

**EXPOSURE AND RISK ASSESSMENT OF BENZENE, TOLUENE,
ETHYL BENZENE AND XYLENE (BTEX) IN A PETROCHEMICAL
DEPOT AT HEIDELBERG, SOUTH AFRICA**



UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

Richard John Mdlalose

Student number: 600722

Supervisor: Dr Masilu Daniel Masekamani
Faculty of Health Sciences, School of Public Health, Occupational Health Division
University of the Witwatersrand

A research report submitted in the Faculty of Health Sciences, University of the
Witwatersrand, Johannesburg in partial fulfilment of the requirements for the degree of
Master of Public Health (Occupational Hygiene)

31 March 2022

Declaration

I, **Richard John Mdlalose (student number: 600722)** declare that the research project entitled “*Exposure and risk assessment of Benzene, Toluene, Ethyl Benzene and Xylene (BTEX) in a petrochemical depot at Heidelberg, South Africa*” is my research work undertaken under the supervision of Dr Masilu Daniel Masekameni. The work is being submitted in partial fulfilment for the degree of Master of Public Health in the field of Occupational Hygiene at the School of Public Health, University of the Witwatersrand, Johannesburg. This work has not been presented for examination at any other university. The author designed the study, conducted all field data collection, data analysis, and writing the research report. Parts of this research report have been planned to be published in peer-reviewed journals and presented at conferences. All the sources cited in this study have been acknowledged through comprehensive references. The senate plagiarism policy is signed and attached as an Appendix A: Plagiarism Declaration Form.

Dedication

This is in memory of my late father who had been my pillar of strength and who inspired me to pursue my studies against all odds as it has the potential to unlock opportunities. This research report is also dedicated to my wife Annah Malifu Mdlalose and kids (Okuhle, Nongcebo, Nontokozo, Nkululeko, Mlungisi and Nonkululeko) for their unwavering support, care, and love throughout the journey of my studies. To my lifelong wife thank you so much more for the understanding, patience, caring, love, and guidance. I will be forever, indebt to all of you.

Abstract

Background

The International Labour Organization estimated 2.2 million workers are dying yearly from work-related accidents and occupational diseases, whilst about 270 million suffer serious injuries, and 160 million become ill due to their work. It is further estimated that work-related accidents and diseases cause 4% of annual Global Gross Domestic Product or US \$1.25 trillion due to lost working time, workers' compensation, the interruption of production, and medical expenses. In 2005, the ILO estimated that 440 000 people died throughout the world because of exposure to hazardous chemicals.

In 2018 chemicals production was the second largest production sector in the world. Chemicals are indispensable and critical part of life. Their visible positive outcomes are quite palpable. They are well recognized for instance pesticides improve the quality of food production, pharmaceuticals cure illness, cleaning products help to establish hygienic living conditions. Chemicals are key development of final products that make life little easy for human beings, etc. Controlling employees' exposure to chemicals and preventing or minimizing emissions remains a significant challenge in workplaces throughout the world.

The production, storage, and handling of petrochemical products particularly BTEX emissions are known and associated with potential harm to human and aquatic organisms. Some of the health effects associated with exposure to BTEX are the health effects on hematopoietic system, including pancytopenia. The benzene exposure leads to an acute myelogenous leukemia. The exposure to toluene, ethylbenzene, and xylene have been linked to the damaging the central nervous system and irritation of the respiratory system. Benzene and ethylbenzene are confirmed carcinogens (Benzene is classified as a Group 1 and ethylbenzene is a Group 2 B carcinogens).

Purpose

To characterize, assess exposure and health risk assessment to benzene, toluene, ethylbenzene, and xylene (BTEX) at the petrochemical depot at Heidelberg in Gauteng, South Africa.

Methods

Exposure sampling was done using a MiniRAE 3000 Photoionization detector (PID). The PID (equipment) was calibrated before the commencement of the monitoring program following the manufacturer's operating manual. The PID equipment was used to collect the BTEX samples. The PID was mounted on a marked tripod stand at 1.5 m above ground and approximately 0.2 m to 0.5 m in the microenvironment (Exposure scenario) of the depot workers (Controllers and/or laboratory assistant) with the probe extended or placed within 30cm of the breathing zone of the depot workers.

Sampling was conducted at three different exposure scenarios (workstations) i.e., density huts, laboratory, and during plant equipment cleaning in the plant (strainer removal) over three days period. The sampling started from 08h00 to 17h00. One workstation was sampled per day. The sampling of BTEX per workstation took 30 minutes per hour over ten hours, every hour BTEX was sampled for a duration of 30 minutes and in totality ten samples were collected per 12-hour shift, a total of 30 BTEX samples were collected over the 3 days period. Additionally, the measured BTEX concentrations were used to obtain dose estimates. Data from the equipment was exported to a Microsoft Excel spreadsheet. All outliers were removed from the data and a correction factor was applied to derive the final concentration. Thereafter, statistical tests using student F-test and Test were performed to evaluate for significant differences amongst paired comparisons.

Results

The highest average BTEX concentrations were measured in the laboratory, followed by density huts and the least was measured during the removal of the strainer (plant equipment cleaning). The activity areas (exposure scenarios) served as direct sources for the BTEX vapours. The average benzene concentrations measured in three activity areas ranged from 469 ppm to 542 ppm. The highest benzene concentration was found to be 542 times higher than the current South African Occupational Exposure Limits of 1ppm. The average toluene concentrations measured ranged from 1335 pm to 1542 pm; the highest toluene concentration was found to be more than 30 times above the South African Occupational Exposure Limits of 50 ppm. The average ethylbenzene concentrations measured ranged from 433 ppm to 500 ppm; the highest concentration was found to be 5 times above the South African Occupational Exposure Limits of 100 ppm. The average xylene concentrations measured ranged from 1372 ppm to 1584 ppm, the highest concentration was found to be more than 15 times above the South African Occupational Exposure Limits of 100 ppm. All

the measured BTEX compounds were found to be above their respective South African Occupational Exposure Limits.

The cancer risk was determined to be 13×10^{-2} (male) and 10×10^{-2} (female), 14×10^{-2} (male) and 11×10^{-2} (female), 16×10^{-2} (male) and 13×10^{-2} (female), 12×10^{-3} (male) and 10×10^{-3} (female) for the workers in the density huts, laboratory, strain remover (plant equipment cleaning), respectively.

In all exposure scenarios (male and female) the cancer risk was found to be higher than the acceptable risk levels of $1E^{-4}$. There were 13 males and 10 females in the population of 100 controllers who were likely to develop cancer when working density huts environment. In the laboratory work environment, 14 males and 11 females in a population of 100 controllers were likely to develop cancer, whereas 16 males and 13 female laboratory workers were likely to develop cancer in a population of 100 laboratory workers, and during plant equipment cleaning 12 males and 10 female controllers were likely to develop cancer in a population of 1000.

Therefore, the potential of developing cancer was heightened by working in the laboratory and density huts. The risk of the number of employees who were likely to develop cancer was reduced when doing plant equipment cleaning. In all three activity areas, cancer risk for males was higher than for their female counterparts. This finding denotes that male were more vulnerable than females even though the exposure concentration is the same. The higher number of males who were likely to develop cancer in all the activity areas were influenced by two factors i.e., males have a shorter average life expectancy and higher average body weight versus their females' counterparts.

A hazard quotient was used to determine the non-carcinogenic health effects, a hazard quotient of greater than 1 was used as a reference value. A value greater than 1 denoted a higher possibility that depot workers will get health effects from exposure to the Toluene, ethylbenzene and xylene (TEX). The hazard quotient for males ranged from 4.6 to 577.5, the highest hazard quotient was more than 577 times above the HQ reference value. The lowest was at density huts for xylene and the highest was at the laboratory for a chemist for xylene. The hazard quotient for females ranged from 3.15 to 399.00, the highest hazard quotient was more than 399 times above the HQ reference value. The lowest was at density for xylene and the highest was at the laboratory for laboratory assistant. From the results,

both males and females had a hazard quotient far above 1 which means health effects arising from TEX exposure were anticipated.

Conclusion

The results showed highest constant BTEX concentrations in the three exposure scenarios over the 12 hours shift. The BTEX emissions were generated by activities that were performed by the depot workers. Highest BTEX concentrations were measured at laboratory, followed by density huts and the least was measured during the removal of the strainer (plant equipment cleaning). The lack of effective vapour recovery system and natural ventilation in the laboratory and in density huts also contributed to the high BTEX concentrations measured in these areas. Individual BTEX component results measured in the three activity areas indicated concentrations that were far above the South African Occupational Exposure Limits for individual BTEX. The cancer risk score was found to be far above the reference USEPA cancer risk value and denoting that depot workers were likely to develop cancer. The hazard quotient for the three exposure scenarios was also found to be greater than the reference value of 1 which indicates the potential to develop non-carcinogenic health effects due to exposure in three exposure scenarios.

Recommendations

The following recommendations are made to assist management of the depot to control employees' exposure to BTEX emissions per activity area:

Density huts

The practicality of introducing a vapour recovery system on workbenches to extract the VOCs generated during sample collection and from density measuring jugs should be investigated or alternatively, the introduction of an online fuels and density analysis should be investigated or the practicality of introducing sample bombs to collect fuel samples should be investigated. Keep the windows opened to promote an ingress of fresh air and allow BTEX emissions to escape. A practicality of introducing a controlled mechanical ventilation to blow vapours away from the breathing zone of the depot workers should be investigated.

Laboratory

The practicality of automating or modifying the GC equipment in the laboratory to be able to conduct an online petrochemical analysis to control employees' exposure should be investigated. The tasks that require rinsing of testing tubes with fuels, refilling of the testing tubes, and discarding of superfluous samples should be performed under controlled conditions, the practicality of introducing a vapour recovering system to control vapours emissions should be investigated. The current practice of keeping the decanting drum open should be discontinued to prevent the accumulation of vapours in the laboratory or alternatively, it should be kept under a vapour recovery system. The practicality of keeping the retained fuel samples under the vapour recovery system in the laboratory storage should also be investigated. The fume hood and two extraction units should be serviced on a regular basis.

Cleaning of plant equipment (strainer removal)

The practicality of automating the removal and lifting the strainer to be cleaned to increase the distance between the strainer and receptors (controllers) should be investigated. The practicality of putting the clogged-up strainer in degreaser bath to remove and clean the strainer with the view of automating the task to prevent employees 'exposure to VOC emissions.

Recommendations applicable to all activity areas

Employees exposed to BTEX including the other petrochemicals should undergo a risk-based medical surveillance program including biological monitoring to evaluate the efficacy of the existing controls and as part of a preventative medical surveillance program. Provide information, instruction, and training at regular interval about: - petrochemicals (BTEX) that employees are potentially exposed to at workplace and duties of persons who are likely to be exposed to VOCs vapour. The names and potential harmfulness of the BTEX at the workplace and the employees who are likely to be exposed. Significant findings of the BTEX exposure assessment (an occupational health risk assessment survey). Information on how to access the relevant safety data sheets and information that each part of an SDS provides. The work practices and procedures that must be followed for the use, handling, storage, transportation, spillage, and disposal of samples, in emergency situations, as well as for good housekeeping and personal hygiene. The necessity of personal exposure air sampling, biological monitoring, and medical surveillance; The need for engineering controls and how to use and maintain them. The need for personal protective equipment, including respiratory protective equipment, and its use and maintenance. The precautions that must be taken by an employee to protect themselves against health risks associated with exposure, including wearing and using protective clothing and respiratory protective equipment. The necessity, correct use equipment, maintenance and potential of safety facilities and engineering control measures provided. Supervisor/Line Manager must give written instructions of the procedures to be followed in the event of spillages, leakages, or any similar emergency situations to employees. Once the aforementioned information, instruction and training have been provided, enforce the wearing of the prescribed PPE including ABEK respirator and no employee should be allowed to enter and remain in respiratory zone without the prescribed PPE and respiratory protection equipment (ABEK respirator).

