25	5	15	75	57.7
Tremor	10	10	0	0	20	15.4
Scurvy	0	5	0	0	5	3.8
Petechial	5	0	0	0	5	3.8
Tachycardia	10	5	5	5	25	19.2
Unconsciousness	10	0	0	0	10	7.7
Anemia	5	5	0	0	10	7.7

3.1.6 Knowledge on benzene, toluene, ethylbenzene and xylene (BTEX) exposure

As can be inferred from the pie chart below, 90.77% of the sampled population had little or no knowledge of BTEX exposure and health risk, while all participants **(100%)** demonstrated their interest for a training on this subject.

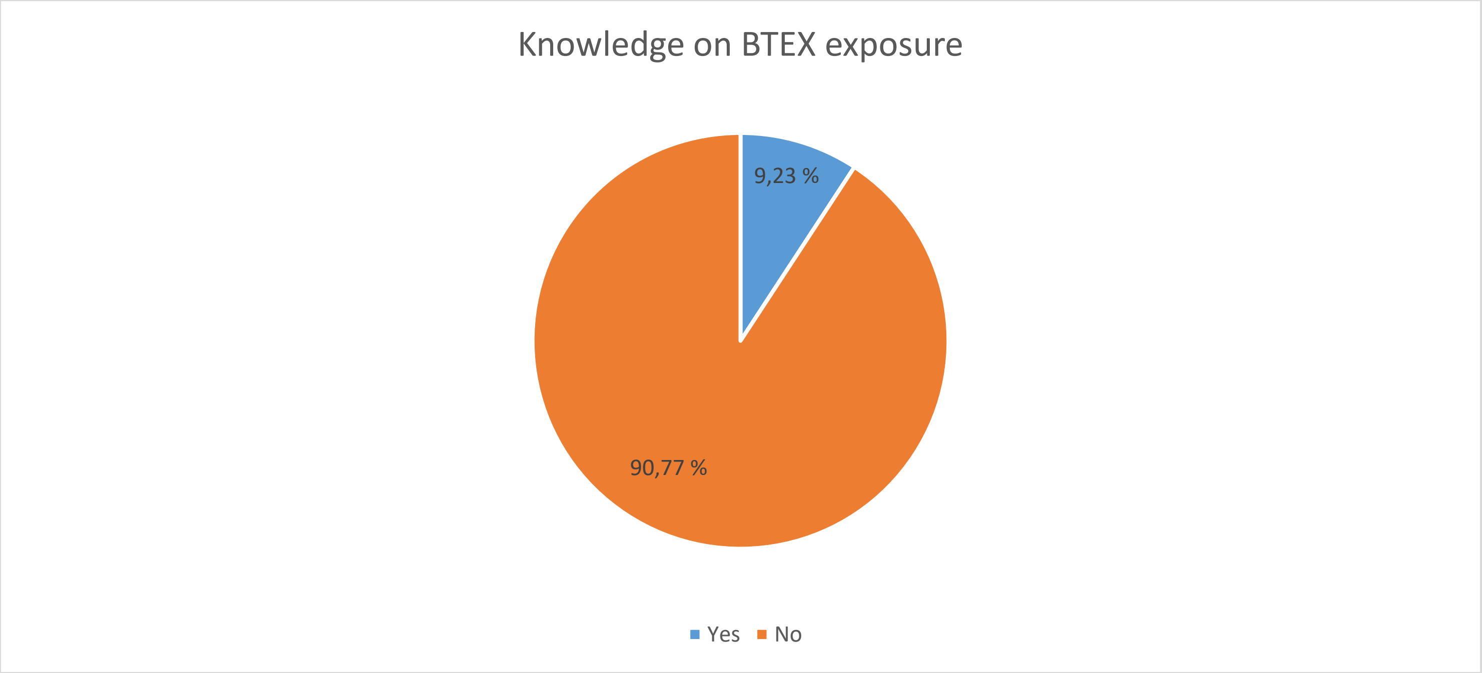


Figure 27: knowledge on BTEX exposure

3.2 VOCS (BTEX MONITORING)

3.2.1 Mean and standard deviation of VOCs (BTEX) by filling station/fuel depot

The analysis of BTEX (benzene, toluene, ethylbenzene, and xylene) and VOC concentrations across filling stations revealed alarmingly high levels, often exceeding occupational safety limits. Average benzene levels ranged from **7.63 ppm** to **14.21 ppm**, with peaks up to **19.64 ppm**, far above OSHA's permissible exposure limit of 1 ppm for an 8-hour workday. Toluene and xylene concentrations also varied significantly, with maximum values reaching **19.71 ppm** and **31.70 ppm**, respectively, posing risks of neurological and systemic toxicity. VOC concentrations peaked at **50 ppm**, indicating cumulative exposure to harmful compounds. Stations such as FS9, FS15, and FS26 consistently recorded the highest levels (table 9), highlighting potential hotspots of occupational hazard.

Table 9: Mean and standard deviation of ambient VOCs (BTEX) concentrations at the offloading bay across filling stations/fuel depots (at a constant temperature of 31 °C).

Filling point	Benzene concentration(ppm)			Toluene concentration(ppm)			Xylene concentration(ppm)			VOC concentration(ppm)		
	Mean (SD)	Min	Max	Mean (SD)	Min	Max	Mean (SD)	Min	Max	Mean (SD)	Min	Max
FS1	8.89(5.01)	4.22	16.88	12.27(5.47)	5.08	19.06	10.56(6.13)	4.48	17.82	12.82(3.85)	8.98	17.85
FS2	9.67(5.58)	5.40	19.16	9.95(4.63)	7.37	18.18	12.67(6.62)	4.90	19.71	13.44(5.87)	5.46	21.10
FS3	11.29(5.70)	4.58	18.93	10.85(3.94)	4.33	14.99	13.99(4.83)	8.40	19.44	9.68(5.76)	5.01	17.13
FS4	10.87(7.28)	4.60	18.92	10.82(3.69)	4.33	14.99	9.67(2.12)	6.18	11.50	10.16(3.27)	7.58	15.38
FS5	13.80(5.23)	5.60	18.02	12.42(3.70)	7.50	16.16	11.46(3.98)	8.38	18.14	10.79(4.25)	6.68	16.10
FS6	9.73(5.02)	4.96	16.33	8.93(5.32)	5.19	18.27	12.73(6.66)	5.37	19.99	9.59(3.46)	5.50	13.31
FS7	8.91(3.97)	4.44	13.83	11.24(4.63)	7.34	18.95	10.29(5.81)	4.73	19.37	13.66(4.10)	7.64	17.00
FS8	9.60(6.14)	4.66	16.74	13.39(3.13)	10.40	18.61	10.57(5.26)	5.34	19.09	12.71(4.25)	8.22	17.13
FS9	14.21(6.31)	5.30	19.64	13.51(4.73)	8.15	17.91	13.97(4.98)	8.17	18.90	15.45(3.31)	10.05	17.80
FS10	12.67(6.83)	4.80	18.86	11.41(4.73)	7.10	17.76	10.10(4.60)	4.91	17.22	13.40(5.65)	6.02	21.50
FS11	8.09(2.94)	5.68	12.57	9.41(3.70)	4.87	13.35	12.57(3.45)	9.50	18.42	12.15(4.22)	6.45	16.20
FS12	12.76(5.26)	5.00	18.70	8.31(2.56)	6.32	11.61	8.99(2.97)	6.10	12.40	13.52(6.52)	6.88	23.90
FS13	10.53(5.55)	4.60	16.60	10.93(4.73)	6.04	17.81	10.08(5.31)	4.89	18.15	13.72(5.21)	8.57	22.20
FS14	9.18(2.98)	6.10	13.72	9.89(2.95)	7.37	14.08	11.88(5.28)	6.75	19.82	11.34(5.69)	5.60	18.74
FS15	8.70(3.25)	4.50	13.54	10.78(5.47)	4.59	16.44	12.23(6.06)	5.50	19.49	16.29(6.30)	7.58	22.60
FS16	9.04(2.91)	5.20	12.25	9.23(4.85)	4.62	17.24	10.01(4.54)	4.77	16.09	10.47(5.85)	5.54	18.60
FS17	14.19(4.29)	6.70	16.93	13.31(5.89)	6.04	19.71	16.25(2.72)	12.20	18.93	11.47(4.74)	4.40	17.70
FS18	7.63(2.55)	4.70	11.51	14.92(3.16)	10.75	18.84	13.46(4.85)	5.17	16.80	11.36(5.00)	6.02	16.89
FS19	10.2(4.17)	4.30	15.97	13.57(4.9)	4.72	16.51	9.98(5.08)	2.00	16.06	12.62(4.77)	5.04	17.84
FS20	11.32(6.72)	4.40	19.35	11.90(5.12)	5.52	19.16	10.33(5.23)	5.55	18.68	12.54(6.23)	4.08	19.32
FS21	9.24(6.51)	4.20	19.42	13.34(2.94)	9.32	17.31	9.15(3.93)	5.85	15.06	13.69(2.45)	9.93	16.71
FS22	9.69(4.51)	4.50	14.48	11.13(4.49)	5.36	15.40	16.50(9.75)	4.42	31.70	11.67(4.70)	6.40	17.27
FS23	11.54(5.20)	4.50	16.69	13.95(4.58)	8.04	19.48	13.18(3.55)	7.00	16.09	11.03(3.63)	7.86	16.33
FS24	12.07(5.63)	4.70	17.94	10.82(4.25)	6.22	14.92	13.48(5.14)	4.69	16.96	10.94(4.90)	5.46	**16.90**
FS25	8.81(4.48)	3.20	15.27	8.28(4.22)	4.80	14.43	10.90(4.40)	4.90	15.83	16.02(13.4)	5.96	39.00
FS26	9.72(6.43)	2.50	16.87	11.81(6.22)	4.00	19.39	12.07(6.65)	4.30	19.18	14.28(19.99)	4.22	50.00

SD : standard deviation min : minimum value max : maximum value ppm : parts per million

3.2.2 Average BTEX concentrations (in ppm) at different work areas.

Average BTEX concentrations (in ppm) in the refueling bays, offloading bays, laboratories and offices (average atmospheric temperature during the monitoring period was 31 °C) are presented in table 10 below.

Table 10: Average BTEX concentration per work area

Work Area	Benzene	Toluene	Xylene	VOCs
Loading/refueling bay				
Mean	100.5	103.9	107.6	161.2
Minimum	42.9	44	47	59.5
Maximum	248	245.5	258	249.7
Standard deviation	45.5	50.8	46.4	59.5
Offices				
Mean	10.5	11.4	11.8	12.5
Minimum	7.6	8.3	8.99	9.6
Maximum	14.2	14.9	16.5	16.3
Standard deviation	1.9	1.8	2.0	1.8
Offloading bay				
Mean	10.48	11.4	11.81	12.49
Minimum	2.50	4.00	2.00	4.22
Maximum	19.64	19.71	31.7	50.0
Standard deviation	5.4	4.38	5.0	5.67
Laboratory				
Mean	17.8	20.0	17.9	20.4
Minimum	10.9	12.3	8.5	12.5
Maximum	24.3	26.3	25.2	29.6
Standard deviation	3.6	3.4	3.8	4.8

3.2.3 Correlation between worker's health history from survey and Average BTEX concentration.

Correlation Between Xylene and Symptoms

- **Strong Correlations:** Drowsiness ($r=0.5$, $p<0.001$), burning sensation ($r=0.382$, $p<0.001$), skin rashes ($r=0.361$, $p<0.001$), and throat irritation ($r=0.337$, $p<0.001$) exhibited moderate to strong correlations, suggesting significant effects of xylene exposure on these symptoms.
- **Moderate Correlations:** Symptoms such as anorexia ($r=0.295$, $p=0.002$), unusual tiredness ($r=0.31$, $p=0.001$), and unconsciousness ($r=0.371$, $p<0.001$) also showed meaningful relationships.