Acknowledgments

I cannot find a better word to express my sincere gratitude to an individual who made my study and research a great success. Firstly, my gratitude goes to my supervisor Dr. Masilu Daniel Masekameni who has been actively involved in guiding, coaching me throughout my study and research journey. Your patience, guidance, nurturing, and mentorship are greatly valued and appreciated. I will forever be indebted to you.

To my fellow compatriots (Moses Mokone, Richard Gumede, Thulile Zamisa, and Chimsy Dhlamini) thank you for being a great team. Your invaluable encouragement, contribution, and support are greatly valued and appreciated.

Table of Contents

Declaration	i
Dedication	ii
Abstract	iii
Recommendations	vii
Table of Contents	x
List of abbreviations	xiii
List of Tables	xvi
1. Background	1
1.1. History of the chemical industry	1
1.2. Impact of chemicals	1
1.3. Health and economic impact associated with workplace occurrences and properties and sources of BTEX	2
2. LITERATURE REVIEW	4
2.1. BTEX release mechanism as part of VOC's.	4
2.2. Sources of BTEX	5
2.3. BTEX emissions from industrial activities	5
2.4. BTEX emissions from non-industrial activities	5
2.5. BTEX emissions from mobile sources	6
2.6. Use of BTEX	6
2.7. Occupational exposure to BTEX	7
2.8. Residential exposure to BTEX	8
2.9. BTEX route of entry into the human body	9
2.10. Inhalation as a route of entry	9
2.11. Incidental oral ingestion as a route of entry	10
2.12. Dermal absorption as a route of entry	11
2.13. Health effects associated with exposure to BTEX	11
2.14. Occupational controls of BTEX exposure	13
2.14.1 Hierarchical approach	13
2.14.2 Engineering controls	14
2.14.3 Administrative controls	15
2.14.4 Use of personal protective equipment (PPE)	15
2.15. Problem statement	16
2.16. Study Aim	18
2.17. Hypothesis	18
2.18. Objectives	18

2.19.	Justification	18
3.	METHODOLOGY	20
3.1.	Methods and materials	20
3.1.1	Description of the study settings	20
3.1.2	The density huts	21
3.1.3	The laboratory	22
3.1.4	Cleaning of plant equipment (strainer removal)	23
3.2.	Study population	24
3.2.1	Study population	24
3.2.2	Study sample	24
3.2.3	Sample size	24
3.2.4	Data collection process	25
3.2.5	Data collection using questionnaire, checklist and PID equipment for pilot study	25
3.3.	The description of BTEX monitoring instrument set-up	26
3.4.	BTEX Sampling	27
3.5.	Data analysis	27
3.5.1	Processing of BTEX data from PID	27
3.5.2	Calculation of BTEX Concentration	27
3.6.	Statistical analysis	29
3.7.	Determination of exposure assessment	29
3.7.1	Toxicity Assessment and Risk Characterization	32
3.8.	Quality control	33
4.	RESULTS	34
4.1.	Pilot study	34
4.2.	Petrochemical Depot – demographic information, duration of exposure and controls	34
4.3.	BTEX exposure scenario at the density huts	37
4.4.	BTEX exposure scenario at the Laboratory	38
4.5.	BTEX exposure scenario during the removal of strainer (cleaning of plant equipment (the strainer))	40
4.6.	BTEX emissions at different activity areas	40
4.7.	Individual BTEX specie average concentration for the different activity area	44
5.	DISCUSSION AND CONCLUSION	51
5.1.	Synopsis of study findings	51
5.1.1	BTEX concentrations in three activity areas	51
5.1.2	Laboratory	53
5.1.3	Density huts	53
5.2.	Statistical analysis of BTEX concentrations in the three activity areas (Density huts, laboratory, and strainer removal)	53

5.2.1	Potential Health Risk Analysis for BTEX	54
5.3.	Study limitations	56
5.4.	Study strengths	57
5.5.	Future research and recommendations	57
5.6.	Recommendations	58
5.6.1	Density huts	58
5.6.2	Laboratory	58
5.6.3	Cleaning of plant equipment (strainer removal)	58
5.6.4	Recommendations applicable to all activity areas	58
5.7.	Conclusion and significant	59
5.	REFERENCES	61
	DATA CAPTURING SHEET	68
1.	APPENDIX A: QUESTIONNAIRE	68
2.	APPENDIX B: CHECKLIST	71

List of abbreviations

AT	Years in a lifetime/number of days per year
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
BW	Body weight
C	Area concentration
CDI	Chronic daily intake
CF	Conversion factor
COPD	Chronic obstructive pulmonary disease
CR	Cancer risk
ED	Exposure duration
GC	Gas chromatograph
HQ	Hazard quotient
HVAC	Heating, Ventilation, Air Condition System
ILO	International Labour Organization
IR	Inhalation rate
KPa	Kilopascal
LCD	liquid-crystal display
N	Number of samples
PAH	Polycyclic aromatic hydrocarbons
PID	Photo ionization detector
PM	Particulate matter
PPE	Personal protective equipment
PPM	Parts per million
PTFE	Polytetrafluoroethylene
RFC	Reference concentration

SF	Slope factor
TEX	Toluene, Ethylbenzene and Xylene
UK	United Kingdom
US EPA	United States Environmental Protection Agency
US \$	United States Dollar
VOCs	Volatile organic compounds
WHO	World Health Organization
YE	Years of exposure

List of Figures

Figure 1: Schematic diagram for the density hut activity area.	21
Figure 2: Schematic diagram for the Laboratory activity area.	23
Figure 3: Schematic diagram for the Strainer removal activity area.	24
Figure 4: Concentration of benzene per activity area	44
Figure 5: Concentration of Toluene per activity area.	45
Figure 6: Concentrations of Ethylbenzene per activity area..	45
Figure 7: Concentrations of xylene per activity area.	46
Figure 8: Concentrations of individual components for BTEX at the Density hut.	46
Figure 9: Concentrations of individual components for BTEX at the Laboratory.	47
Figure 10: Concentrations of individual components for BTEX at Strainer removal.	48

List of Tables

Table 1: BTEX concentrations incorporating correction factor provided by Technical Note TN – a guideline for PID instrument response	28
Table 2: Converting ppm into mg/m ³	28
Table 3: Summary of exposure scenario factors and values was used during data analysis	29
Table 4: Benzene slope factor, and toluene, ethylbenzene, and xylenes (TEX) inhalation reference values.	32
Table 5: The average of BTEX at the three activity areas (density hut, laboratory, and strainer removal)	41
Table 6: Pairwise comparison per individual activity area	41
Table 7: Pairwise comparison for three activity areas	42
Table 8: Total individual component of BTEX per activity area	43
Table 9: Carcinogenic and non – carcinogenic risks for male and female controllers, and laboratory workers (chemist and laboratory assistant)	49

CHAPTER 1

This chapter begins with an overview of volatile organic compounds specific to Benzene, Toluene, Ethyl benzene and Xylene (BTEX) and its natural and anthropogenic sources and their impact on occupational exposure. The release of BTEX from petrochemicals is outlined and the chapter further describes the occupational exposure to BTEX use and the health effects associated with such exposure. It gives a comprehensive description of the release mechanism of BTEX from the source to the compartment (air, land, or soil) which could serve as receptor or pathway to reach the receptor. A short description of sources for BTEX both are also discussed both natural and man-made causes are briefly discussed. It further discussed the BTEX from industrial and non-industrial, and mobile sources. The uses of BTEX are discussed, briefly followed by a discussion of the three routes of entry for BTEX into the human body, followed by occupational and residential exposure to BTEX, health effects associated with BTEX and ending discussing the control of occupational exposure to BTEX focusing on hierarchy of control. The problem statement and justification of the study are outlined, and the chapter ends by presenting the study aim, hypothesis, and objectives.

1. Background

1.1. History of the chemical industry

In 2018 chemicals production was the second largest production sector in world. China is the largest producer of chemicals in the world, it accounts for 37% and 16% of the world production and market share respectively. Asia is the largest producer and consumer of chemicals in the world, it is followed by Europe and America respectively and America accounts for 13% market share. World production of chemical nearly double between 2000 and 2017. The global value chain of chemical production starts with the extraction of raw material, then chemical manufacturing, then downstream chemical products manufacturing, then industrial and consumer products manufacturing, then industrial and consumer products use and reuse, and industrial and consumer product disposal and waste (1).

1.2. Impact of chemicals

Not only exposure to chemicals can cause health effects but it has potential to cause immediate harm and loss of life and economy to workers, communities, and surrounding environment. The impacts and costs associated with industrial disaster, accidents/incidents,

injuries and disease to human, social and economy have long been documented and cause for concern to key stakeholders (workers, communities, government and international bodies) (1).

1.3. Health and economic impact associated with workplace occurrences and properties and sources of BTEX

The International Labour Organization estimated 2.2 million workers are dying yearly from work-related accidents and occupational diseases, whilst about 270 million suffer serious injuries and 160 million become ill due to their work. It further estimated the work-related accidents and diseases cause 4% of annual Global Gross Domestic Product or US \$1.25 trillion due to lost working time, workers' compensation, the interruption of production and medical expenses. In 2005, the ILO estimated that 440 000 people died throughout the world as a result of exposure to hazardous chemicals (2).

It was estimated that 2.34 million workers were killed every year in 2013 by work related accidents and diseases. By far majority of the workers were killed by occupational diseases, the number was estimated to be 2.02 million per year (3). This is translated to an estimated 195 000 workers losing their life per month, resulting to an estimated daily death of 6300 and 5500 (87%) of the 6300 was estimated to had been caused by a wide range of occupational diseases. When this number is further broken down per hour in a day, it was estimated that 263 people died as a result of work-related injuries and diseases (3).

In Bangladesh 600 workers died in work related accidents, 170 of 600 were from formal sector and the remainder from informal sector. Whereas 488 workers were injured, 225 of injured workers were from formal sector and the remainder from informal sector. From January to June 2015, there were 1088 workers that were casualties in Bangladesh, translating to almost 6 workers being killed per day, nearly 182 being killed per month which is quite high (4).

It was estimated that in 2011, 666 000 workers lost their life due cancer, again the estimated number of the workers who perished as a result of cancer increased in 2015 to 742 000 (1). In 2018, the International Labour Organization (ILO) released the latest statistics indicating a surge in work-related cancer (1). In 2011, 666 000 workers died due to death attributed to cancer and again in 2015 the number moved upwards to 742 000. The statistics for work-related cancer world-wide continue to be on upwards trend (1). It is safe to draw a conclusion

that in 2021 the number of workers who will be dying due to work-related cancer will surpass the number reported in 2015 by ILO.

The production, handling, storage, and usage of chemicals at work has a potential to cause fire and explosions, with a potential to cause massive destruction on an infrastructure, loss of life and injuries. Recently, a classical example in August 2020, Beirut was rocked by series of explosion caused by stored ammonia nitrate and as a result more 200 people were killed and more than 7500 were injured (1).

BTEX is part of volatile organic compounds (VOCs) and characterized by boiling point that ranges 50 to 260 degree Celsius and vapour pressure in excess of 10^{-2} KPa (5). However, BTEX is characterized by high vapour pressure and as a result, it is found in a gaseous state (6). BTEX is mono-aromatic hydrocarbon compounds. The configuration of six carbon atoms in aromatic compounds is known as a benzene ring and part of volatile compounds which are produced from different activities or processes (7).

Occupational injuries and disease statistics for South Africa is quite limited. However, in 1996 who reported that the injury frequency rate was standing 89 workers per 1000 and 93 fatalities per 100 000. The Sub-Sahara estimated burden of occupational disease statistics to be 537 400 to 1 105 600 (8).

Predominately, BTEX compounds are produced in the fuel processing sectors such as oil and gas production. Activities such as flaring, and venting (combusting and releasing of petrochemical products) are reported associated with an increase release of BTEX. Notably petrochemical products such as diesel and petrol contain a number of short-chain organic compounds, light-chain volatile compounds and heavy-chain compounds (9). The BTEX is a light-chain volatile organic compounds and is designated as toxic to human (9). These volatile organic compounds have been linked to outdoor activities which later contaminate the indoor air spaces (10).

Levels of BTEX in an indoor environment such as schools, boutique salon, domestic residential area are strongly influenced by outdoor activities such as traffic condition, land use, smoking and also indoor activities such as the use of printers, burning of fossil fuels (wood or coal) for warming or cooking purpose (11-13). Vehicular emission is amongst the major sources of BTEX due to the combustion of petrol or diesel (14). It is suggested that

while vehicle engine is at low speed or idle, the emissions of BTEX are higher (15). Consequently, the indoor/ outdoor air in surrounding activity area are often exceeding World Health Organization (WHO) guidelines (16). Higher probability of BTEX concentrations indoors are further influenced by indoor activities and lack of control measures such as ventilation (16).

2. LITERATURE REVIEW

2.1. BTEX release mechanism as part of VOC's.

VOCs once released from their original sources are then transferred to the air, water or soil compartment depending on the process. Moreover, BTEX are often released as air-borne contaminants in aerosol or gaseous form (13). The emissions of VOCs, BTEX at petrochemical depots are well known and documented (9, 17-19). To sustain human life hood, development and advancement plus economy activities throughout the world energy is key, the main sources of energy is fossil fuels (6). The production of energy using fossil fuels has some unintended consequences of producing byproducts which pollute the environment (air, land and water) which can have adverse effects such as global warming, ozone depletion, acid rain, and photochemical smog (6). BTEX emitted as aerosols especially from combustion process once in the air compartment, they undergo transformation in a form of chemical reaction and change from particle based aerosol to gas (13). Depending, on the environmental conditions BTEX can remain suspended or in the air mixture for a prolonged period of time (13). However, BTEX emitted from an enclosed system such as fuel tanks are released as vapours that may contaminate the air compartment (13). Air-borne BTEX emissions are then transferred through an environmental (air, soil or water) media in order to reach the receptor (9).

The BTEX have lipophilic (ability of chemical to be soluble/dissolve in fats such as solvents e.g. toluene) characteristics and are diverse in various forms in the contaminated media leading to several ways of human intake (20). Potentially workers may be exposed while performing their duties to BTEX through physical contact with the source or contaminated media. The three common exposure intake routes includes dermal absorption, inhalation and ingestion (20, 21). There is compelling evidence pointing out that inhalation is the most common route of BTEX entry in the human system (9, 20, 21). BTEX has a high volatility due to high vapour pressure and as a result when released indoors, it easily become airborne

and hence, it is easy for the BTEX to be inhaled by receptors (22, 23). Therefore, it remains important to consider all possible routes of exposure in assessing exposure to BTEX. However, a defined exposure scenario needs to be contextualized to select the most appropriate intake route in an occupational setting.

2.2. Sources of BTEX

The sources of BTEX can be divided into natural and anthropogenic sources (6, 24, 25). Sources in an indoor environment could come from combustion when cooking, construction materials, furnishings, paints, varnishes and solvents, adhesives and caulks, office equipment, and consumer products. Other major contributor sources for indoor VOCs including BTEX are vehicular, burning of municipality waste and industrial emissions (11, 21). Wildfires are also contributors for VOCs, PAHs and fine particulate matter (PM) as the fires burn organic materials the VOC's, PAHs and PM are emitted to environment (water, land and air) (24).

2.3. BTEX emissions from industrial activities

Fossil fuels are also used for cooking, running some house activities such as heating and cooling home. BTEX are part of VOCs and they are emitted from various anthropogenic sources such as chemical manufacturing factories, refineries, commercial and consumer products, motor vehicle exhausts and biogenic sources such as trees and wildfires (6, 13, 26-28). The rapid population growth has created the desire to continue enhancing quality of life through the increased consumption of energy, through the use of fossil fuels in order to fulfil basic human necessities such as warming up home, cooking, promotion of development of industries and also enhancing social welfare (6). The unintended consequences of continuous exploitation of fossil fuels are the pollution of water, air, and soil. For instances the atmospheric photochemical reactions that contribute to ozone depletion, global warming, acid rain, photochemical smog formation and potential harmful health effects to human due to exposure to pollutant toxins (6, 26).

2.4. BTEX emissions from non-industrial activities

Sources of VOCs emissions in non-industrial settings are attributed to burning of fossil fuels to continue meeting necessities such as cooking, ironing, heating, or cooling home. Coal, paraffins and woods are some of the fossil fuels that are used (13, 29). Domestic burning of fossil fuels to meet their day to day necessities has also unintended consequences where

byproducts of combustion are accidentally liberated as pollutants to the surroundings (water, soil and air) for instance particulate matter, Sulphur dioxide, carbon monoxide, nitrogen monoxide, nitrous oxide, methane, carbon dioxide and VOCs (13, 29-31). Several studies confirmed pollutants that are emitted by the domestic burning of fossil fuels. The pollutants produced by domestic burning process are dependent on the materials being used as a source of energy for instance coal will produce a plethora of raw gases and particulate matter and whilst others may not produce traces of VOCs (13, 29-31). A particular concern is when hazardous emissions are released indoors, and the receptors are in a nearfield compartment. This could also be exacerbated by poor ventilation and possible of over exposure and development of health effects cannot be ruled out (30).

Hairdressers are continuously treating customers' hair using various chemicals to meet their customers' requirements. Some of these chemicals are quite hazardous to hairdressers and to all occupants. Plausibly causing headache, dizziness, eye and respiratory irritation, birth defects, neurocognitive problems, and cancer (32-35).

2.5. BTEX emissions from mobile sources

The advent of machineries and automobiles necessitated the energy production of fuels from fossil fuels in order to propel them to fulfill a specific mandate (36). Although the fuel is quite good in advancing the development of human race, it has some negative impacts in terms of polluting the environment. Fuels emissions does not only escape during the manufacturing processes but when it loaded into tankers, offloading and refilling of automobile and machineries (36). The transportation of fuels from refineries and depots to filling stations also contribute to the liberation of VOCs and other gases via exhaust system which further pollute the environment (36). Areas where there is high density of traffic are closely linked and associated with the excessive liberation of BTEX emissions to the environment. Houses in the proximity may be prone to have high concentrations of BTEX and the residents of the impacted areas are highly likely to overexposed to the BTEX emissions. The high concentrations of BTEX in the areas are closely linked with certain diseases or health problems.

2.6. Use of BTEX

BTEX is part of petrochemical products such as fuels which are mainly produced from fossil fuels – diesel and petrol are used for various purposes that includes powering light passenger vehicles, general freight vehicles, machineries and also to generate power (6, 37). Benzene

is a versatile chemical substance in terms of uses, it is part of fuels and a mixture of aromatic compounds that are used as an anti-knock ingredient in petrol and have replaced lead.

Benzene is common in unleaded fuel, where it is added as a substitute for lead, allowing smoother running (38-40). It is used as a solvent and start material for chemical synthesis, although the use is restricted due to its toxicity, it is used primarily as chemical intermediate for production of major industrial products alkylated derivatives such as ethyl benzene and cumene which are used as basic materials for the production of styrene, long chain alkylbenzenes and phenol (38-40).

BTEX are further used as a feedstock for manufacturing surfactants. Benzene is hydrogenated to form a cyclohexane, and also oxidized to produce maleic anhydride, nitrated to obtain nitrobenzene as an intermediate in the production of aniline, and halogenation to obtain chlorobenzene derivatives (38, 40).

Toluene is part of aromatic compounds that are part of fuels(41) and used in the production of cresol and benzene by dealkylation process, in production of toluene diisocyanate through nitrotoluene intermediates, in the production of benzoic acid and benzaldehyde, and benzyl alcohol through oxidation process, used in the application as an aromatic solvent, the production of toluene diisocyanate through nitrotoluene intermediates, it also used production of plant protection agents and dyestuffs through chlorinated derivatives O-and p-chlorotoluene, benzyl chloride, and benzo trichloride, it is has replaced benzene in majority of consumer products an (42, 43). The sulfonic acids of toluene are applied as surfactants (42).

Ethylbenzene is produced when benzene and ethylene react in presence of catalyst called acidic zeolite through an alkylation process (44). It is used to produce a styrene monomer through an oxidative dehydrogenation process of the ethylbenzene (45, 46). Xylene isomers (O-, m and p-xylene) are produced from benzene and toluene raw materials through the oxidation process (47).

2.7. Occupational exposure to BTEX

There is growing concern in respect of occupational exposure to BTEX by workers and this is due to the toxicity of BTEX. Acute and chronic exposure to BTEX in occupational settings in developed countries are well documented. Exposure to high levels of benzene over a short term it has been found to been associated with toxicity or even death whereas long term exposure to low levels is associated with hematologic disease, pancytopenia, aplastic

anemia, leukemia, and bone marrow abnormality. Whereas chronic exposure and inhalation to low levels of toluene, ethylbenzene and xylene are associated with the damaged of the central nervous system and irritation of respiratory system (9, 13, 19, 23, 48).

There are several work activities that contribute directly to workers' exposure to BTEX at work. Workers who are involved with handling municipal solid waste management including landfill sites, recycling plants and healthcare waste recycling units are potential exposed to various BTEX levels. Conversion of municipal solid waste into compost is known to contribute to soil fertility and during different stages of municipal solid waste composting including shredding and fermentation has a potential to form and emit VOCs including BTEX emissions, consequently, the emissions directly affecting the compost workers who are handling and managing. It has a potential to migrate to nearby communities who live next to the facilities. The communities exposed to the migrating VOCs/including BTEX are likely to be impacted and it has become a major health concern (49). Activities such as shoe making, and solvent painting, traffic controlling, petrochemical refining, gasoline filling station, transporting, motorcycling and healthcare waste treatment autoclaving workers may be exposed to BTEX emissions (49). Further workers could be exposed to BTEX emissions that are originating from gasoline vapour during loading, offloading, refilling of automobiles and also from exhaust emissions (49).