- **Weak or Non-Significant Correlations:** Symptoms such as dizziness (r=0.22, p=0.025) and sleeplessness (r=0.232, p=0.0) exhibited weak correlations but were still statistically significant.
- **No Correlation:** Symptoms like cracked skin, numbness, and vomiting showed no significant correlation.

Table 11:Correlation between Xylene and Symptoms

Symptoms	Correlation coefficient (r)	p-value	Significance level
Breathlessness	0.181	0.066	
Cough/hoarseness	0.111	0.262	
Burning nose/congestion	0.059	0.554	
Throat irritation	0.337	<0.001	**
Dizziness	0.22	0.025	*
Headache	0.131	0.184	
Sleeplessness	0.232	0.018	*
Cracked skin	-0.085	0.389	
Skin rashes	0.361	<0.001	**
Burning sensation	0.382	<0.001	**
Burning eyes	0.177	0.072	*
Fatigue	NA	NA	
Numbness	-0.081	0.413	
Anorexia	0.295	0.002	**
Blurred vision	0.201	0.041	
Tight chest	-0.107	0.279	
Vomiting	0.006	0.954	
Muscle weakness	0.071	0.474	
Cramp	0.101	0.31	
Drowsiness	0.5	<0.001	**
Depression	0.169	0.086	
Confusion	0.263	0.007	**
Unusual tiredness	0.31	0.001	**
Tremor	0.187	0.057	
Scurvy	-0.074	0.453	
Petechial	0.17	0.085	
Tachycardia	0.024	0.806	
Unconsciousness	0.371	<0.001	**
Anemia	0.224	0.022	*

Correlation Between Benzene and Symptoms

- **Strong Correlations:** Skin rashes (r=0.376, p<0.001), burning sensation (r=0.308, p=0.001), and unconsciousness (r=0.4, p<0.001).
- **Moderate Correlations:** Symptoms such as throat irritation (r=0.297, p=0.002) and drowsiness (r=0.462, p<0.001).
- **Weak or Non-Significant Correlations:** Breathlessness (r=0.197, p=0.045) and sleeplessness (r=0.225, p=0.022) were significant but weak.
- **No Correlation:** Symptoms like tight chest, muscle weakness, and vomiting showed no relationship.

Table 12: Correlation Between Benzene and Symptoms

Symptom	Correlation coefficient (r)	p-value	Significance level
Breathlessness	0.197	0.045	*
Cough/hoarseness	0.042	0.674	
Burning nose/congestion	0.049	0.619	
Throat irritation	0.297	0.002	**
Dizziness	0.191	0.052	
Headache	0.124	0.21	
Sleeplessness	0.225	0.022	*
Cracked skin	-0.18	0.068	
Skin rashes	0.376	<0.001	**
Burning sensation	0.308	0.001	**
Burning eyes	0.158	0.112	
Fatigue	NA	NA	
Numbness	-0.095	0.336	
Anorexia	0.288	0.003	**
Blurred vision	0.127	0.199	
Tight chest	-0.086	0.384	
Vomiting	-0.074	0.455	
Muscle weakness	0.027	0.787	
Cramp	0.066	0.504	
Drowsiness	0.462	<0.001	**
Depression	0.061	0.54	
Confusion	0.204	0.037	*
Unusual tiredness	0.248	0.011	*
Tremor	0.151	0.126	
Scurvy	-0.097	0.329	
Petechial	0.185	0.06	
Tachycardia	0.042	0.671	
Unconsciousness	0.4	<0.001	**
Anemia	0.137	0.166	

Correlation Between Toluene and Symptoms

- **Strong Correlations:** Symptoms such as throat irritation (r=0.395, p<0.001), drowsiness (r=0.472, p<0.001), and burning sensation (r=0.388, p<0.001).
- **Moderate Correlations:** Burning eyes (r=0.232, p=0.018) and anorexia (r=0.257, p=0.009).
- **Weak Correlations:** Dizziness (r=0.228, p=0.02), sleeplessness (r=0.214, p=0.029), and confusion (r=0.241, p=0.014).
- **No Correlation:** Cracked skin and tachycardia exhibited negligible correlations.

Table 13: Correlation between Toluene and Symptoms

Symptom	Correlation coefficient (r)	p-value	Significance level
Breathlessness	0.157	0.112	
Cough/hoarseness	0.096	0.33	
Burning nose/congestion	0.114	0.251	
Throat irritation	0.395	<0.001	**
Dizziness	0.228	0.02	*
Headache	0.146	0.139	
Sleeplessness	0.214	0.029	*
Cracked skin	-0.076	0.444	
Skin rashes	0.353	<0.001	**
Burning sensation	0.388	<0.001	**
Burning eyes	0.232	0.018	*
Fatigue	NA	NA	
Numbness	-0.082	0.411	
Anorexia	0.257	0.009	**
Blurred vision	0.209	0.034	*
Tight chest	-0.116	0.242	
Vomiting	0.072	0.469	
Muscle weakness	0.133	0.179	
Cramp	0.169	0.086	
Drowsiness	0.472	<0.001	**
Depression	0.237	0.015	*
Confusion	0.241	0.014	*
Unusual tiredness	0.292	0.003	**
Tremor	0.189	0.055	
Scurvy	-0.045	0.647	
Petechial	0.191	0.052	
Tachycardia	-0.001	0.992	
Unconsciousness	0.343	<0.001	**
Anemia	0.157	0.112	

Correlation Between VOCs (Combined) and Symptoms

- **Strong Correlations:** Drowsiness (r=0.582, p<0.001), burning sensation (r=0.486, p<0.001), and tremor (r=0.377, p<0.001).
- **Moderate Correlations:** Throat irritation (r=0.354, p<0.001), cramp (r=0.387, p<0.001), and unconsciousness (r=0.351, p<0.001).
- **Weak Correlations:** Symptoms like sleeplessness (r=0.21, p=0.033) and muscle weakness (r=0.209, p=0.034).
- **No Correlation:** Fatigue and cracked skin show no significant association.

Table14: Correlation between VOC and Symptoms

Symptom	Correlation coefficient (r)	p-value	Significance level
Breathlessness	0.175	0.076	
Cough/hoarseness	0.15	0.129	
Burning nose/congestion	-0.043	0.662	
Throat irritation	0.354	<0.001	**
Dizziness	0.347	<0.001	**
Headache	0.151	0.127	
Sleeplessness	0.21	0.033	*
Cracked skin	-0.011	0.91	
Skin rashes	0.36	<0.001	**
Burning sensation	0.486	<0.001	**
Burning eyes	0.108	0.278	
Fatigue	NA	NA	
Numbness	0.006	0.95	
Anorexia	0.213	0.03	*
Blurred vision	0.232	0.018	*
Tight chest	0.065	0.512	
Vomiting	0.115	0.246	
Muscle weakness	0.209	0.034	*
Cramp	0.387	<0.001	**
Drowsiness	0.582	<0.001	**
Depression	0.339	<0.001	**
Confusion	0.254	0.009	**
Unusual tiredness	0.221	0.024	*
Tremor	0.377	<0.001	**
Scurvy	0.097	0.328	
Petechial	0.258	0.008	**
Tachycardia	0.149	0.13	**
Unconsciousness	0.351	<0.001	
Anemia	0.161	0.103	

3.3 Risk Assessment of Filling Stations and Fuel Depots

The risk assessment of filling stations and fuel depots identified several hazards, including overfills, uncontrolled vapor release, leaks, and fire/explosion risks during tanker offloading, fuel storage, and dispensing/loading operations. The results demonstrated that almost all the filling stations had the same potential hazards and similar probability of occurrence except for FS26 where the probability of occurrence was higher. Existing control measures, such as high-level alarms, leak detection systems, firefighting equipment, and absorbent materials, mitigate some risks, with FS26 having more stringent measures in place. However, significant gaps were noted, including the absence of vapor recovery systems to control emissions, inadequate staff training on safety protocols, and lack of personal protective equipment like respirators, leaving workers exposed to harmful vapors and increasing environmental, health, and safety risks (table 15 and 16).

Table 15: Risk Assessment of Filling Stations and Fuel Depots

STATION	**HAZARDS**							
	Overfill/ Spillage	**Uncontrolled Vapor Release**	**Fire/ Explosion**	**Leaks**	**Ignition Sources**	**Vehicle Impact**	**Equipment Failure**	**Members Of The Public**
FS1	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS2	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS3	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS4	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS5	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS6	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS7	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS8	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS9	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS10	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)

STATION	HAZARDS							
	Overfill/ Spillage	**Uncontrolled Vapor Release**	**Fire/ Explosion**	**Leaks**	**Ignition Sources**	**Vehicle Impact**	**Equipment Failure**	**Members Of The Public**
FS11	Yes(rare)	Yes(Constantly present).	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS12	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS13	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS14	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS15	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes(common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS16	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS17	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS18	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes(common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS19	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS20	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS21	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS22	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS23	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS24	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS25	Yes(rare)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes (common)	Yes (rare)	Yes (rare)	Yes(Constantly present)
FS26	Yes(common)	Yes(Constantly present)	Yes(rare)	Yes (common)	Yes(rare)	Yes (rare)	Yes (common)	No

Table 16: Hazard Mitigation Measures

STATION	CONTROL MEASURES								
	High level alarm	**Vapor recovery systems**	**Firefighting equipment**	**Retention systems**	**Leak detection systems**	**Gauge systems**	**Staff training**	**Emergency procedures**	**Use of PPE**
FS1	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators)
FS2	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS3	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS4	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS5	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS6	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS7	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS8	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS9	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS10	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS11	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS12	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS13	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS14	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS15	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators

FS16	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
STATION	**CONTROL MEASURES**								
	High level alarm	**Vapor recovery systems**	**Firefighting equipment**	**Retention systems**	**Leak detection systems**	**Gauge systems**	**Staff training**	**Emergency procedures**	**Use of PPE**
FS17	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS18	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS19	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS20	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS21	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS22	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS23	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS24	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS25	No	No	Yes(fire extinguisher)	Yes	No	Yes	Yes (rare)	Yes	Yes (except respirators
FS26	Yes	No	Yes (sophisticated equipment)	Yes	Yes	Yes	Yes (common)	Yes	Yes (except respirators

DISCUSSION

The overall objective of this study was to evaluate the occupational safety and health (OSH) of workers in the various filling stations/fuel depots in Yaounde involved in the manipulation of petrochemical agents and attempt to characterize the associated family health risk. For this purpose, a sample of 130 employees of filling stations/ fuel depots without distinction of sex, nor activity were interviewed to gather information on worker's personal health history and any associated family health risk. 520 air samples were analyzed on-site for VOC (BTEX) levels of ATEX zones with the portable pump suction gas detector, including VOC levels for offices to evaluate the impact of work post to BTEX exposure. However, it was considered important to associate with this air analysis, Risk assessment of the 26 filling stations and fuel depots to identify and evaluate other hazards or risks, other than exposure to VOCs (BTEX).