2.8. Residential exposure to BTEX

Majority of time is spent by residents in an indoor environment. The time spent by residents in an indoor environment, it increases the chance of being exposed to indoor pollutants (12, 50-52). Some sources of indoor environment pollutants are from external sources that are near the environment. Pollutants including BTEX ingress the indoor environment via the doors, windows, cracks, air conditioning system (Heating, Ventilation, and air conditioning). BTEX exhaust emissions for an automobile idling or running from the attached garage can migrate from it to the occupied space of the house leading to exposure to BTEX. It can also come from idling lawn mowers. Other BTEX emissions sources are cooking, furniture, cigarette smoke, burning of fossils, oil and lubricants, some consumer products such as detergents, adhesives, glue, thinners or even benzene and building materials. BTEX has a high vapour pressure, and this makes it readily available in an indoor environment. It is easily available to enter the residents' body through inhalation. Inhalation is the most route of intake for the BTEX (12, 50-52). Exposure to BTEX has a significant impact to the exposed occupants, it is associated with development of chronic asthma, cancer (Benzene can cause increased risk of leukemia, aplastic anemia), some neurological disorders and symptoms

such as weakness, loss of appetite, fatigue, confusion, nausea, irritation of the eyes, skin, mucous membranes, and respiratory tract.

A risk assessment study for BTEX concentrations caused by coal combustion was conducted in residential area in South Africa (13), it revealed the potential of increased cancer risk due to exposure to benzene and also non-carcinogenic risks such as liver, kidney and central nervous system damage for the residential occupants who were exposed (13).

2.9. BTEX route of entry into the human body

BTEX is usually released from the source such as industries, automobile, fuel combustion etc. and thereafter migrates to the nearest surroundings where they may have a half-life of anything from second to several months. During the loading, offloading, and filling and refilling of vehicles in filling stations BTEX emissions are released and migrate to nearby areas, such surroundings may also include residential areas (21, 53, 54). BTEX is highly volatile and as a result is easily airborne and available as air pollutant. Once BTEX is liberated from the source is available to interact with the environment and including human's microenvironment. BTEX can enter human body through ingestion, skin and inhalation (21, 53, 54).

2.10. Inhalation as a route of entry

Exposure to BTEX can enter human body through three common routes, which are ingestion, dermal, and inhalation (9, 20, 21, 55, 56). The route of entry via inhalation is the most predominant and potent route due to their volatility volatile (vapour pressure and viscosity) (57). The vapour pressure of BTEX makes it readily available for inhalation. Chemical substances that are liquid at room temperature of 25°C and pressure (1 atmosphere) will partially exist in a gaseous phase called vapour (57). BTEX has high vapour pressure, and it is this physical property that makes it to evaporate easily and becomes airborne. It will continue to evaporate until a state of equilibrium is reached. The inhalation route of entry is the easiest and most potent and effective way the BTEX enters the human body. This could be since air contaminated by BTEX is already mixed and offers less resistance during breathing (21, 53, 54). A receptor who is in an air environment that is already saturated with BTEX is likely to be exposed to BTEX and chances of inhaling air contaminated by BTEX is enhanced. The amount of BTEX inhaled/ingested/absorbed is dependent on the concentration of BTEX in the air, the duration of exposure and rate of ventilation, which increases with increased workload. Once inhaled it will be absorbed through the blood stream and distributed to organs with strong affinity (57).

2.11. Incidental oral ingestion as a route of entry

Direct oral ingestion of BTEX is very uncommon and rare, however, indirect through contaminated food and water is very common (58-60). Workers do not deliberately ingest or swallow chemicals at workplace, however, workers can accidentally ingest chemical because of contaminated work areas, fingers, hands, and food etc. Poor work practices such as drinking, eating and smoking in work areas where chemicals are manufactured, handled, processed or stored could result in chemical being accidentally ingested. Chemicals that are being inhaled could be deposited on the throat ending up being swallowed. Chemicals that have been deposited in the upper respiratory system or from bronchioles could be moved upwards by propelling movements of the mucous lining the respiratory tract into the throat where the chemical will be swallowed into the stomach (57). Main source for oral ingestion is consuming contaminated food or water. Sources of water pollution are petrochemical industry waste streams, municipality landfill sites, domestic wastes, oil spillages and rainwater (58-60). Contaminated water streams from petrochemical industry end up contaminating underground water. Chemical including BTEX from municipality landfills is seeping through soil layers ending up contaminating ground water. Chemicals including BTEX being disposed of as part of domestic wastes by residents into water reticulation system. Major oil spillages have potential to be washed off to a nearest water collection points or seeping through soil layers ending up contaminating ground water basin. Air contaminated by chemicals including BTEX have a potential to be washed down by rain downpours that could end up in water catchment area or seeping through the soil layers ending contaminating underground water (58-60). Many of these environmental toxic substances take time to dissolve in water and remains for a very long time in the environment causing long term community exposure. The toxicity of the chemical is dependent on concentrations and the distance of the receptors from the sources, the closer the receptors to the sources, the higher the exposure (21). The winter season favours the endurance of BTEX compounds and such has a potential to make receptors to be exposed to them for an extended period, consequently, the higher the accumulation of the chemical to receptors' body, associated with increased health risks and health effects arising from such exposure cannot be ruled out (21).

2.12.Dermal absorption as a route of entry

Skin is the second largest organ in a human body after lungs. It is about 2mm thick, and it offers protection against external environment, including invasion against hazardous substances to a certain degree. The epidermis stratum corneum acts as a barrier to an entry of foreign chemicals through regulating its non-permeability. The skin is made out stratum corneum, hair follicles and sweat ducts. The stratum corneum is the largest skin surface and plays major part in skin absorption and whereas the follicles and sweat glands have minor and negligible contribution on skin absorption. Certain factors of skin conditions such as dermatitis, lacerations and punctures promote and contribute to the increased rate of skin absorption (57).

The rate of absorption of some organic chemicals is influenced by temperature and perspiration. The higher absorption rate is expected during hot days or warm seasons. The absorption of organic chemicals may occur because of skin surface or clothes contamination with a liquid organic chemical. It may occur because of high concentration of vapour pressure in the environment, and it has been found that the absorbed organic vapours were corresponding to the number/concentrations of vapours in the air. The process of absorption of BTEX through the skin is caused by the deposition of the BTEX onto the skin and thereafter the penetration of the substance through the skin. BTEX are fat soluble or lipophilic chemicals which are able to pass through the intact skin and blood-brain barrier (57).

2.13.Health effects associated with exposure to BTEX

The emissions of volatile organic compounds and polycyclic aromatic hydrocarbons (PAHs) by veldfires are known or suspected carcinogens and also toxic when human beings become exposed to (24). BTEX has a potential to cause harm to human, plants and aquatic organisms (6). Occupational exposure to benzene can occur in many different industries such as petroleum, chemical production, and manufacturing, here workers could be exposed to excessive level of benzene (39). It was further demonstrated via laboratory studies applying both *in vitro* (cell cultures) and *in vivo* (animal studies) that acute and chronic exposure to BTEX lead to several health effects damage to the hematopoietic system, including pancytopenia.

The relationship between benzene exposure and the development of acute myelogenous leukemia has been established in epidemiological studies. Toluene, ethylbenzene and xylene have been linked to damaging central nervous system and irritation of respiratory system (9,

13, 19, 23, 48). In other setting it was found that VOCs are associated with environmental alterations such as ozone depletion (9, 13, 19, 48).

Benzene and ethylbenzene are confirmed carcinogens (Benzene is classified as a Group 1 and ethylbenzene is a Group 2 B carcinogens) (9, 17-19). The United States Environmental Protection Agency (USEPA) has classified benzene as a human carcinogen. Exposure to benzene has also been found to have toxic effects on hematopoietic system (such as leukemia and hematopoietic cancers (7, 9). Toluene, ethylbenzene, and xylene (TEX) are associated with the alteration of the central nervous system, cardiovascular, reproductive system (7, 9, 61, 62). Inhalation of air contaminated by BTEX is associated with the development of a chronic obstructive pulmonary disease (COPD) (21). It has also been established that chronic BTEX exposure even at a lower inhalable levels is associated with adverse health effects in the cardiovascular, endocrine and respiratory systems (50).

In the central nervous system (neurological effects) TEX exposure produces symptoms such as headache, mental confusion, dizziness, fatigue, nausea, tremors, incoordination, anxiety, impaired short-term memory, and inability to concentrate (7, 9, 61, 62). Cardiovascular system related illnesses are inclusive of chronic disorders such as aplastic anemia and pancytopenia (7, 9, 13, 48, 61, 62). In the respiratory system symptoms and illnesses associated are with throat irritation, shortness of breath and the induction of asthma attacks (7, 9, 13, 48, 61, 62). Exposure to benzene, ethylbenzene, toluene, and xylene was found to cause female infertility, birth defects, intrauterine growth retardation and reproductive system related disorders (7, 9, 13, 48, 61, 62).

In the central nervous system (neurological effects) TEX exposure produces symptoms such as headache, mental confusion, dizziness, fatigue, nausea, tremors, incoordination, anxiety, impaired short-term memory, and inability to concentrate (7, 9, 61, 62). Cardiovascular system related illnesses are inclusive of chronic disorders such as aplastic anemia and pancytopenia (7, 9, 13, 48, 61, 62).

In the respiratory system symptoms and illnesses associated are with TEX exposure are throat irritation, shortness of breath and the induction of asthma attacks (7, 9, 13, 48, 61, 62). Exposure to benzene, ethylbenzene, toluene, and xylene was found to cause female infertility, birth defects, intrauterine growth retardation and reproductive system related disorders (7, 9, 13, 48, 61, 62).

Eye problems such eye irritation and blurred vision (7, 9, 13, 48, 61, 62). Nevertheless, despite dearth of literature on this subject reference is often made from developed countries with poor evidence documentation of such incidences in developing countries. Therefore, it is suggested in several literatures that additional studies on this subject is necessary, especially in developing countries, including South Africa (13, 63).

2.14. Occupational controls of BTEX exposure

2.14.1 Hierarchical approach

Chemicals are indispensable and critical part of life, their visible positive outcomes are quite palpable and well recognized for instance pesticides improve the quality of food production, pharmaceuticals cure illness, cleaning products help to establish hygienic living conditions and chemicals are key development of final products that makes life little bit ease for human beings etc. The controlling employees 'exposure to chemicals, and also preventing or minimizing emissions remains a significant challenges in workplace throughout the world (64).

The continuous occupational exposure to BTEX at low concentrations is associated with chronic health effects and whereas acute health effects are linked with exposure to high concentrations of BTEX, these are well documented on literatures (9, 13, 19, 23, 48, 65, 66). Hence in South Africa, the statutory provision requires every employer to provide and maintain as far as reasonably practicable a working environment that is safe and without risk to health of his employees (67). In the effort to comply with the prescript of the legislative requirements, the employer is obliged to establish what hazards to the health or safety of workers are attached to any work which is performed (67). The employer is required to take steps as far as reasonably practicable to eliminate or mitigate any hazard or potential hazard to the safety or health of workers before resorting to personal protective equipment (PPE) (67). The employer is also required to further establish what precautionary measures should be taken with respect to such work in order to protect health and safety of workers and should also provide the necessary means to apply such precautionary measures (67). To fulfil and meet the legislative prescript a hierarchical control measures needs to be implemented and maintained at a working environment. The hierarchy of control is comprised of elimination, substitution, engineering, administrative and PPE (67, 68). The most preferred, desired, and effective control is elimination. When a hazard attached to any work is eliminated, the health and safety of workers is total insulated against the removed/eliminated hazard. Whereas the

application or usage of PPE as a control measure leaves a significant degree of risk untreated. The workers are still potential exposed to the risks, hence is the least preferred method of controlling the risks. Its effectiveness is dependent on number of factors such as the capability of the PPE giving the intended protection, the training provided to the workers on how to use the PPE and the correctly use of the PPE by the workers. Hence, the legislative has high emphasis on elimination and engineering control measures. The degree of effectiveness and desirability is reduced as you go down with the list of hierarchy of control i.e. elimination, substitution, engineering, administrative and personal protective equipment (68). The legislation also requires workers to obey a lawful instruction issued by the employer in the interest of health and safety at workplace. This include the use of precautionary measures to control risks, agree to maintain housekeeping in interest of health and safety at workplace, undergo medical assessment, carry/wear occupational hygiene equipment/devices to monitor and quantify personal exposure, adhering to all health and safety rules issued by employer in the interest of health and safety and the correct wearing PPE (65, 67).

2.14.2 Engineering controls

Engineering controls are designed to segregate/seclude contain hazardous substances with the view to protect workers and community at large. It involves at number of designs considerations to treat the hazards/risks. The hazardous substances are treated at source by containing them or reducing their toxicity to ensure that workers are not harmed when exposed. The engineering controls could also be implemented along the pathway of the hazardous substances to make the pathway less hazardous when workers are exposed, for instance a pipeline carrying hazardous substances, is built in such a way that the hazardous material is contained inside the pipeline (65-68). The engineering control could also be introduced/implemented on recipient/receptor's side to ensure that the workers are not exposed to hazardous substances, for instance housing the receptors in a control room to lockout the hazards (65-68). The effectiveness of engineering controls is dependent on the design in mitigating the risks and the training given to the end user to get maximum benefits from the engineering controls. The maintenance of engineering on a continuous basis is quite critical and a requisite as well. The maintenance of controls is key in retaining the intended design, efficacy, performance, and competency (65-68).

2.14.3 Administrative controls

When the most effective controls were unable to completely remove the exposure to the risk, an administrative control needs to be introduced to further assist in controlling the exposure to the BTEX. An administrative control regulates the behaviour of the exposed workers through introducing policies, work instructions, standard operating procedures, and provision of training. The success of administrative control is dependent on the given training, understanding and cooperation of the exposed workers (65-68). Hence, it is having a minimal to moderate success in controlling the exposure. As part of an effort by the employer to reduce workers' exposure to BTEX, the employer can introduce job rotation, restricting numbers of workers allowed to be exposed, provide training to workers on precautionary measures provided to control exposure to BTEX and how to use the precautionary measures to control their exposures. The job rotation is aimed to reduce the duration of workers' exposure to BTEX for instance a shift team with eight workers, only four workers would be allowed to work for four hours in BTEX area. Thereafter, the other four workers who were not working in the BTEX area will be assigned to work in the area (They will be relieving each other). Whereas the restriction of number of workers that enter the BTEX area is aimed to reduce the number of workers expose to BTEX at a specific time interval for instance, eight workers are competent to work in a BTEX area but the employer allows one worker to be exposed for the entire eight hour shift (65-68).

2.14.4 Use of personal protective equipment (PPE)

PPE is considered as a last defense and resort when it comes to hierarchy of controls. In work area where there is still a residual risk after applying the other (Elimination, substitution, engineering, administrative) controls, then PPE is usually considered to deal with the residual risk. PPE is used to screen and create a barrier, filter, protect body parts against potential risks (65-68). The PPE covers the entire body parts, and the following are some of PPE: hardhat, safety glasses/goggles, respirators (dust mask, cartridge respirator, respirators connected to self-containing breathing apparatus and respirator connected online air supply), overalls, specialized body suits, coveralls, gloves, and safety boots. The type of PPE is dependent on the task to be performed. The effectiveness of the PPE is dependent on several factors such as the protection factor, comfortability, training provided to the user, correct use, and fitting of PPE. Although PPE is used as a last resort, there is an instance where PPE is used a first line of defense, in an emergency for instance a burning chemical building, factory, burning road tankers, entering a confined space in a sewer line, entering unknown

chemical buildings, factory and tanks, diving into chemical sump/dam and uncontrolled released chemical plume. In such instance a self-containing breathing apparatus, and a respirator connected to a line that supplies fresh air and impervious chemical suit, safety shoes and gloves are usually used to save life (65-68).

2.15. Problem statement

Workers' exposure to chemicals occurs throughout entire life cycle of chemicals. When raw materials are extracted to be used in the production, workers become exposed, when the raw materials are further processed to produce chemicals workers are exposed, when chemicals are used to manufacture downstream chemical products workers are exposed, when industrial and consumer products are manufactured, when industrial and consumer products are used and reused workers and communities become exposed, and when industrial and consumer products are disposed of as waste workers become exposed as well. Therefore, workers are exposed throughout their entire chemical value chain (1).

The energy situation is not unique in South Africa, energy demand has been constantly going up due to economic activities. Fuels are used to power the machines, trucks and cars, and electricity generation in country. In the main, the inland provinces, particularly the economic hub -Gauteng Province get petrol, diesel, and jet fuels from the Port of Durban. The fuels are transported via rail, road, and pipeline. However, the pipeline was not able to carry required fuels volumes. It was able to carry only one grade of fuel. This necessitated the construction of a new multi-purpose pipeline that would be able to carry the required fuels (69-71).

To sustain the demand for the petrochemical products a new multi-purpose pipeline was constructed and commissioned by a state-owned logistic company with the view to augment the existing energy requirements for Gauteng Province and surrounds (69-71). Despite the inherent economic benefits in energy trading, there are unfortunately exposure to health damaging pollutants during production, handling, transportation, and use of petrochemical products.

Notably, BTEX are emitted during processing, handling, and transportation events in petrochemical depots. Exposure to BTEX constitutes a health risk and dearth of literature is well documented globally (7, 9, 72-74). Several studies on exposure to BTEX were done both international and in South Africa (7, 9, 63, 72, 73). Most studies done on BTEX

exposure focused on residential health risk from nearby industrial or mobile activities. Very few studies have been done in South Africa assessing the risk of exposure to BTEX among petrol attendants and depot workers.

Like other developing countries, South Africa has seen an increase in demand of energy products in the transport sector such as petrol, diesel, and jet fuel. To support the substantial increase of motor vehicles and the economic activities, there is growing pressure in this sector to produce more fuels (19, 69, 74, 75). Majority (60%) of crude oil is imported from abroad to meet South African energy requirements, particularly to support the economic hub of Gauteng Province (69).

Petrochemical products are shipped to Durban from oil producing countries such as Middle East, Angola, Nigeria, Libya, Gabon and Russia (76, 77). Once received in Durban is pumped to refineries which refine the crude into petrol, diesel and jet fuels (78).

Currently, Durban Port handles and processes South Africa's crude oil requirements (78). Some of final products (petrol, diesel and jet fuels) are pumped to a state owned facility in Durban - Tank farm for storage and distribution via a pipeline (78). It is also distributed to other parts of the country including Gauteng via road and rail (78).

In turn, the Durban - Tank farm pumps the products through the newly commissioned multipurpose pipeline to a depot in Heidelberg(79, 80). The Heidelberg Depot also store the product in a Tank farm facility. The Heidelberg Depot also receives feeds from two inland refineries, one situated in Sasolburg in the Free State Province and the other in Secunda in the Mpumalanga Province. The products are distributed from the Heidelberg Depot to a number of satellite depots, where it would be collected by tankers to feed various retail depots for sale to the public (79-81).

There is a growing concern among workers in petrochemical industries regarding exposure assessments and risk characterization. Currently, risk assessment is done as a compliance tool, whereas efforts to demonstrate appropriate methodologies for accurate risk assessment are still lacking. Regulatory risk assessment is basic and form no basis for individual risk communication and management (82).

2.16. Study Aim

To characterize, assess exposure and health risk assessment to benzene, toluene, ethylbenzene, and xylene (BTEX) at the petrochemical depot at Heidelberg in Gauteng, South Africa.

2.17. Hypothesis

This study hypothesized that the BTEX concentration activity based will be higher corresponding to specific high VOCs emitting activities in contrary to an 8-hour time-weighted average.

2.18. Objectives

To achieve the above aim the following objectives were set out:

- a) To describe the exposure scenarios per work activity in a work area for petrochemical depot controllers and laboratory assistant.
- b) To quantify zone concentrations of BTEX per work activity in the working areas which controllers and laboratory assistant are potentially exposed to.
- c) To carry out risk assessment of exposure and associated health effects to BTEX.

2.19. Justification

Whereas exposure to BTEX being acknowledged as a potential risk amongst exposed individual in South Africa, there is a paucity of information on this subject. Consequently, due to lack of information on assessments there is a growing gap in a regulatory framework particularly in labour organizations and workers' forum. The current practice in South African regulatory framework focuses on regulatory risk assessment, where worker's characteristics and activity patterns are often ignored.

In addition, risk assessment data currently available provides for time aggregate exposure concentration over a working shift (15, 83, 84). However, it must be noted that employees often spend their time in different areas in the workplace. Consequently, time aggregate exposure concentration provides limited information regarding actual exposure concentration per workstation area (exposure scenario) over a given time. Therefore, this

kind of data sets does not assist much in the implementation of much needed controls to prevent or reduce the degree of future exposures.

This study adopted a different approach to the current regulatory exposure and risk assessment, where zone concentrations was used as proxies to calculate total worker exposure over a prescribed working period. Furthermore, risk assessment was based on mixed methodologies using exposure assessment data, USEPA default human parameters and exposure scenario data based on the study site worker distribution.

No similar study was conducted for the petrochemical depots in South Africa. This study offers a unique opportunity to study and advance information and knowledge on the existing paucity for chronic health risk of exposure to BTEX in the petrochemical depots.

This study is relevant in that it builds on the current paucity of information and knowledge on carcinogenic and non-carcinogenic risks of exposure to BTEX in petrochemical depots. The information might be useful in developing the preventative control measures, policy, and awareness programs.

This chapter begins with a description of study settings and describe the three exposure scenarios, followed by describing the study population, data collection process, data collection using questionnaire, checklist and PID equipment, the description of BTEX monitoring instrument set-up, description BTEX monitoring, data analysis, BTEX concentration, application of correction factor on BTEX specie, statistical analysis and quality control measures applied to ensure the data is reliable and valid.

3. METHODOLOGY

3.1. Methods and materials

3.1.1 Description of the study settings

A quantitative cross-sectional study was conducted at Petrochemical Depot in Heidelberg in Sedibeng District Municipality in Gauteng Province, South Africa. The depot is situated in the east of Johannesburg City Centre and falls just outside the boundary of the City of Ekurhuleni Metropolitan Municipality. The petrochemical Depot is about 54,7 km from Johannesburg Central Business District (CBD), 6.9 km from Heidelberg and 9.4 km from Nigel. Only one depot was used in the study. The selection of the Heidelberg Depot was based on fact that it is the main depot that supplies the other sub depots i.e., the Alrode in Alberton and Kendal in Ogies, Langlaaste in Johannesburg, Krugersdorp, Potchefstroom and the sub depots further supply other satellite depots. The main depot was convenient regarding access and have similar activities to other sub depots. It had a capacity storage for petrol both 93 and 95 octane, jet fuels and diesel and the depot ran a 24 hours and 365 days per year operations (85, 86).

Three activity areas namely density huts, laboratory, and cleaning of plant equipment (strainer removal) were used as BTEX exposure scenarios for depot workers (Controllers and laboratory workers (chemist and laboratory assistant)).

3.1.2 The density huts

The density huts were in the plant of depot and comprised of a solid building structure made of corrugated iron (IBR sheeting) both the roofs and walls, on both sides of walls had openable windows but at the time of sampling they were closed. One side of the wall structure was fitted with a door and the door was always kept open, allowing ease access into by the depot workers. Inside the density huts there were two workbenches positioned on each side of the door. The height of each workbench was approximately at abdomen's height. Each workbench was fitted with sample points for both diesel and petrol 93 and 95 octane, a measuring jug containing density probe immersed in fuels (used for fuel density analysis) and decanting area (points) for discarding superfluous samples, rinsing sample bottles and density measuring jug. The decanting point was connected to the sump via an enclosed pipeline. The density huts did not have other means of natural or mechanical ventilation other than the only entrance (door) that was kept open.