Findings showed that majority of the filling station and fuel depot employees **(72.3%)** were male which contradicts the findings of Thetkathuek *et al*., 2023**,** who studied the characteristics of gas station employees in Rayong Province, Thailand and found most to be female workers (68.5%), but agrees with the findings of a study conducted in Yaounde- Cameroon, which found that the vast majority of service station employees were male (80%) (Luc-Aimé, 2021). The average age of participants in the present study, **42(38-50)[31-58**] years, is in better agreement with the results of a previous study **(**S ELsayed *et al.,* 2018), which investigated occupational hazards amongst gas station workers in Egypt and discovered that the mean age of gas station workers was 38.42±9.22 years. In the present study, **50%** of workers had completed secondary school, which is consistent with the results of a study conducted in Brazil, which found that 50.2% had graduated with secondary education (Laurelize *et al*, 2014)**. 76 (58.5%)** of the study population consumed alcohol which may increase the rate at which toxic metabolites of benzene are formed (Pope & Rall, 1995).

Results from the analysis of BTEX and total VOC concentrations in 26 filling stations and fuel depots highlighted a critical occupational and environmental health concern. The elevated levels of benzene, toluene, xylene, and VOCs (Correa *et al.,* 2012) observed significantly exceed safety thresholds set by occupational and environmental standards, particularly the OSHA permissible exposure limit (PEL) of 1 ppm for benzene (Paxman *et al,* 1990), the ACGIH PEL of 20 ppm for toluene and ethylbenzene, and the German maximum workplace concentrations of 50ppm for xylene, with NIOSH defining even lower PEL of 0.1ppm for Benzene and toluene whereas the occupational exposure limit of 23 ppm for xylene is defined for Poland (Rahimpoor *et al*., 2022). The World Health Organization (WHO, 2010) states that benzene is a known human carcinogen and thus no safe level of exposure can be recommended. This suggests that workers and individuals in proximity to these filling stations are at heightened risk of exposure to toxic air pollutants. Benzene, as a known carcinogen, poses risks of leukemia and other hematological disorders, while elevated levels of toluene and xylene are associated with neurological and respiratory problems. The findings are alarming as they demonstrate localized hotspots (FS9, FS15, and FS26) where pollutant levels are disproportionately high. Such variability could be influenced by factors like operational practices, the volume of fuel dispensed, and environmental conditions like wind direction and temperature. Additionally, the VOC concentrations reaching as high as 50 ppm suggest substantial emissions from fueling operations and absence or potential vapor recovery system failures, which may contribute to broader air quality degradation in urban settings.

Survey results indicated that filling station and fuel depot workers experience significant adverse health effects, likely due to BTEX exposure (Cezar-Vaz *et al*, 2012). The most prevalent symptoms included fatigue **(100%),** headache **(96.2%),** cough/hoarseness **(73.1%),** burning eyes **(73.1%),** and dizziness **(57.7%),** highlighting widespread respiratory and neurological impacts. Moderate symptoms such as burning nose/congestion **(42.3%),** sleeplessness **(42.3%),** and muscle weakness **(53.8%)** further emphasize systemic strain. Less frequent but concerning symptoms like tight chest **(15.4%),** tachycardia **(19.2%),** anemia **(7.7%),** and unconsciousness **(7.7%)** point to potential severe and long-term health risks, particularly hematotoxicity and cardiovascular effects. The study also highlighted significant correlations between exposure to BTEX compounds and various health symptoms among workers. Xylene exposure was strongly linked to symptoms such as drowsiness, burning sensations, skin rashes, and throat irritation. Benzene showed similar associations, particularly with skin rashes, drowsiness, burning sensations, and unconsciousness. Toluene exposure is also correlated with throat irritation, drowsiness, burning sensations, and confusion. Combined VOC exposure amplified these effects, with strong correlations observed for drowsiness, burning sensations, and tremors. Across all VOCs, neurological (e.g., drowsiness, confusion), respiratory (e.g., throat irritation), and dermatological symptoms (e.g., skin rashes) were consistently reported. In a study by Tunsaringkarn *et al*, 2011 in Bangkok, it was concluded that, continued exposure to BTEX compounds is significantly associated with the prevalence of headaches, fatigue, dizziness and throat irritation while benzene, toluene, ethylbenzene and xylene found in gasoline has been shown to have potential of red blood cell toxicity (Tunsaringkarn *et al*, 2013). Further, an empirical study in Iraq involving 48 adult subjects working in gasoline filling stations revealed that long-term exposure to petroleum derivatives increases the risk of liver and hematopoietic toxicity (Mahmood *et al*, 2012).

Most workers **65.4%** worked for 8-12hours and **13.8%** worked for more than 12-hours a day, as gathered from this study, which exceeds the OSHA standards (8 hours) and perhaps one of the reasons for the high prevalence of adverse health effects.

Risk assessment of filling stations and fuel depots identified several hazards, including overfills, uncontrolled vapor release, leaks, and fire/explosion risks during tanker offloading, fuel storage, and dispensing/loading operations. The results demonstrated that almost all the filling stations had the same potential hazards and similar probability of occurrence except for FS26 where the probability of occurrence was higher. Existing control measures, such as high-level alarms, leak detection systems, firefighting equipment, and absorbent materials, mitigate some risks, with FS26 having more stringent measures in place. However, significant gaps were noted, including the absence of vapor recovery systems to control emissions, inadequate staff training on safety protocols, and lack of personal protective equipment like respirators, leaving workers exposed to harmful vapors and increasing environmental, health, and safety risks. The most frequently occurring occupational accidents were outpouring of fuel (gasoline, kerosene, diesel) on the worker (50.8%), contact between fuel and skin, eye contact with fuel, and fuel leaks, which were reported by 60 workers (46.1%) each, followed by fuel inhalation reported by 54 workers (41.5%) mostly for loading or refueling workers, due to proximity of the worker to the orifice of the loading chamber and vapors emitted by vehicles. Depending on the number of working hours, the fuel exposure can be larger or smaller. The greater the fuel exposure, the greater the chance of contact with the skin and eyes of workers (Cezar-Vaz et al, 2012). The hazards identified in this assessment align with findings from previous studies examining occupational safety in fueling stations. Astbury, 2008 emphasized that fuel handling processes expose workers to significant risks of vapor inhalation, fire, and explosion, particularly in the absence of vapor recovery systems. Moreover, Jafari *et al*., 2007 reported that poorly maintained equipment, lack of safety training, and insufficient protective measures in fuel stations exacerbate occupational hazards. Vapor emissions during fuel dispensing are particularly concerning, as they contribute to environmental pollution and increase workers' exposure to hazardous compounds. Like our findings, these studies highlight the importance of installing vapor recovery systems to minimize uncontrolled emissions. The fire and explosion risks identified in this study reflect observations from Khan *et al*., 2015, who noted that ignition sources, such as car exhausts and electrical sparks, are frequent causes of fuel station fires. Proper maintenance of storage tanks, regular leak detection, and strict safety protocols are critical to reducing these risks. The gaps identified in staff training and the use of personal protective equipment (PPE) are consistent with findings by Kyalo, 2020, who reported that inadequate knowledge of safety practices among fuel station workers significantly increases the likelihood of accidents and exposure to harmful chemicals. Providing routine safety training and equipping workers with PPE, such as respirators and fire-resistant gear, can greatly improve occupational safety.

The survey findings also highlighted significant reproductive and family health concerns among filling station and fuel depot workers, potentially linked to occupational exposure to BTEX and other hazardous chemicals. Among the 36 female participants, 20 (55.5%) reported being pregnant while working in this sector, raising concerns about maternal exposure during critical periods. Additionally, 23 (17.7%) of the overall study population reported experiencing miscarriages, either personally or through their spouses, suggesting a link between occupational exposure and pregnancy loss. Furthermore, 9 (6.9%) of workers reported having children suffering from chronic or genetic diseases, indicating potential long-term effects of parental exposure on offspring health. The finding that 55.5% of female workers reported being pregnant while working in this sector is concerning, as studies, such as those by (Protano et al., 2012; Patelarou et al., 2014), have linked maternal exposure to benzene with increased risks of fetal growth restriction, premature births, and pregnancy complications. Additionally, the reported miscarriage rate of 17.7% among the study population is consistent with evidence associating benzene exposure with higher miscarriage risks due to its hematotoxic effects. These findings emphasize the potential harm of occupational exposure to BTEX on reproductive health, reinforcing the need for improved workplace safety measures

LIMITATIONS, CONCLUSION, RECOMMENDATIONS AND PERSPECTIVES

LIMITATIONS OF THE STUDY

This research was conducted in Yaounde, Centre Region, one out of the ten regions of Cameroon, which restricts the generalizability of the findings across the entire country. Since filling stations may be owned by different marketers in different regions, worker's practices, and control measures may vary widely across regions. Furthermore, conducting this research in Cameroon presented unique challenges, as there are no prior studies on occupational exposure of filling station and fuel depot workers to Benzene, Toluene, Ethyl benzene and Xylene in Cameroon (making sample size calculation difficult). This thesis represents the first attempt to evaluate the occupational safety and health amongst workers in filling stations/fuel depots (with focus on BTEX exposure) in Cameroon, making it necessary to rely on studies from other countries, for example, Nigeria, Ghana, and Thailand, where similar research has been conducted. Another great challenge was the inability of the equipment (portable pump suction gas detector) to measure ethyl bene levels, hence total VOC levels considered in place of ethylbenzene levels. Another limitation encountered was the reluctance of some workers to participate in the survey portion of the study. The lack of receptiveness from these workers restricted the diversity and quantity of data collected.

CONCLUSION

Based on the findings from this study and the discussions, the hypothesis that "there is a significant association between occupational exposure to hazardous substances at filling stations/fuel depots and adverse health outcomes among workers" was validated. Therefore, it can be concluded that:

1. BTEX concentrations in ambient air of filling stations and fuel depots in Yaounde are considerably high (B[10.48], T[11.4], X[11.81], VOC[12.49]), often exceeding safety thresholds, thereby, providing evidence of significant occupational health risks (fatigue, headaches, respiratory irritation, and dizziness, with severe effects such as tachycardia, anemia, and miscarriages) faced by workers due to exposure to volatile organic compounds.
2. Filling stations and fuel depots face significant safety and health risks, primarily from overfills, uncontrolled vapor release, leaks, and fire/explosion during tanker offloading, fuel storage, and dispensing/loading operations. Current reliance on basic systems such as fire extinguishers and retention systems is insufficient to fully address these risks. There is a critical need to adopt more sophisticated safety measures, including vapor recovery systems, high-level alarms, and advanced leak detection technologies, alongside strengthening staff training, emergency protocols, and proper use of PPE including respirators (nose mask) to enhance safety and mitigate risks effectively**.**

3. There is a strong potential link between occupational exposure to BTEX and significant reproductive and family health concerns among filling station and fuel depot workers. A percentage of female workers reporting pregnancies during employment, combined with miscarriages, and chronic or genetic diseases in workers' children, underscores the risks of maternal and paternal exposure to hazardous chemicals like benzene.