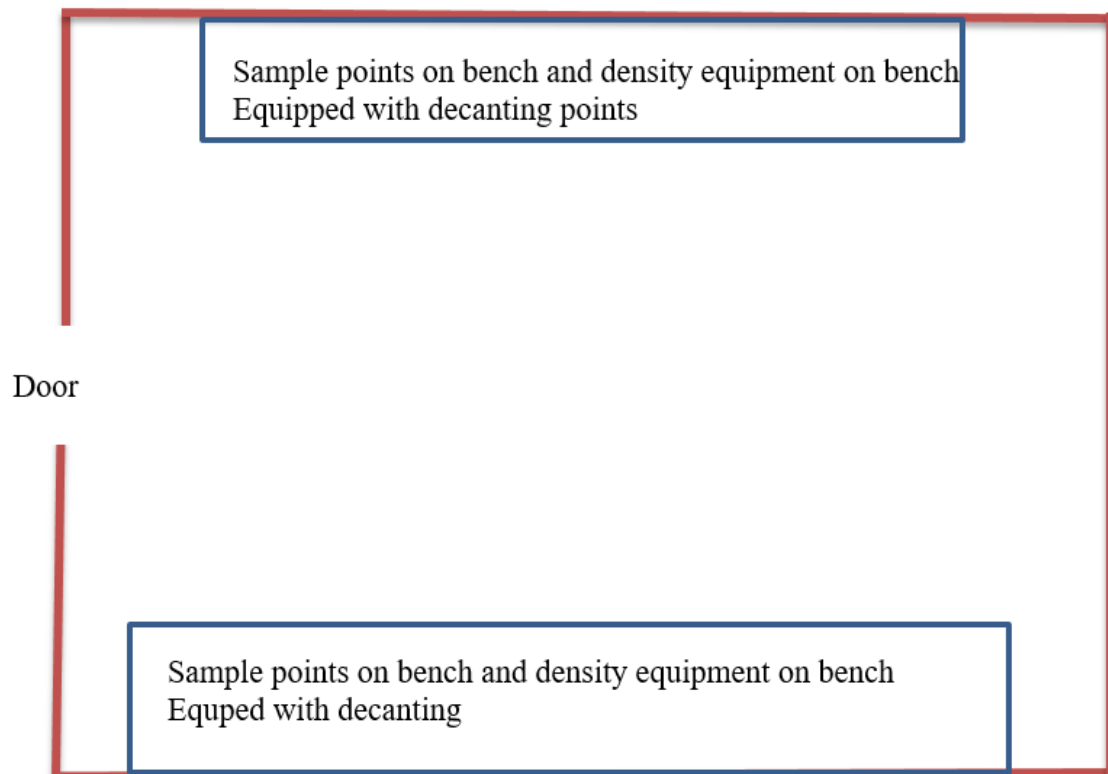


Figure 1: Schematic diagram for the density hut activity area.

3.1.3 The laboratory

The laboratory was situated on eastern side of the depot and on the periphery of the plant. It was made of solid double walls and with solid roof structure. It had two main heavy metallic doors, located one on the western and other on the eastern side of the building. The doors equipped with an automated closing mechanism that completely lockout any ingress of pollutants. The entire laboratory was under positive pressure and vapours were unable to ingress the building. The main laboratory was further divided into main laboratory and storage area (holding room) which was used a storage room for empty and full retained samples. The main laboratory was directly communicating with the sample holding room. The laboratory was equipped with three extraction systems namely fume hood; two small extraction units mounted on the walls. The main laboratory was equipped several gas chromatographs (GC) equipment and other laboratory equipment capable to conduct required petrochemical analysis. A kept open decanting drum was placed at the end of the equipment station for decanting superfluous/leftover samples or rinsing testing tubes. The entire laboratory was empowered with a heating, ventilation, and air conditioning system (HVAC) which was capable to filter pollutants out of the building and provided fresh air. The laboratory did not have a vapour recovery system to cover workstations and decanting drum other than the two extraction units mounted on the walls and the extraction system attached to the fume hood. Three extractions covered the general area of laboratory excluding the open decanting drum and workstation where fuel samples are handled. The laboratory did not have any means for natural ventilation it relied upon installed HVAC system.

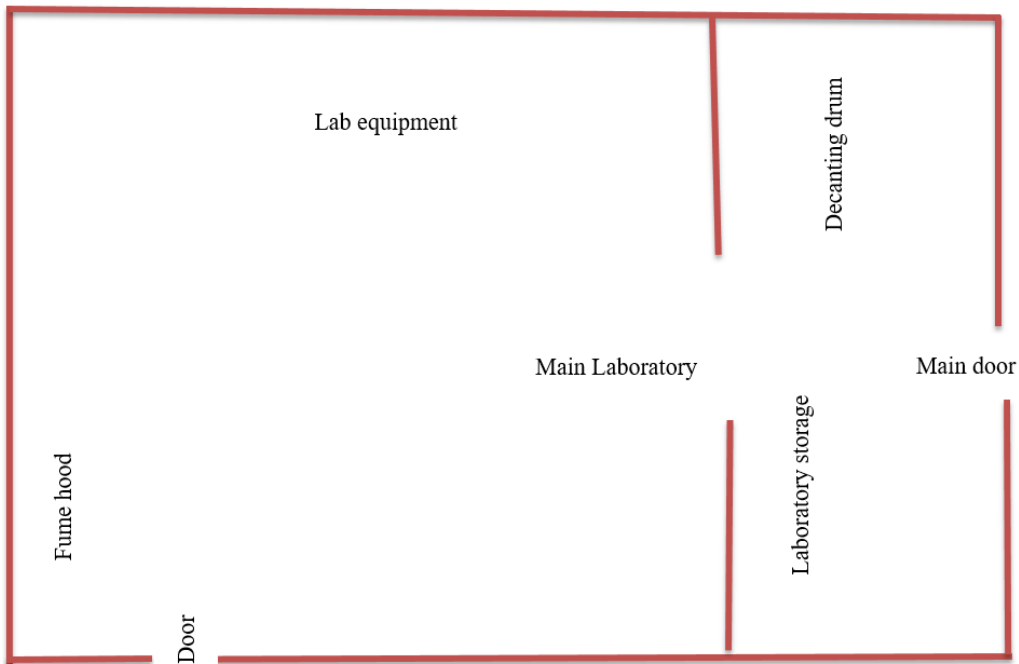


Figure 2: Schematic diagram for the Laboratory activity area.

3.1.4 *Cleaning of plant equipment (strainer removal)*

The plant was situated on western side of laboratory building and north of the control room building. It was comprised of several pipelines, control valves and strainers. The strainers and valves were part of pipeline infrastructure. The strainers were housed inside the strainer holders. They were responsible to filter fuels as it was passing through the pipelines. The plant was completely exposed to the ambient conditions.

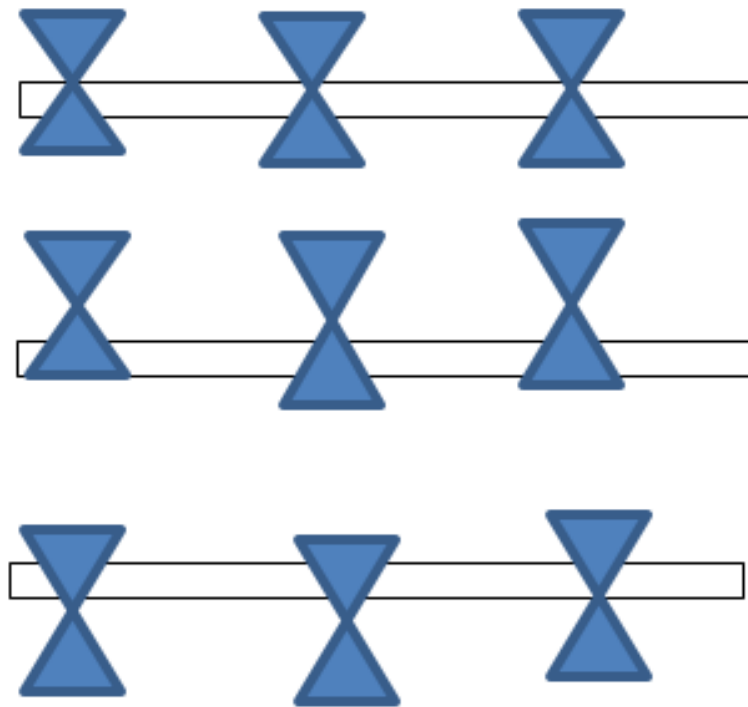


Figure 3: Schematic diagram for the Strainer removal activity area.

3.2. Study population

3.2.1 Study population

The study population comprised of all petrochemical depot workers (controllers and laboratory workers) in Gauteng Province i.e., Krugersdorp, Langlaaste in Johannesburg, Alrode in Alberton, and Heidelberg

3.2.2 Study sample

The study sample was all the depot controllers and laboratory workers (laboratory assistant and chemist) based at Heidelberg depot.

3.2.3 Sample size

Due to a relative study sample size of twelve (12) employees, a convenient sampling technique was used to enroll participants to the project. Prior final field survey a pilot study was conducted with two employees to test the data sampling tool (questionnaire) and the instrument. The remaining ten (10) employees excluding those who participated during the pilot survey were used for the final survey.

3.2.4 *Data collection process*

Data collection commenced only after approval by the University of the Witwatersrand Human Research Ethics Committee. Data was collected using a questionnaire, constructed using close -ended questions, to describe employee's activity patterns. This was used to characterize the exposure scenarios per activities in each work area. It considered time spent per work activity, also accounted annual leave days, statutory training, duration of the shift and number of days given to workers as off per week, time for tea and lunch breaks. The checklist was used to collect data for climatic conditions (weather patterns, season of the year, wind speed and humidity level), plant condition, utilization of PPE and compliance, standard operating procedure, awareness training exposure to hazardous chemical agents, precautionary to taken against exposure including wearing of personal protective equipment (PPE), storage of PPE, laundry facility for contaminated PPE and accessibility to ablution facility on the days of the study.

3.2.5 *Data collection using questionnaire, checklist and PID equipment for pilot study*

A pilot study conducted at petrochemical depot, the purpose of the study was to pre-test the questionnaire (the questionnaire was developed by the researcher for sole purpose of the study informed by the purpose of the study), checklist and the PID equipment with the aim of testing and validating, identifying potential gaps, deficiencies on them prior undertaking the actual study. A walkthrough survey was conducted at the petrochemical depot and the purpose of the walkthrough was to understand the process flow, work patterns, exposure scenarios and number of workers per exposure scenarios. Thereafter, three exposure scenarios and two homogenous exposure groups (controllers and laboratory workers) were identified. One worker per exposure scenario i.e., a controller and chemist and one exposure scenario were selected to partake on the pilot study after a consent was obtained. The two workers were excluded on the main study.

The questionnaires were administered to two depot workers (a controller and a chemist) to obtain demographic information, work shift patterns, duration of shift, number of days off, the activity patterns, petrochemicals (petrol and diesel) used when performing activity. The safety data sheets for the petrol and diesel to check chemical composition of the fuels. The PID was tested in the density hut when the controller was collecting samples and when the chemist was busy calibration and verifications of analyzed samples by the controller. The researcher completed a checklist form. Both the questionnaires and checklist forms had no names and identity numbers of the participants. The outcome assisted the researcher to

understand whether the questionnaire was easily understood by participants. The two depot workers were excluded in the main study.

3.3. The description of BTEX monitoring instrument set-up

BTEX concentrations were monitored using MiniRAE 3000 a direct reading instrument, photoionization detector (PID) with a 9.8 eV, 10.6 eV or 11.7 eV gas-discharge lamp and Keison Products, UK. The instrument consists of a PID with associated microcomputer and electronic circuit. This unit is housed in a rugged case with a backlit LCD and 3 keys to provide easy user interface. The instrument includes an integrated sampling pump. The diaphragm type provides a 450 to 550 cubic centimeter (cc) per minute flow rate. Connecting a Teflon or metal tubing with 1/8 inside diameter to the gas inlet port of the instrument, this pump can pull in air samples from 30 m away horizontally or vertically (87).

The pump was turned on when a sampling manually started and turns off when the monitoring was complete. If liquid other objects were pulled into the inlet port filter, the instrument detected the obstruction and immediately shut down the pump. The alarm was activated, and a flashing pump icon was displayed. The user acknowledged the obstruction by clearing it. External filter was made of PTFE (Teflon) membrane with a 0.45-micron pore size to prevent dust or other particles from being sucked into the sensor manifold, which could cause extensive damage to the instrument. The instrument has three data log types:

Auto – default mode. Collects data log information when the instrument is sampling.

Manual – data logging occurs only when the instrument's data is manually started.

Snapshot – data logs only during snapshot (single-event capture, initiated by pressing the “Mode” sampling.

Only one data log type can be active at a time. For sampling the BTEX the auto data log type was used. When data logging was enabled, measured readings were being saved. The data were stored in groups or events. A new event was created and stored each time the instrument was turned on and set to automatic data logging or a configuration parameter was changed, or data logging was interrupted. The maximum time for one event was 24 hours or 28 800 points. If the event exceeded 24 hours, a new event was automatically created (87). The samples were drawn in through the inlet port filter running at flow rate of 450 to 440 cc per minute (87).

3.4. BTEX Sampling

The PID equipment was calibrated before the commencement of monitoring program following manufacture's operating manual i.e., before the monitoring, the PID was pre-calibrated through by following the 2 steps of calibration. Zero calibration using clean air assuming was free from any contaminants. Thereafter, a span calibration using the Isobutylene by connecting the cylinder to the PID probe by a telfon tube. The PID was set to log data, capture data and averaging at 5 seconds interval.

Sampling was conducted at three different activity areas (exposure scenarios) over three days period. The monitoring started from 08h00 to 17h00. One exposure scenario was sampled per day. The PID was mounted on a marked tripod stand at 1.5m above ground and approximately 0.2m to 0.5m in the microenvironment (exposure scenario) of the receptors with the probe extended or placed within 30cm of the breathing zone of the depot workers (Controllers and/or laboratory assistant). The breathing zone was used as a proxy for a potential exposure for the controller and/or laboratory assistant.

The sampling of BTEX per workstation to took 30 minutes per hour over ten hours, every hour BTEX was sampled for a duration of 30 minutes and in totality ten samples were collected per 12-hour shift, a total of 30 BTEX samples were collected over the 3 days period.

3.5. Data analysis

3.5.1 Processing of BTEX data from PID

BTEX concentrations from the MiniRAE 3000, were corrected at concentration as prescribed by the manufacturer to minimize errors and uncertainty of the obtained final concentrations. BTEX concentration data were plotted into graphs and tables and comparison will be made based on different concentrations for each sampling location. A time-weighted average concentration for each location were determined and data were merged to time spend by each group of workers for use in risk assessment. Risk assessment was estimated based on a chronic life-time dose calculated using USEPA modelled calculation.

3.5.2 Calculation of BTEX Concentration

The PID was set with a benzene lamp during field VOC's monitoring. Then after, the percentage (%) of each BTEX specie as per safety data sheet chemical composition was used

to derive the concentration. Equation 1 was used to calculate the concentration of each BTEX specie from the total VOC's concentration.

$$C_{ppm} = C_i \times P_i \quad \text{Equation 1}$$

Where C_i is the derived PID concentration and P_i is the % of each BTEX specie.

Then after the mixture correction factor for each BTEX specie as in **Error! Reference source not found.** was applied:

Table 1: BTEX concentrations incorporating correction factor provided by Technical Note TN – a guideline for PID instrument response

Correction factor (0.6) for benzene:	
Area	Calculation benzene concentration
Density huts	0.6 X 480 ppm = 288 ppm
Laboratory	0.6 X 542 ppm = 325.2 ppm
Strainer removal	0.6 X 469 ppm = 281.4 ppm
Correction factor (0.51) for Toluene	
Area	Calculation of toluene concentration
Density huts	0.51 X 1365 ppm = 696.15 ppm
Laboratory	0.51 X 1542 ppm = 786.42 ppm
Strainer removal	0.51 X 1542 ppm = 786.42 ppm
Correction factor (0.51) for Ethylbenzene	
Area	Calculation of ethylbenzene concentration
Density huts	0.51 X 443 ppm = 225.93 ppm
Laboratory	0.51 X 500 ppm = 255 ppm
Strainer removal	0.51 X 433 ppm = 220.83 ppm
Correction factor (0.43) for Xylene	
Area	Calculation of xylene concentration
Density huts	0.43 X 1402 ppm = 602.86 ppm
Laboratory	0.43 X 1584 ppm = 681.12 ppm
Strainer removal	0.43 X 1372 ppm = 589.96 ppm

Since for risk assessment estimation the concentration of BTEX must be in mg/m^3 . Equation 2 and **Error! Reference source not found.** was used to convert from ppm to mg/m^3 .

$$\text{Conc. (mg}/\text{m}^3) = \frac{[\text{Conc. (ppmv)} \times \text{mol. wt. (g/mole)}]}{\text{molar gas volume (L)}} \quad \text{Equation 2}$$

Where conc is the derived BTEX concentration in ppm, mol is the molecular weight of BTEX specie and molar gas is the standard Avogadro constant of 24.5.

Table 2: Converting ppm into mg/m^3

Converting concentration in ppm into mg/m^3 per substance in activity:	
Benzene calculation for CDI at three activity areas	
Area	

Density huts	921.95 mg/m ³
Laboratory	1041.04 mg/m ³
Strainer removal	900.83 mg/m ³
Toluene calculation for CDI at three activity areas	
Density huts	2628.82 mg/m ³
Laboratory	2969.70 mg/m ³
Strainer removal	2571.05 mg/m ³
Ethylbenzene calculation for CDI at three activity areas	
Density huts	983.05 mg/m ³
Laboratory	1109.53 mg/m ³
Strainer removal	960.86 mg/m ³
Xylene calculation for CDI at three activity areas	
Density huts	2622.94 mg/m ³
Laboratory	2963.43 mg/m ³
Strainer removal	2566.81 mg/m ³

3.6. Statistical analysis

A T-test for the null hypothesis that two normal populations have the same variance was used in the data analyses. This test can be used in practice, with care, particularly when a quick check is required, and is subject to associated diagnostic checking. Large alpha levels, (at least 0.05), were used and balanced layouts because the T-test is relatively robust. The T-test can be used to determine the type of T-test to employ (i.e., T-test (i): Two samples assuming equal variances or T-test (ii): Two samples assuming unequal variances). A P-Value >0.05 indicates that the variances are the same; a P-Value <0.05 indicates that the variances are unequal.

A two-tailed student T-test (at 95% confidence level) was used for statistical evaluation of the potential BTEX inhalation data. Note: for the purposes of this study, a significant number meant that the P-Value was less than 5% ($p < 0.05$); a number that was not significant meant that the P-Value was greater than 5% ($p > 0.05$).

3.7. Determination of exposure assessment

For exposure assessment the estimated internal dose was expressed as chronic daily intake (mg/kg/day) (30). The breathing zone near-field concentration was used as proxy for risk assessment and was assumed to be equal to the internal dose. Chronic daily dose was calculated for both female and male controllers, male and female laboratory assistant and US EPA default values was used in the absence of local statistics on population characteristics as in **Error! Reference source not found.** (30).

Table 3: Summary of exposure scenario factors and values was used during data analysis

Parameter	Description	Value	Unit
C	Area concentration	-	mg/m ³
IR	Inhalation rate	20	m ³ /day
BW	Body weight	70 males/ 60 kg females	Kg
ED	Exposure days	208/220 (12 hours per day)	Days/ year
YE	Years of exposure	25 (occupational)	Years
AT	Years in lifetime	60 male/67 female	Years

The default inhalation rate, body weight, and occupational exposure from U.S. Environmental Protection Agency (USEPA), while the male and female years in life were adopted from (88).

Since, this was done in real-world situation using near-field breathing zone concentration simulating the occupational exposure, where information on population demographics was not present, the study adopted some of the parameters for the exposure scenario from the USEPA's risk assessment guidelines and South African Statistics, as in **Error! Reference source not found.** The chronic daily intake was calculated using equation 3 (30).

$$CDI(\text{ averaged daily intake}) = \frac{C \times CF \times IR \times ED}{BW \times AT} \quad (3)$$

The chronic daily intake (CDI) determination was used as a basis for risk assessment calculation, similar to the current risk assessment studies [66,68–70] (30), where:

CDI was the chronic (averaged) daily intake over a year (mg/kg/day);

C was the area zone concentration of BTEX in (µg/m³), derived from occupational exposure event.

CF was the concentration conversion (mg/µg = 0.001 or 1 µg) factor.

IR was the inhalation rate (default in adults, 20 m³/day);

ED was the exposure duration as in Equation 2 (208/220 days);

BW was the average body weight (70 kg, 60 kg for male and female adults, respectively).

AT was the number of days per year.

Equation 4 indicated a daily average exposure, given that the exposure involves a 8-hour duration over a 208/220-day period in a year from this source (to allow for a full season) (30).

$$ED = \frac{\text{Actual exposure duration}}{24 \text{ hours}} \times 208/220 \text{ days} \quad (4)$$

where:

ED was the exposure duration (days/year);

Actual exposure duration is the 8-hour day shift;

24 hours was the total hours in a day; and

208/220 days was the number of exposure days in a year.

In Equation 5, an average annual chronic daily intake was determined. However, for the risk assessment, a cumulative lifetime exposure concentration intake was completed. In Equation 3, the average 25 years chronic dose (CDI 25 year) was calculated by using the 30 year occupational exposure duration, as obtained from USEPA default value (30):

$$CDI(25 \text{ years dose}) = \sum \frac{CDI \times 365 \times YE}{60 / 67} \quad (5)$$

where:

CDI was the cumulative average 25-year dose (mg/kg/day);

CDI was the chronic daily intake (mg/kg);

YE was estimated lifetime occupational exposure duration, which was equivalent to 25 years.

365 was the total number of days in a year.

60 was the male life expectancy, and 67 was the female life expectancy in South Africa.

Therefore, for a risk assessment calculation, we needed the adjusted lifetime chronic daily intake (CDIadj.), taking in to account the life expectancy for a female and a male South African adult resident. In Equation 6, we calculated the average CDIadj., assuming a lifetime daily dose intake (30).

$$CDIadj. = \frac{CDI(25 \text{ years average dose})}{\text{life expectancy in days}} \quad (6)$$

We assumed that the average chronic daily adjusted dose over a lifetime amongst female and male adults was better simplify the risk assessment calculation, as in Equation 6.