RECOMMENDATIONS

1. Government:

   Implement strict regulations such as ventilation controls, installation of vapor recovery systems on refueling pumps and safety practices, as well as annual enforcement controls on employers to prevent or minimize worker's exposure to BTEX.

2. Employers

   Organize regular trainings for filling station/fuel depot workers to educate them on possible occupational hazards in filling stations/fuel depots and health risks of BTEX exposure.

   Institute and ensure strict utilization of appropriate Personal Protective Equipment (PPE) including respirators (nose masks) for all workers involved in the manipulation of petrochemicals or at risk of inhalation exposure to these chemicals.

   Ensure strict respect of operational procedures and implement the Standard Operating Procedures (SOPs) proposed by Andin Josephine Wambang to prevent or minimize risk of BTEX exposure.

3. Workers

   Adherence to regulations, safety protocols and operational procedures.

   Promptly report all accidents or near misses to employers for more stringent measures to be put in place.

PERPECTIVES

Future research should focus on the following areas:

- Strategies to mitigate secondary exposure risks to workers' families, and the effectiveness of current safety protocols.
- A similar research in all the ten regions of Cameroon for stakeholders and policy makers to get a broader picture of the risk of exposure and to set BTEX permissive exposure limits for Cameroon.
- Risk assessment of workers to BTEX exposure by analyzing urine and blood samples.
- Evaluation of indoor air pollution levels for houses around filling stations and fuel depots.

Stakeholders must collaborate to ensure adherence to occupational safety standards and prioritize the health and well-being of workers and their families in such high-risk industries.

This study serves as a call to action for policymakers, industry leaders, and public health advocates to address the critical occupational safety and health challenges in this sector.

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APPENDICES:

Appendix A: Data Capture Sheet

THE UNIVERSITY OF YAOUNDE I
UNIVERSITE DE YAOUNDE I

FACULTY OF SCIENCES
FACULTE DES SCIENCES

DEPARTMENT OF BIOCHEMISTRY
DEPARTEMENT DE BIOCHIMIE

LABORATORY OF PHARMACOLOGY AND TOXICOLOGY
LABORATOIRE DE PHARMACOLOGIE ET TOXICOLOGIE

Safety and Health Evaluation Questionnaire – Data capture sheet

Dear Madam/Sir,

I am a professional master's student in the Department of Biochemistry, Faculty of Science of the University of Yaoundé 1, with specialty in Public Health Biotechnology. I am carrying out a research on occupational safety and health of workers in various filling stations/points in Yaoundé.

This questionnaire will give us information about your exposure to health hazards, safety practices and measures put in place to minimize the exposure, the effect of this exposure to your health and that of your family. There are no correct or wrong answers. Accurate and thoughtful responses will allow us to pinpoint your good practices as well as the practices that you may consider changing or modifying. It is anonymous so your name and contact details are not required.

A. Socio-demographic variables

Due date: _________________

Interviewer: ___________________________________ Today's date: _____________

Company name: SCDP ( ); TOTAL ( ); TRADEX ( ) ; OLA ( ); CORLAY( ); NEPTUNE ( ) .

Location: ______________________________ Gender: ______________________________

Age: ______________________________ Weight: ______________________________ Height: ______________________________ Occupation: ______________________________.

Level of education: illiterate ( ); primary ( ); secondary ( ); university.

Smoking history: currently smoking ( ); stopped smoking ( ); never smoked ( ).

Marital status: married ( ); single ( ); divorced ( ); widowed ( ). Alcohol consumption: Yes ( ); No ( ); Never( )

Total number of children (less than 12 years old): ______ boys and ______ girls, Age of youngest: _______

Total number of adult children (more than 18 years old): ______ boys and ______ girls, Age of oldest: _______

Total number of Grande children: ______________________________

B. Employment history and occupational exposure

B.1. Personal Hygiene

1. Do you eat or drink at your work post? Yes ( ); No ( ).
2. Do you wash your hands before eating or drinking? Yes ( ); No ( ).
3. What food do you usually eat? home food ( ); from company restaurant( );from road vendors
4. What is your source of water when you are at work? Mineral water ( ); CAM water ( ); well water ( ); any source ( );
5. How often do you clean your working space: ______________________________?
6. How often do you wash your work cloth: ______________________________?
7. Do you shower after working hours? Yes ( ); No ( ).
8. Do you go back home with duty uniform? Yes ( ); No ( ).

B.2. Work history and exposure to VOC (BTEX).

1. Which is your working area? Loading ( ); off-loading ( ); laboratory ( ); office( ); maintenance work shop( ).
2. How many hours do you work per day? 8hours ( ); 8-12hours( ); > 12hours
3. How many days do you work per week? <5 days ( ); 5 days ( ); 6 days ( ); 7 days ( )
4. For how long have you been working in this sector? < 2years ( ); 2-10years( ); 10-20years( ); > 20years ( ).
5. Do you wear safety glasses during work? Do not have ( ); do not use ( ); use ( ).
6. Do you wear mask during work? Do not have ( ); do not use ( ); use( ).
7. Do you wear gloves during work? Do not have ( ); do not use ( ); use( ).
8. Do you use boots/safety shoes during work? Do not have ( ); do not use ( ); use ( ).
9. Do you wear long –sleeved cotton shirts during work? Do not have ( ); do not use ( ); use( ).
10. Do you wear long pants during work? Do not have ( ); do not use ( ); use ( ).

B.3. Occupational accidents

Have you been involved in any of the following accidents? You can tick more than one answer.

Fuel leak ( ); Skin contact with fuel (gasoline, kerosene, diesel) ( ); Outpouring of fuel on the worker ( ); Eye contact with fuel( ); Contact with other substances (detergent, grease, dust) in the eyes ( ); Fuel inhalation ( ); fuel ingestion( ), Collision between car and worker( ), slip/drip( ); fall ( ).

B.4. Workers Health History

Section 1: Health Information

1. How often do you go for medical checkups? Monthly ( ); every 6months( ); once a year( ); when I feel sick ( ). Who is responsible for the bills? You ( ) Your company( ).

2. Have you ever been sick and all routine medical test are negative? Yes ( ); No ( ).
3. Have you been diagnosed of any chronic disease? Yes ( ); No ( ) .if yes which: ______________________________?
4. Have you ever experienced breathing difficulties during work? Often ( ); sometimes ( ); rare ( ); never ( );
5. Have you ever experienced stress during work? Yes ( ). No ( ).
6. Have you ever experienced headache during work? Yes ( ). No ( ).
7. Have you been pregnant or know someone pregnant while working in this sector? Yes ( ); No( ).
8. Have you/your wife ever suffered from any miscarriages? Yes ( ); No( ). How many times______________________________?, when______________________________?.
9. Did you change your post of work during pregnancy? Yes ( ). No ( ).
10. Do you have a child with any chronic/genetic disease? Yes ( ); No ( ). if yes which disease
11. Do you have a grandchild with any chronic/genetic disease? Yes ( ). No ( ). If yes which disease.

	Section 2: Chronic Diseases (you may tick more than one answer, where applicable)			
Disease types	Do you have any chronic disease?			
	Yes	**For how long**	**No**	**I don't know**
Diabetes				
Hypertension				
Chronic respiratory disease				
Cancer				
HIV				
Genetic disorders				
	Section 3: Adverse health effects related to BTEX toxicity			
Mild Signs and symptom	have you ever experience any of the following signs and symptoms			
	Yes	**How often**	**No**	**I don't know**
Cough/hoarseness				
Burning nose/congestion				
Sore throat				
Breathlessness				
Dizziness				
Headache				
Sleeplessness				
Cracked skin				

Skin rashes				
Burning sensation				
Burning eyes				
Fatigue				
Numbness				
Moderate symptoms	have you ever experience any of the following signs and symptoms			
	Yes	**How often**	**No**	**I don't know**
Anorexia				
Blurred vision				
Tight chest				
Vomiting				
Muscle weakness				
Cramp/nausea				
Drowsiness				
Depression				
Confusion				
Unusual tiredness				
Tremor				
Scurvy				
Severe symptoms	have you ever experience any of the following signs and symptoms			
	Yes	**How often**	**No**	**I don't know**
Petechia (blood in the yes)				
Tachycardia (fast heart beats)				
Unconsciousness				
Anemia				

C. Knowledge on BTEX (benzene, toluene, ethylbenzene and xylene) exposure

1.Have you heard of BTEX before? Yes ( ). No ( ).

2. Do you consider them harmful to your health? Yes ( ). No ( ).

3.What are some of the harmful effects?

4. Have you had any training on how to protect yourself from these exposure?

5.Will you be ready to get training in this area?

THE UNIVERSITY OF YAOUNDE I
UNIVERSITE DE YAOUNDE I

Faculty OF SCIENCES **DEPARTMENT OF BIOCHEMISTRY**
FACULTE DES SCIENCES DEPARTEMENT DE BIOCHIMIE

LABORATORY OF PHARMACOLOGY AND TOXICOLOGY
LABORATOIRE DE PHARMACOLOGIE ET TOXICOLOGIE

Questionnaire d'évaluation de la sécurité et de la santé - Feuille de saisie des données

Madame/Monsieur/Mademoiselle,

Je suis étudiante en master professionnel au Département de Biochimie de la Faculté des Sciences de L'université de Yaoundé 1, avec une spécialisation en Biotechnologie de la Santé Publique. J'effectue une recherche sur la sécurité et la santé au travail des travailleurs dans différentes point de vente/points de stockage des produits pétrolier à Yaoundé.

Ce questionnaire nous donnera des informations sur votre niveaux d'exposition aux risques sanitaires, les pratiques de sécurité et les mesures mises en place pour minimiser les conséquences des produits pétroliers sur votre santé ainsi que de votre famille. Toutes vos réponses seront prises en compte. La précision sera nécessaire en fin de nous permettre d'évalue vos bonnes pratiques, celle de vos proches, ils comprirent les propositions, une éventuel amélioration et même modification des mauvais pratiques.

N.B : Le questionnaire étant anonyme, votre nom et vos coordonnées ne sont pas nécessaires.

A. Variables sociodémographiques

Date d'échéance : ________________

Intervieweur : ________________________________ Date du jour : ____________

Nom de l'entreprise : SCDP ( ) ; TOTAL ( ) ; TRADEX ( ) ; OLA ( ) ; CORLAY( ) ; NEPTUNE ( ) .

Lieu de travail : ____________________________ Gendre : ____________________________

Âge : ____________________________ Poids : ____________________________ ____________________________ Taille : ____________________________ Occupation : ____________________________.

Niveau d'éducation : analphabète ( ) ; primaire ( ) ; secondaire ( ) ; université.

Antécédents tabagiques : fume actuellement ( ) ; a arrêté de fumer ( ) ; n'a jamais fumé ( ).

État civil : marié ( ) ; célibataire ( ) ; divorcé ( ) ; veuf ( ). Consommation d'alcool : Oui ( ) ; Non ( ).

Nombre total d'enfants (moins de 12 ans) : ______ garçons et ______ filles, Âge du plus jeune : _______

Nombre total d'adultes (plus de 18 ans) : ______ garçons et ______ filles, Âge du plus âgé : _______

Nombre total de grands enfants : ____________________________

B. Antécédents professionnels et exposition professionnelle

B.1. Hygiène personnelle

1. Mangez-vous ou buvez-vous à votre poste de travail ? Oui ( ) ; Non ( ).

2. L'avez-vous les mains avant de manger ou de boire ? Oui ( ) ; Non ( ).

3. Quelle nourriture mangez-vous habituellement ? nourriture maison ( ) ; restaurant de l'entreprise ( ) ; vendeurs sur la route.

4. Quelle est votre source d'eau lorsque vous êtes au travail ? Eau minérale ( ) ; eau SNEC ( ) ; eau de puits ( ) ; n'importe quelle source ( ) ;

5. A quelle fréquence nettoyez-vous votre espace de travail ? ______________________________.

6. A quelle fréquence l'avez-vous votre vêtement de travail ? ______________________________.

7. Pensez-vous une douche après les heures de travail ? Oui ( ) ; Non ( ).

8. Rentrez-vous chez vous avec votre uniforme de travail ? Oui ( ) ; Non ( ).

B.2. Antécédents professionnels et exposition aux COV (BTEX).

1. Quelle est votre zone de travail ? Chargement ( ) ; déchargement ( ) ; laboratoire ( ) ; bureau ( ) ; atelier de maintenance ( ).

2. Combien d'heures travaillez-vous par jour ? 8 heures ( ) ; 8-12 heures ( ) ; > 12 heures

3. Combien de jours travaillez-vous par semaine ? <5 jours ( ) ; 5 jours ( ) ; 6 jours ( ) ; 7 jours ( )

4. Depuis combien de temps travaillez-vous dans ce secteur ? < 2 ans ( ) ; 2-10 ans ( ) ; 10-20 ans ( ) ; > 20 ans ( ).

5. Portez-vous des lunettes de sécurité pendant votre travail ? N'en ont pas ( ) ; n'en utilisent pas ( ) ; en utilisent ( ).

6. Portez-vous un masque pendant le travail ? Ne pas avoir ( ) ; ne pas utiliser ( ) ; utiliser ( ).

7. Portez-vous des gants pendant le travail ? Ne pas avoir ( ) ; ne pas utiliser ( ) ; utiliser ( ).

8. Utilisez-vous des bottes/chaussures de sécurité pendant le travail ? N'en ont pas ( ) ; n'en utilisent pas ( ) ; en utilisent ( ).

9. Portez-vous des chemises en coton à manches longues pendant le travail ? Ne pas avoir ( ) ; ne pas utiliser ( ) ; utiliser ( ).

10. Portez-vous des pantalons longs pendant le travail ? Ne pas avoir ( ) ; ne pas utiliser ( ) ; utiliser ( ).

B.3. Accidents du travail

Avez-vous été impliqué dans l'un des accidents suivants ? Vous pouvez cocher plusieurs réponses.

Fuite de carburant ( ) ; Contact de la peau avec du carburant (Essence, Kérosène,

Diesel) ( ) ; déversement de carburant sur le travailleur ( ) ; contact du carburant avec les yeux ( ) ; contact avec d'autres substances (détergent, graisse, poussière) dans les yeux ( ) ; inhalation de carburant

( ) ; ingestion de carburant ( ) ; collision entre la voiture et le travailleur( ), glissade/égouttement( ) ; chute ( ).

B.4. Antécédents médicaux des travailleurs

Section 1 : Informations sur la santé

1. À quelle fréquence passez-vous des examens médicaux ? Tous les mois ( ) ; tous les 6 mois ( ) ; une fois par an ( ) ; lorsque je me sens malade ( ).Qui est responsable des factures ? Vous ( ) Votre entreprise ( ).

2. Avez-vous déjà été malade alors que tous les tests médicaux de routine étaient négatifs ? Oui ( ) ; Non ( ).

3. Une maladie chronique vous a-t-elle été diagnostiquée ? Oui ( ) ; Non ( ). Si oui, laquelle ? ______________________________.

4. Avez-vous déjà éprouvé des difficultés respiratoires au travail ? Souvent ( ) ; parfois ( ) ; rarement ( ) ; jamais ( ) ;

5. Avez-vous déjà été stressé(e) au travail ? Oui ( ). Non ( ).

6. Avez-vous déjà eu des maux de tête au travail ? Oui ( ). Non ( ).

7. Avez-vous été enceinte ou connaissez-vous une femme enceinte pendant que vous travailliez dans ce secteur ? Oui ( ) ; Non ( ).

8. Avez-vous (votre femme) déjà fait une fausse couche ? Oui ( ) ; Non ( ).Combien de fois______________________________ ?, quand______________________________ ?.

9. Avez-vous changé de poste de travail pendant votre grossesse ? Oui ( ). Non ( ).

10. Avez-vous un enfant atteint d'une maladie chronique/génétique ? Oui ( ) ; Non ( ). Si oui, de quelle maladie s'agit-il ?

11. Avez-vous les petits-enfants atteint d'une maladie chronique ? Oui ( ). Non ( ). Si oui, de quelle maladie s'agit-il ?

	Section 2 : Maladies chroniques (vous pouvez cocher plus d'une réponse, le cas échéant)			
Types de maladies	**Souffrez-vous d'une maladie chronique ?**			
	Oui	Pendant combien de temps	Non	Je ne sais pas
Diabète				
Hypertension				
Maladie respiratoire chronique				
Cancer				

HIV				
Troubles génétiques				
	Section 3 : Effets indésirables sur la santé liée à la toxicité des BTEX			
Signes et symptômes légers	**Avez-vous déjà ressenti l'un des signes et symptômes suivants?**			
	Oui	à quelle fréquence	Non	Je ne sais pas
Toux/irritation				
Nez brûlant/congestion				
Maux de gorge				
Essoufflement				
Vertiges				
Maux de tête				
Insomnie				
Peau craquelée				
Éruptions cutanées				
Sensation de brûlure				
Yeux brûlants				
Fatigue				
Engourdissement				
Symptômes modérés	**Avez-vous déjà ressenti l'un des signes et symptômes suivants ?**			
	Oui	à quelle fréquence	Non	Je ne sais pas
Anorexie				
Vision floue				
Peine de poitrine Serrée				
Vomissements				
Faiblesse musculaire				
Crampes/nausées				
Somnolence				
Dépression				

Confusion				
Fatigue inhabituelle				
Tremblements				
Scorbut				
Symptômes graves	Avez-vous déjà ressenti l'un des signes et symptômes suivants ?			
	Oui	à quelle fréquence	Non	Je ne sais pas
Pétéchies (sang dans les yeux)				
Tachycardie (battements de cœur rapides)				
Perte de conscience				
Anémie				

C. Connaissances sur l'exposition aux BTEX

1. Avez-vous déjà entendu parler des BTEX (benzène, toluène, éthylbenzène et xylène) ? Oui ( ). Non ( ).

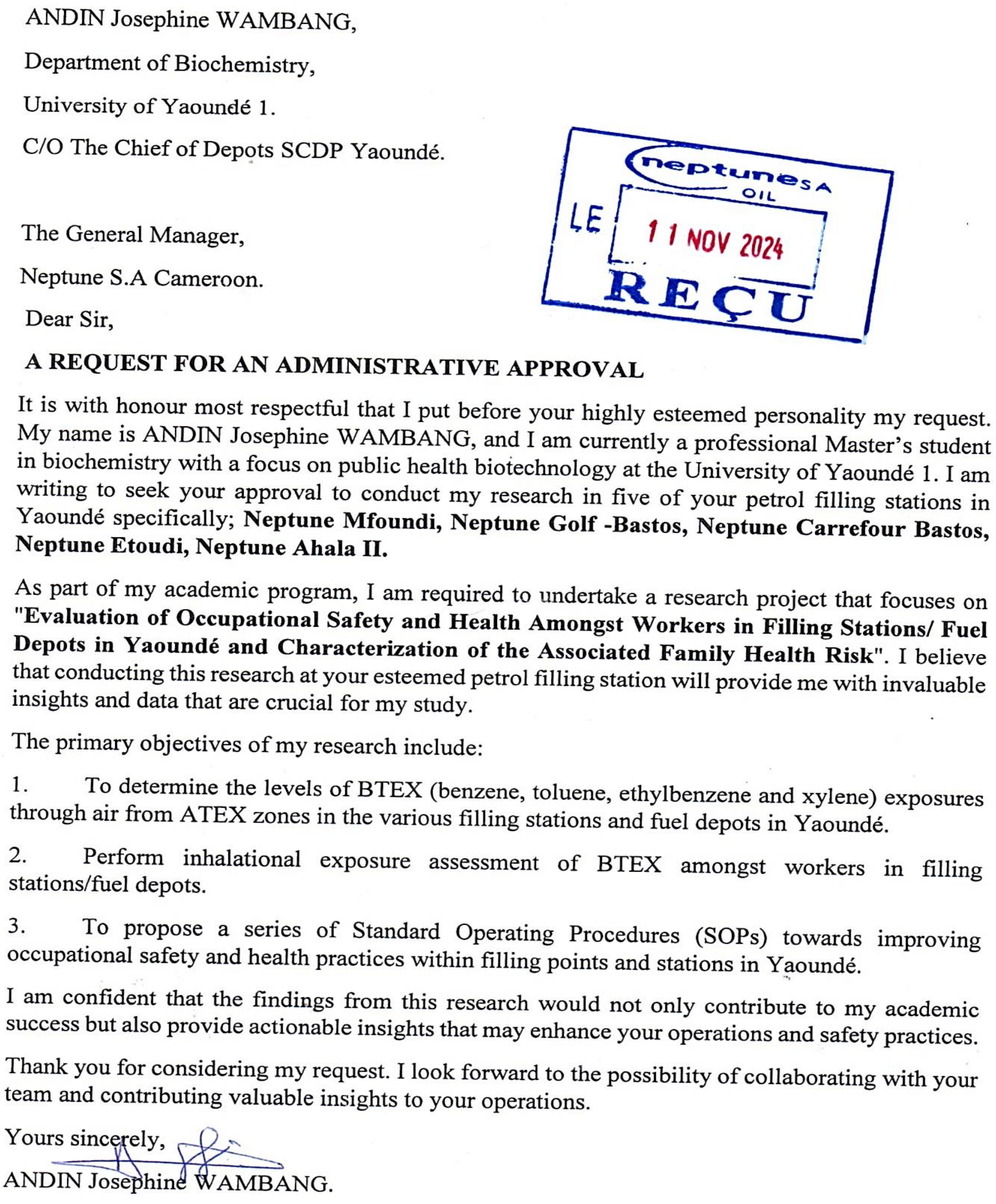
2. Considérez-vous qu'ils sont nocifs pour votre santé ? Oui ( ). Non ( ).

3. Quels sont les effets nocifs ?

4. Avez-vous reçu une formation sur la manière de vous protéger contre ces expositions ?

5. Serez-vous prêt à suivre une formation dans ce domaine ?

Appendix B: A Request for Administrative Clearance.



ANDIN Josephine WAMBANG,
Department of Biochemistry,
University of Yaoundé 1.
C/O The Chief of Depots SCDP Yaoundé.

The General Manager,
Neptune S.A Cameroon.

neptune SA
OIL
LE 11 NOV 2024
REÇU

Dear Sir,

A REQUEST FOR AN ADMINISTRATIVE APPROVAL

It is with honour most respectful that I put before your highly esteemed personality my request. My name is ANDIN Josephine WAMBANG, and I am currently a professional Master's student in biochemistry with a focus on public health biotechnology at the University of Yaoundé 1. I am writing to seek your approval to conduct my research in five of your petrol filling stations in Yaoundé specifically; **Neptune Mfoundi, Neptune Golf -Bastos, Neptune Carrefour Bastos, Neptune Etoudi, Neptune Ahala II.**

As part of my academic program, I am required to undertake a research project that focuses on **"Evaluation of Occupational Safety and Health Amongst Workers in Filling Stations/ Fuel Depots in Yaoundé and Characterization of the Associated Family Health Risk"**. I believe that conducting this research at your esteemed petrol filling station will provide me with invaluable insights and data that are crucial for my study.

The primary objectives of my research include:

1. To determine the levels of BTEX (benzene, toluene, ethylbenzene and xylene) exposures through air from ATEX zones in the various filling stations and fuel depots in Yaoundé.
2. Perform inhalational exposure assessment of BTEX amongst workers in filling stations/fuel depots.
3. To propose a series of Standard Operating Procedures (SOPs) towards improving occupational safety and health practices within filling points and stations in Yaoundé.

I am confident that the findings from this research would not only contribute to my academic success but also provide actionable insights that may enhance your operations and safety practices.

Thank you for considering my request. I look forward to the possibility of collaborating with your team and contributing valuable insights to your operations.

Yours sincerely,

ANDIN Josephine WAMBANG.

Appendix C: Data Base laboratory

Benzene

	Moyenne	Ecartype	Min	Max
Benzene FS1	15,33	9,16	4,6	29,41
Benzene fS2	20,64	13,63	4,9	32,09
Benzene FS3	20,67	13,81	6,5	38,31
Benzene FS4	12,9	10,51	4,2	29,94
Benzene FS5	21,74	13,19	5,1	35,39
Benzene FS6	18,26	8,85	4,8	26,98
Benzene FS7	18,34	11,76	5,3	32,31
Benzene FS8	18,9	11,57	5,1	33,5
Benzene FS9	14,93	11,56	4,51	29,76
Benzene FS10	19,15	16,21	4,3	37,76
Benzene FS11	22,59	15,68	5,4	38,5
Benzene FS12	13,93	10,39	4,5	30,67
Benzene FS13	18,7	9,97	4,2	28,69
Benzene FS14	23,53	13,21	5,5	36,83
Benzene FS15	16,03	9,48	4	28,54
Benzene FS16	18,05	17,79	4,7	38,83
Benzene FS17	18,35	17,15	5,44	38,14
Benzene FS18	19,36	14,36	4,16	35,62
Benzene FS19	23,07	14,25	3,9	35,04
Benzene FS20	13,56	7,9	4,1	26,08
Benzene FS21	14,54	11,28	3,8	30,58
Benzene FS22	15,61	13,68	4,1	37,49
Benzene FS23	14,93	7,02	4,1	23,63
Benzene FS24	24,31	13,2	2,85	38,47
Benzene FS25	14,36	13,32	2,3	31,83
Benzene FS26	10,89	2,09	8,67	13,68

Toluene

	Moyenne	ecartype	min	max
FS1	15,12	8,31	8,2	29,28
TolueneFS2	19,97	12,82	6,6	38,46
Toluene FS3	12,34	6,42	6,04	23,22
Toluene FS2	26,27	15,7	7,6	39,5
TolueneFS3	21,53	13,74	6,45	33,62
Toluene FS4	19,95	12,39	6,5	37,54
Toluene FS3	19,07	11,38	8,7	34,08
TolueneFS4	13,71	10,36	4,57	30,79
Toluene FS5	20,48	14	6,78	38,34
Toluene FS4	17,1	9,51	6,4	27,89
TolueneFS5	24,51	9,36	9,9	32,34
Toluene FS6	25,9	14	5,9	39,46
Toluene FS5	16,34	14,83	4,64	34,9
TolueneFS6	23,09	12,19	7,4	37,78
Toluene FS7	20,33	12,05	5,1	38,77
Toluene FS6	18,05	12,27	8,9	39,32

TolueneFS7	18,11	10,82	8,82	35,23
Toluene FS8	20,72	11,1	11,7	38,13
Toluene FS7	20,57	13,12	8,16	39,83
TolueneFS8	23,38	14,31	5,49	36,98
Toluene FS9	18,03	12,12	9,82	38,12
Toluene FS8	23,24	9,35	13,8	37,08
TolueneFS9	20,54	12,71	1,6	34,65
Toluene FS10	21,61	12,58	4,3	38,4
Toluene FS9	19,52	13,9	3,6	34,57
TolueneFS10	21,4	10,49	7,24	34,65

Xylene

	Moyenne	Ecartype	Min	Max
FS1	8,46	6,8	4,05	20,44
Xylene FS2	12,24	6,11	4,4	18,33
Xylene FS3	17,72	7,74	7,6	28,13
Xylene FS4	13,22	4,79	9,23	21,23
Xylene FS5	16,6	7,79	9,8	29,5
Xylene FS6	18,17	12,22	8,3	37,54
Xylene FS7	21,3	14,35	8,97	38,45
Xylene FS8	19,45	10,79	8,9	36,92
Xylene FS9	17,33	15,22	4,14	36,44
Xylene FS10	19,61	13,6	7,3	37,45
Xylene FS11	14,39	4,2	8,5	20,07
Xylene FS12	20,8	10,61	5,5	34,52
Xylene FS13	22,86	12,57	5,5	35,47
Xylene FS14	16,44	9,35	6,7	26,56
Xylene FS15	19,64	12,23	5	37,58
Xylene FS16	21,93	9,3	6,8	28,6
Xylene FS17	20,04	8,51	11	29,82
Xylene FS18	15,07	12,93	5,37	37,03
Xylene FS19	22,25	8,5	7,6	28,44
Xylene FS20	21,31	12,35	9,7	35,18
Xylene FS21	14,67	8,01	5,6	24,54
Xylene FS22	14,74	11,29	6,3	31,45
Xylene FS23	16,91	14,35	6,2	39,18
Xylene FS24	20,72	15,07	4,4	38,76
Xylene FS25	14,73	8,22	3,8	24,05
Xylene FS26	25,15	8,8	15,19	34,53

VOC

	Moyenne	Ecartype	Min	Max
VOC FS1	18,94	10,5	10,69	34,81
VOC FS2	22,32	9,56	11,8	34,82
VOC FS3	18,11	12,49	4,77	37,69
VOC FS4	29,65	12,58	8	38,75
VOC FS5	18,56	13,65	8,46	37,04
VOC FS6	18,95	8,96	9,5	33,85
VOC FS7	20,93	11,08	7,76	37,78
VOC FS8	20,36	9,81	8,01	33,23

VOC FS9	22,6	11,14	8,06	36,28
VOC FS10	18,22	7,9	4,65	25,13
VOC FS11	27,98	9,99	14,5	39,09
VOC FS12	22,22	7,98	8,93	28,84
VOC FS13	25,55	8,32	14,12	34,36
VOC FS14	23,55	8,84	14,2	37,64
VOC FS15	18,99	7,53	8,2	29,21
VOC FS16	24,16	14,23	6,8	39,5
VOC FS17	15,27	14,16	4	38,62
VOC FS18	12,62	2,78	9,93	16,25
VOC FS19	14,65	7,72	4,27	25
VOC FS20	12,55	6,71	7	24,1
VOC FS21	28,42	10,89	12	38,42
VOC FS22	13,89	5,62	8,35	22,74
VOC FS23	14,54	6,19	7,7	23,06
VOC FS24	23,28	11,5	9,81	35,34
VOC FS25	24,22	13,99	9,05	45
VOC FS26	22,01	11,08	9,56	38,49

Offices

Benzene

	Moyenne	Ecartype	Min	Max
Benzene FS1	8,89	5,01	4,22	16,88
Benzene FS2	9,67	5,58	5,4	19,16
Benzene FS3	11,29	5,7	4,58	18,93
Benzene FS4	10,87	7,28	4,6	18,92
Benzene FS5	13,8	5,23	5,6	18,02
Benzene FS6	9,73	5,02	4,96	16,33
Benzene FS7	8,91	3,97	4,44	13,83
Benzene FS8	9,6	6,14	4,66	16,74
Benzene FS9	14,21	6,31	5,3	19,64
Benzene FS10	12,67	6,83	4,8	18,86
Benzene FS11	8,09	2,94	5,68	12,57
Benzene FS12	12,76	5,26	5	18,7
Benzene FS13	10,53	5,55	4,6	16,6
Benzene FS14	9,18	2,98	6,1	13,72
Benzene FS15	8,7	3,25	4,5	13,54
Benzene FS16	9,04	2,91	5,2	12,25
Benzene FS17	14,19	4,29	6,7	16,93
Benzene FS18	7,63	2,55	4,7	11,51
Benzene FS19	10,21	4,17	4,3	15,97
Benzene FS20	11,32	6,72	4,4	19,35
Benzene FS21	9,24	6,51	4,2	19,42
Benzene FS22	9,69	4,51	4,5	14,48
Benzene FS23	11,54	5,2	4,5	16,69
Benzene FS24	8,81	4,48	3,2	15,27
Benzene FS25	9,72	6,43	2,5	16,87
Benzene FS26	12,07	5,63	4,7	17,94

Toluene

	Moyenne	Ecartype	Min	Max
Toluene FS1	12,27	5,47	5,08	19,06
Toluene FS2	9,95	4,63	7,37	18,18
Toluene FS3	10,85	3,94	4,33	14,99
Toluene FS4	10,82	3,69	7,78	16,38
Toluene FS5	12,42	3,7	7,5	16,16
Toluene FS6	8,93	5,32	5,19	18,27
Toluene FS7	11,24	4,63	7,34	18,95
Toluene FS8	13,39	3,13	10,4	18,61
Toluene FS9	13,51	4,73	8,15	17,91
Toluene FS10	11,41	4,73	7,1	17,76
Toluene FS11	9,41	3,7	4,87	13,35
Toluene FS12	8,31	2,56	6,32	11,61
Toluene FS13	10,93	4,73	6,04	17,81
Toluene FS14	9,89	2,95	7,37	14,08
Toluene FS15	10,78	5,47	4,59	16,44
Toluene FS16	9,23	4,85	4,62	17,24
Toluene FS17	13,31	5,89	6,04	19,71
Toluene FS18	14,92	3,16	10,75	18,84
Toluene FS19	13,57	4,97	4,72	16,51
Toluene FS20	11,9	5,12	5,52	19,16
Toluene FS21	13,34	2,94	9,32	17,31
Toluene FS22	11,13	4,49	5,36	15,4
Toluene FS23	13,95	4,58	8,04	19,48
Toluene FS24	8,28	4,22	4,8	14,43
Toluene FS25	11,81	6,22	4	19,39
Toluene FS26	10,82	4,25	6,22	14,92

Xylene

	Moyenne	Ecartype	Min	Max
Xylene FS1	10,56	6,13	4,48	17,82
Xylene FS2	12,67	6,62	4,9	19,71
Xylene FS3	13,99	4,83	8,4	19,44
Xylene FS4	9,67	2,12	6,18	11,5
Xylene FS5	11,46	3,98	8,38	18,14
Xylene FS6	12,73	6,66	5,37	19,99
Xylene FS7	10,29	5,81	4,73	19,37
Xylene FS8	10,57	5,26	5,34	19,09
Xylene FS9	13,97	4,98	8,17	18,9
Xylene FS10	10,1	4,6	4,91	17,22
Xylene FS11	12,57	3,45	9,5	18,42
Xylene FS12	8,99	2,97	6,1	12,4
Xylene FS13	10,08	5,31	4,89	18,15
Xylene FS14	11,88	5,28	6,75	19,82
Xylene FS15	12,23	6,06	5,5	19,49
Xylene FS16	10,01	4,54	4,77	16,09
Xylene FS17	16,25	2,72	12,2	18,93
Xylene FS18	13,46	4,85	5,17	16,8

Xylene FS19	9,98	5,08	2	16,06
Xylene FS20	10,33	5,23	5,55	18,68
Xylene FS21	9,15	3,93	5,85	15,06
Xylene FS22	16,5	9,75	4,42	31,7
Xylene FS23	13,18	3,55	7	16,09
Xylene FS24	10,9	4,4	4,9	15,83
Xylene FS25	12,07	6,65	4,3	19,18
Xylene FS26	13,48	5,14	4,69	16,96

VOC

	Moyenne	Ecartype	Min	Max
VOC FS1	12,82	3,85	8,98	17,85
VOC FS2	13,44	5,87	5,46	21,1
VOC FS3	9,68	5,76	5,01	17,13
VOC FS4	10,16	3,27	7,58	15,38
VOC FS5	10,79	4,25	6,68	16,1
VOC FS6	9,59	3,46	5,5	13,31
VOC FS7	13,66	4,1	7,64	17
VOC FS8	12,71	4,25	8,22	17,13
VOC FS9	15,45	3,31	10,05	17,8
VOC FS10	13,4	5,65	6,02	21,5
VOC FS11	12,15	4,22	6,45	16,2
VOC FS12	13,52	6,52	6,88	23,9
VOC FS13	13,72	5,21	8,57	22,2
VOC FS14	11,34	5,69	5,6	18,74
VOC FS15	16,29	6,3	7,58	22,6
VOC FS16	10,47	5,85	5,54	18,6
VOC FS17	11,47	4,74	4,4	17,7
VOC FS18	11,36	5	6,02	16,89
VOC FS19	12,62	4,77	5,04	17,84
VOC FS20	12,54	6,23	4,08	19,32
VOC FS21	13,69	2,45	9,93	16,71
VOC FS22	11,67	4,7	6,4	17,27
VOC FS23	11,03	3,63	7,86	16,33
VOC FS24	16,02	13,34	5,96	39
VOC FS25	14,28	19,99	4,22	50
VOC FS26	10,94	4,9	5,46	16,9

Data Refueling pump

Benzene

	Moyenne	**Ecartype**	**Min**	**Max**
Benzene FS1	99,33	118,529093	11,80	306,00
Benzene FS2	119,466489	170,077998	15,40	422,00
Benzene FS3	45,31	38,1350924	15,50	106,00
Benzene FS4	65,17	65,2599924	15,50	178,00
Benzene FS5	65,82	69,5446761	18,60	188,00
Benzene FS6	73,50	78,7225936	20,50	211,00

Benzene FS7	116,95	127,122845	20,80	340,00
Benzene FS8	111,37	127,12899	21,10	336,00
Benzene FS9	116,95	139,589184	22,30	355,00
Benzene FS10	123,21	172,616631	22,30	430,00
Benzene FS11	112,38	119,71489	24,40	323,00
Benzene FS12	49,22	191,840798	25,50	477,00
Benzene FS13	128,84	176,550901	31,10	444,00
Benzene FS14	97,86	122,109059	36,61	316,00
Benzene FS15	134,96	178,019307	38,40	452,00
Benzene FS16	64,78	53,1484119	22,60	150,00
Benzene FS17	42,85	26,5406003	21,50	88,00
Benzene FS18	98,76	98,7849435	39,80	274,00
Benzene FS19	89,50	84,2513062	40,30	238,00
Benzene FS20	91,91	100,06358	36,60	270,00
Benzene FS21	90,11	101,953859	25,37	267,00
Benzene FS22	91,41	78,4088154	31,70	227,00
Benzene FS23	72,23	57,6734741	23,80	172,00
Benzene FS24	201,49	324,043812	26,67	780,00
Benzene FS25	248,04	421,059811	24,81	1000,00
Benzene FS26	63,19	21,366341	27,50	83,03
Benzene FS27	51,96	31,7529643	18,06	82,70

Toluene

	Moyenne	**Ecartype**	**Min**	**Max**
Toluene FS1	70,20	82,81	11,10	306,00
Toluene FS2	101,52	124,47	28,40	422,00
Toluene FS3	44,01	48,10	17,80	106,00
Toluene FS4	63,13	76,32	25,70	178,00
Toluene FS5	57,92	59,07	25,50	188,00
Toluene FS6	86,16	104,31	30,70	211,00
Toluene FS7	107,08	108,62	39,80	340,00
Toluene FS8	104,31	130,70	38,90	336,00
Toluene FS9	123,22	130,34	33,11	355,00
Toluene FS10	127,87	170,19	32,77	430,00
Toluene FS11	176,99	266,01	61,30	323,00
Toluene FS12	155,44	204,13	51,17	477,00
Toluene FS13	103,86	126,48	14,40	444,00
Toluene FS14	89,71	136,57	17,70	316,00
Toluene FS15	128,32	182,17	11,10	452,00
Toluene FS16	57,19	29,96	22,60	150,00
Toluene FS17	52,34	43,12	21,50	88,00
Toluene FS18	103,03	107,69	45,60	274,00
Toluene FS19	81,72	86,51	39,80	238,00
Toluene FS20	97,24	104,68	36,60	270,00
Toluene FS21	75,81	55,15	25,37	267,00
Toluene FS22	105,76	165,68	4,69	227,00
Toluene FS23	62,42	62,01	12,50	172,00
Toluene FS24	245,46	365,93	26,67	780,00
Toluene FS25	228,93	353,21	24,81	1000,00
Toluene FS26	52,96	20,80	27,50	83,03
Toluene FS27	62,12	24,00	18,06	82,70

Xylene

	Moyenne	Ecartype	Min	Max
XyleneFS1	107	112,09	38,40	306,00
XyleneFS2	138	159,84	41,70	422,00
XyleneFS3	47	37,48	17,80	106,00
XyleneFS4	73	61,72	29,90	178,00
XyleneFS5	75	65,21	28,30	188,00
XyleneFS6	87	72,94	30,70	211,00
XyleneFS7	127	119,25	65,60	340,00
XyleneFS8	103	132,67	15,91	336,00
XyleneFS9	126	128,00	61,10	355,00
XyleneFS10	131	168,86	14,30	430,00
XyleneFS11	108	121,20	26,79	323,00
XyleneFS12	145	185,43	57,90	477,00
XyleneFS13	144	168,48	54,30	444,00
XyleneFS14	103	121,51	15,72	316,00
XyleneFS15	131	179,65	43,90	452,00
XyleneFS16	60	52,03	22,60	150,00
XyleneFS17	48	30,95	21,50	88,00
XyleneFS18	97	100,37	27,82	274,00
XyleneFS19	87	85,76	39,55	238,00
XyleneFS20	96	98,77	35,50	270,00
XyleneFS21	98	95,71	33,10	267,00
XyleneFS22	93	77,13	31,70	227,00
XyleneFS23	57	66,12	15,95	172,00
XyleneFS24	196	327,77	14,18	780,00
XyleneFS25	258	415,09	56,66	1000,00
XyleneFS26	62	18,73	31,64	81,58
XyleneFS27	56	17,57	34,50	82,10

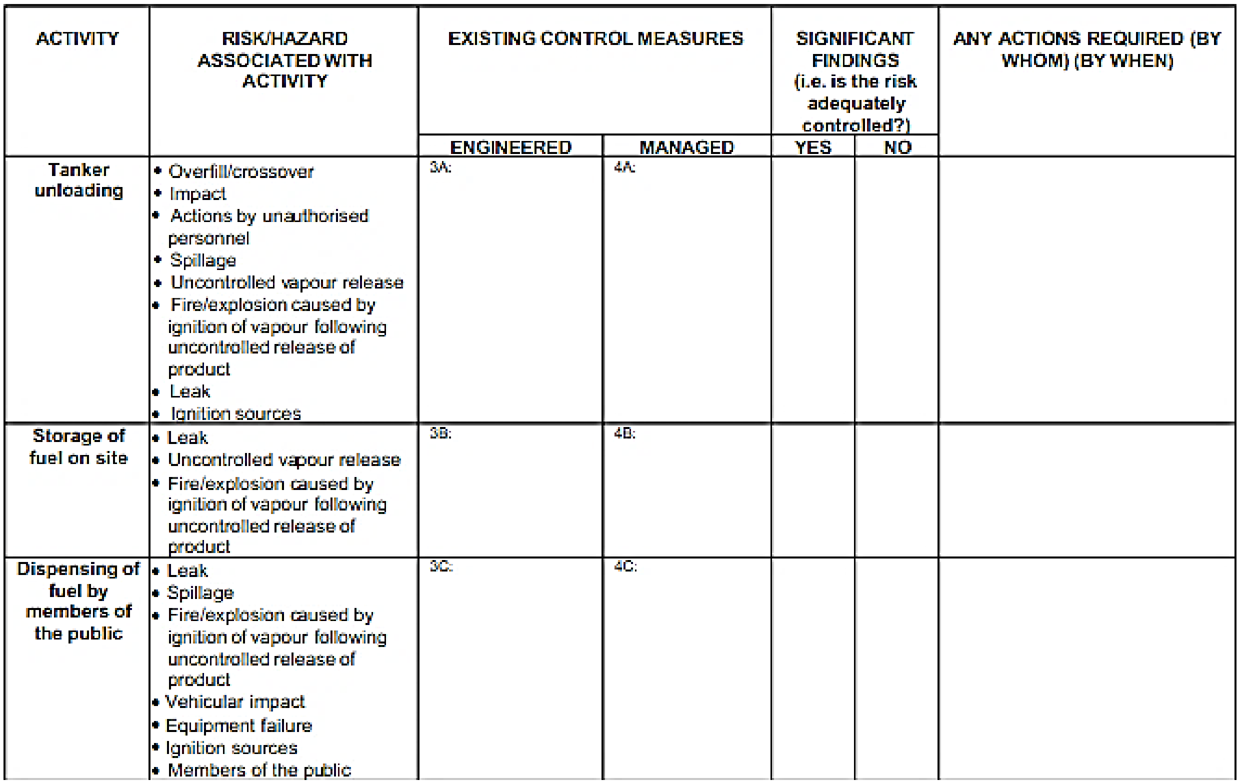
VOC

	Moyenne	Ecartype	Min	Max
VOCFS1	86,95	94,75	12,76	250,10
VOCFS2	195,01	304,66	31,99	738,93
VOCFS3	167,29	283,66	27,13	674,41
VOCFS4	200,28	282,06	50,10	704,21
VOCFS5	163,32	271,34	22,43	647,56
VOCFS6	213,75	344,91	51,30	830,32
VOCFS7	220,82	410,92	23,64	955,57
VOCFS8	108,48	115,62	24,17	310,33
VOCFS9	135,11	176,13	36,05	447,98
VOCFS10	139,74	190,49	37,14	479,96
VOCFS11	249,65	413,74	58,29	989,71
VOCFS12	60,79	38,47	23,50	125,44
VOCFS13	101,55	113,09	26,18	298,56
VOCFS14	202,07	327,48	25,99	787,04
VOCFS15	174,87	251,19	39,63	623,41
VOCFS16	217,19	324,86	51,10	797,75
VOCFS17	190,89	347,85	12,62	811,94

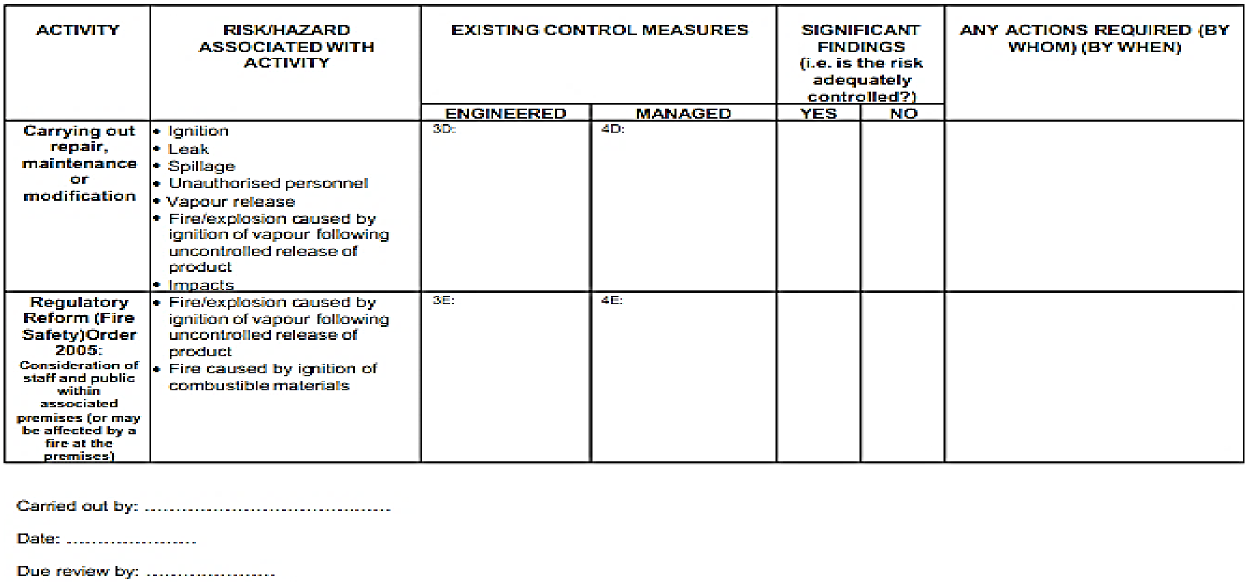
VOCFS18	220,04	387,68	38,73	913,41
VOCFS19	219,39	383,84	37,40	905,78
VOCFS20	129,66	182,69	24,80	455,45
VOCFS21	221,44	372,51	17,48	886,59
VOCFS22	104,17	144,34	14,64	360,87
VOCFS23	70,52	58,95	21,81	170,98
VOCFS24	100,68	129,07	19,84	329,68
VOCFS25	237,41	390,23	25,00	934,28
VOCFS26	59,46	21,27	23,50	79,38
VOCFS27	52,46	18,37	27,90	70,40

Appendix D: Risk assessment template for filling stations/fuel depots

Petrol Filling Station Risk Assessment for ……………………………………….



ACTIVITY	RISK/HAZARD ASSOCIATED WITH ACTIVITY	EXISTING CONTROL MEASURES		SIGNIFICANT FINDINGS (i.e. is the risk adequately controlled?)		ANY ACTIONS REQUIRED (BY WHOM) (BY WHEN)
		ENGINEERED	MANAGED	YES	NO	
Tanker unloading	• Overfill/crossover • Impact • Actions by unauthorised personnel • Spillage • Uncontrolled vapour release • Fire/explosion caused by ignition of vapour following uncontrolled release of product • Leak • Ignition sources	3A:	4A:			
Storage of fuel on site	• Leak • Uncontrolled vapour release • Fire/explosion caused by ignition of vapour following uncontrolled release of product	3B:	4B:			
Dispensing of fuel by members of the public	• Leak • Spillage • Fire/explosion caused by ignition of vapour following uncontrolled release of product • Vehicular impact • Equipment failure • Ignition sources • Members of the public	3C:	4C:			



ACTIVITY	RISK/HAZARD ASSOCIATED WITH ACTIVITY	EXISTING CONTROL MEASURES		SIGNIFICANT FINDINGS (i.e. is the risk adequately controlled?)		ANY ACTIONS REQUIRED (BY WHOM) (BY WHEN)
		ENGINEERED	MANAGED	YES	NO	
Carrying out repair, maintenance or modification	• Ignition • Leak • Spillage • Unauthorised personnel • Vapour release • Fire/explosion caused by ignition of vapour following uncontrolled release of product • Impacts	3D:	4D:			
Regulatory Reform (Fire Safety)Order 2005: Consideration of staff and public within associated premises (or may be affected by a fire at the premises)	• Fire/explosion caused by ignition of vapour following uncontrolled release of product • Fire caused by ignition of combustible materials	3E:	4E:			

Carried out by: …………………………………….

Date: …………………..

Due review by: …………………..

Appendix E: Possible Control Measures.

List of Possible Control Measures for Inclusion within Cells on Risk Assessment Form

ENGINEERED	MANAGED
Cell 3A 1. Overfill prevention/high level alarm 2. Correct labelling of fill points/signage 3. Stage 1b vapour recovery 4. Vent pipe location 5. Location/protection of fill pipes (tanker stand) 6. Impervious surface to tanker stand 7. Drainage of tanker stand/tank fill point area to a retention system (interceptor) 8. Driver controlled delivery equipment 9. Adequate lighting 10. Hazardous area classification/suitability of equipment 11. Provision of fire fighting equipment & absorbent material	**Cell 4A** 1. Inspection/maintenance regime 2. Staff training 3. Delivery documentation 4. Provision of personal protective equipment (PPE) 5. Emergency procedures
Cell 3B 1. Secondary containment 2. Leak detection system 3. Observation/monitoring well(s) 4. Stage 1b vapour recovery 5. Gauge systems 6. Automated reconciliation system 7. Cathodic protection 8. Provision of fire fighting equipment & absorbent material	**Cell 4B** 1. Staff training 2. Third party statistical inventory reconciliation 3. Wetstock reconciliation 4. Inspection/maintenance regime and records 5. Provision of personal protective equipment (PPE)
Cell 3C 1. Dispensers/pumps to approved standard 2. Labelling/signage 3. Adequate lighting 4. Position of dispenser(s)/pump(s) (vision/impact) 5. Isolation/emergency switches 6. Impact protection of dispensers/pumps 7. Under pump valves 8. Loud speaker system 9. Impervious forecourt surface 10. Drainage of dispensing area to a retention system 11. Electrical equipment suitable for hazardous zone 12. Provision of fire fighting equipment & absorbent material	**Cell 4C** 1. Staff training 2. Inspection/maintenance regime 3. Provision of personal protective equipment for staff 4. Provision of first aid equipment and first aid training 5. Emergency procedures
Cell 3D 1. Correct equipment to be used in hazardous areas 2. Provision of suitable lifting equipment available for access chamber covers 3. Provision of fire fighting equipment & absorbent material 4. Provision of cones and barriers 5. Adequate lighting of working area	**Cell 4D** 1. Competent contractors/safety passport 2. Staff training 3. Provision of personal protective equipment 4. Emergency plan 5. Contractors documentation: • clearance certificates • method statement • risk assessment 6. Visitors book
Cell 3E (Regulatory Reform (Fire Safety) Order 2005) 1. Suitable and sufficient means of escape 2. Suitable and sufficient provision of fire fighting equipment 3. Fire alarms and detection 4. Fire resisting separation	**Cell 4E (Regulatory Reform (Fire Safety) Order 2005)** 1. Staff training 2. Maintenance of fire fighting equipment/alarms etc. 3. Emergency plan 4. Risk assessment 5. Competent persons

Appendix F: Hazardous zone definitions:

Zone 0: That part of a hazardous area in which a flammable atmosphere is continuously present, or present for long periods.

Zone 1: That part of a hazardous area in which a flammable atmosphere is likely to occur in normal operation.

Zone 2: That part of a hazardous area in which a flammable atmosphere in not likely to occur in normal operation and, if it occurs, will exist only for a short period. Nominal areas of hazardous zones to be indicated on the hazardous zone drawing:

Zone 0: (Mark red on site plan)

- Within any access chamber or pit in which there are tanker delivery hose connection point(s).
- Within an oil separator (petrol interceptor).

Zone 1: (Mark blue on site plan)

- 1m radius around the road tanker delivery and vapour return hose connections extending down to ground level.
- 1m radius along the delivery hose route from tanker connection point(s) to the tank connection point(s).
- 1m radius from tank filling point (above ground).
- 1m radius from edge of the chamber if fill point is below ground.
- Within petrol tank access chambers which do not have tank fill points.
- 2m radius around tank venting point(s) which do not have stage 1b vapour recovery system.
- 1m radius around a venting point of an oil separator (petrol interceptor).
- Within the access chamber of an oil separator (petrol interceptor).

Zone 2: (Mark yellow on site plan)

- 4m radius of a tank delivery hose connection point(s).
- 4m radius of above ground offset fill connection(s).
- 1m radius around vapour return hose connection point.
- 2m radius around tank venting points where the site has stage 1b vapour recovery installed.
- 2m radius from the edge on an oil separator (petrol interceptor).
- Within a 4.1 radius of a petrol delivery hose connection on a dispenser (with stage 2 vapour recovery in operation).

LPG (Autogas) above ground

Zone 0:

- Inside the storage tank (if nitrogen purging not used).

Zone 1:

- 1.5m radius around tank fill point.
- 1.5m radius around tank ullage level indicator.
- Inside dispenser casing.
- 1.5m radius of a road tanker ullage level indicator.

Zone 2:

- 0.5m radius around a soft seat tank relief valve.
- 2.5m radius around any other type of tank relief valve.
- 1.2m radius around dispenser hose.

- 1m radius around dispenser apertures.
- 0.15m surrounding the dispenser.
- 4m radius around the road tanker pump.
- 1.5m radius around a delivery hose connection point.
- 0.5m radius around a road tanker soft seat relief valve.
- 2.5m radius around any other road tanker relief valve

Appendix G: The researcher in the laboratory of one of the study sites