3.7.1 Toxicity Assessment and Risk Characterization

For risk assessment the cancer risk and hazard quotient were calculated to determine the relative risk of exposure to BTEX for the defined exposure scenario. For benzene the inhalation slope factor was used while for TEX the inhalation reference concentration will be used to calculate the risk as in **Error! Reference source not found.** (30).

Table 4: Benzene slope factor, and toluene, ethylbenzene, and xylenes (TEX) inhalation reference values.

Chemical	Inhalation Reference Concentration (RfC)	Inhalation Slope Factor (SF)
	(mg/m ³)	(mg/kg/day) ⁻¹
Benzene	0.03	0.0273
Toluene	5	N/A
Ethylbenzene	1	N/A
O-xylene	0.1	N/A
P-xylene	0.1	N/A

For carcinogenic pollutants, it must be noted that there is no safe threshold; therefore, the risk characterization followed similar method described by the USEPA's Risk Assessment Guidance for Superfund; risk of cancer was calculated using Equation 7:

$$CR = CDI_{adj} \times SF \quad (7)$$

where:

SF is the slope factor for carcinogenic pollutant (0.0273);

CR is the carcinogenic risk; and

CDI_{adj.} is the cumulative lifetime adjusted dose (Equation 4) over an estimated exposure in a lifetime of 60 or 67 years for male and female adult, respectively.

Therefore, a cancer risk $>1 \times 10^{-6}$ and 1×10^{-4} meant that there were carcinogenic effects of concern, while a cancer risk $<1 \times 10^{-6}$ and $<1 \times 10^{-4}$ meant that there was a designated cancer severity indicator.

For non-carcinogenic pollutants, a hazard quotient (HQ) was used to estimate the potential health risk of the controllers. Where a HQ value was greater than one, it was regarded as a hazardous exposure; a HQ value of less than one meant that there was a low probability of developing the associated health effects. In Equation 8, the procedure for calculating HQ is shown (30).

$$HQ = CDI_{adj.} ((mg/kg)/day) / (RfC(mg/m^3) \times 20m^3 / (70 kg)) \quad (8)$$

where:

HQ is the hazard quotient.

CDI_{adj.} is the cumulative intake dose;

RfC is the reference.

20 m³ is the default value for the average adult daily air volume; and

70 kg is the average body weight for a male adult, while 60 kg will be used for female adult.

3.8. Quality control

A pilot study testing a questionnaire was carried out prior the major study. The PID was external calibrated by a South African National Accreditation System (SANAS) laboratory. The PID was calibrated before monitoring and again checked on completion of the survey to ensure that the instrument's flow rate remained constant.

Before monitoring began, two steps calibration was done in the following sequence zero calibration using clean air free from any contaminants and ran for 30 seconds. After completing the first step, the instrument moved to the second step, the span calibration involving using the Isobutylene (reference gas) by connecting the cylinder to the PID probe by a telfon tube and it ran for 30-seconds then once the calibration was completed the PID indicated the 100 ppm concentration equivalent to the concentration of the reference gas. The instrument was left to ran for 30 minutes before monitoring was done (87). The instruction of the instrument manufacturer was carefully followed during calibration, sampling, and analysis process.

Ten measurements were taken ten times at each measurement location. In strengthening data quality confidence, each area was sampled ten times and standard deviation was calculated to check for comparability.

The chapter presents the pilot study, the description of the petrochemical depot-demographic information, shift patterns and duration and existing controls, description of the three activity areas (exposure scenarios), emissions from the exposure scenarios, individual BTEX specie average concentration for the different activity areas and briefly discussion on the carcinogenic and non – carcinogenic risks.

4. RESULTS

4.1. Pilot study

A pilot study was conducted at the study site. The purpose of the pilot study was to check the feasibility and acceptability of the questionnaire, checklist, and the response of the instrument. Two depot workers (one controller and one chemist) out of the 12 depot workers (ten controllers and two laboratory workers (chemist and laboratory assistant) participated on the study. The feedback obtained from participants indicated that the questionnaire was well understood by participants. The checklist completion by the researcher was easy to follow and complete and assisted the researcher to obtain the required data. The PID equipment was calibrated and thereafter used to monitor BTEX when the controller was collecting sample in the density hut and when the chemist was conducting equipment calibration and analytical verifications of fuels in the laboratory. The PID performed in accordance with the set performance parameters by original instrument manufacturer. The outcomes of tools pre-test indicated satisfactory performance and no changes required. However, the two participants who partook on pilot study were excluded on the main study.

4.2. Petrochemical Depot – demographic information, duration of exposure and controls

Demographic data				
No:	Number of workers	Estimated age range in years	Gender of workers	Homogeneous exposure group

1.	2	25 - 35	Male	Controllers
2.	8	25 - 35	female	Controllers
3.	1	30 - 39	Male	Laboratory worker (Chemist)
Age	1	30 - 39	Male	Laboratory worker (Laboratory assistant)
Duration, operation, and PPE				
Duration of shift	Controllers worked 12 hours shift, day, and night shift and two controllers per shift for seven days and seven days off, on average they worked 14 days and 14 days off per month			
	Laboratory workers worked 8 hours day shift for 5 days and overage they work 20 days and 8 days off per month			
Cycle of operation	A 24-hour and 365 days operation to process petrochemical products and thereafter, distributed to various inland satellite depots 24 hours and 365 days per year			
PPE	Each depot worker is provided with flame retardant overalls, safety shoes, safety glasses, nitrile gloves and ABEK respirator			

All of them started their working career at the depot. All controllers worked a shift system and two laboratory workers only worked dayshift and five days per week. All the depot workers were invited and selected to participate in the study with exception of the two participants who participated during the pilot study. An effort was made to involve all study participants. However, only six controllers and a laboratory assistant participated in the study due to outbreak of corona virus (Covid-19 virus) and the subsequently, introduction of Disaster Management Act and lockdown regulations.

The four controllers and one of laboratory chemist were working from home as part of the depot effort to comply with the lockdown regulations and control Covid-19 virus transmission. Two out five workers working from home were the two workers who partook on the pilot study. The four controllers and laboratory chemist working from home were on standby and required to be available as and when required for instance in case of an emergency or if the shift bound controller(s) were not available.

The 24 hours depot operation was managed by four controllers. Two worked twelve hours day shift and other two worked twelve-night shift. Whilst the other two controllers were off duty. Both shifts worked uninterrupted seven days and thereafter, they had seven days off, on average they worked fourteen days and fourteen days off in a month. The controllers were not allocated an official tea and lunch breaks, they ate and drank tea in between tasks in a designated eating area in control room. On a yearly basis they were required to undergo statutory training for a period of three days and such training was held off site (away from the depot) and each controller gets 28 days leave days per year.

The two controllers alternated their tasks everyday i.e., on the first day one controller was assigned to work outside in the plant and the second controller was working in the control room, on the second day, the roles were reversed i.e., the controller who worked in the control room on the first day, worked in the plant and the controller who worked in plant on the first day, worked in control room. The inside controller managed the entire operation via a display unit (which is configured to control and automate the operation of all the plant equipment) in the control room. The controller assigned to work in the control room was not exposed to the plant environment at all for the entire shift (she spent the entire twelve-hour shift in the control room) unless there was a triggered plant equipment maintenance i.e., cleaning plant equipment.

Whilst the outside controller who was assigned to work in the plant was exposed to plant conditions. On average she spent six hour of her shift collecting diesel and petrol samples from the plant and other six hours was spent conducting diesel and petrol analysis in the laboratory. On average each controller spent seven days working in the plant and the other seven days in control room in a month.

The laboratory assistant spent entire shift in working in the laboratory i.e., seven hours on average carrying out her tasks in laboratory, 30 minutes on administrative tasks in office and 30 minutes on an official lunch break per day. She worked five days a week and two days

off. On average she worked 20 days and eight days off in a month, she was required to undergo mandatory statutory training for three days per year and she was given 28 leave days per year.

The controllers and laboratory assistance were trained on standard operating procedure on how to carry out their tasks and a refresher course was available on request or as and when required. They were given awareness training on the potential health effects associated with their exposure to petrochemical products and precautionary measures to be taken when handling or process the petrochemical products. They were provided with hardhat, flame retardant overalls, safety glasses, nitrile gloves and ABEK respirator and safety shoes. They were also provided with personal protective equipment (PPE) lockers to store clean PPE. However, dirty PPE was taken home for washing and cleaning. They were provided with containers to dispose of contaminated PPE. Shower, ablution facilities were also provided.

Data from questionnaire was first checked for its completeness. Incomplete questionnaires or incorrectly completed answers were rejected for the next analysis process. Data collected using both questionnaires and checklist forms after being completed by the researcher and confirmed by the participants were immediately scanned and sent to researcher's personal computer via photocopier machine with build-in capability to send emails. The personal computer was equipped with a password sensitive security and data encryption mechanism which was capable to encrypt data in case the personal computer was lost/stolen or tampered with. Once questionnaires and checklist forms were scanned through, they were kept in lockable cupboard for a week and thereafter, they were destroyed via shredding machine.

Description of exposure scenarios

4.3. BTEX exposure scenario at the density huts

The density hut was made of IBR roof sheeting and side panels also made of IBR sheeting and with a permanent kept open door and openable windows on each side of the wall directly opposite to each workbench and at time of the samplings they (windows) were closed. Inside the density hut had two workbenches on each side of the side panel (one on left hand side and other on right hand side as you enter the door) and the workbenches were approximately at abdomen height equipped with sampling points for both diesel and petrol 93 and 95 octane, a measuring jar for measuring density and decanting area for rinsing sample bottles and decanting superfluous samples. The only source of fresh air was the door permanently kept open. It did not only allow the ingress of fresh air but also allowed vapours to passively

escape (passive vapours dilution). The decanting area was connected by means of an enclosed piping line to a sump. Decanted samples were drained into the sump.

Every hour, the controller collected samples (Diesel, petrol 93 and 95 octane) as informed production schedule. The type of samples collected were dependent on petrochemical product being pumped into the depot. The controller collected 12 sets of samples per shift i.e., one set per hour. On average the sample collection took about 30 minutes.

The process of collecting a sample involved rinsing a sample bottle (collector) with the product to be collected i.e., a diesel or petrol from the sample point. The sample collector was rinsed three times and each time of rinsing the used diesel or petrol was decanted into a decanting point. Thereafter, the required sample was collected. When measuring a density of the collected fuels, the process begun by decanting the previous collected sample in the measuring jar into the decanting point. Thereafter, the measuring jar was rinsed thrice with the product of fuels to be done density measurement. Each time of rinsing the measuring jar, the used sample was decanted into the decanting point.

Once properly rinsed, the measuring jar was refilled with the required diesel/petrol to the required level. Thereafter, the density meter (probe) was submerged into the measuring jar with fuels. After conducting a density measurement, the measuring jar was left unclosed with density probe still immersed with the fuels. Fuels vapours were released during sample bottle rinsing, decanting, and refilling, and when rinsing, decanting, and refilling of the density measuring jar, and unclosed measuring jar continued liberating vapours.

The controller wore safety shoes, flame retardant overalls and nitrile gloves. Ten BTEX PID samples to quantify BTEX concentrations in the density hut were carried on the first day whilst the controller was collecting fuel samples (petrol and/or diesel). About 50 percent of shift was spent by the controller collecting fuel samples.

4.4. BTEX exposure scenario at the Laboratory

The laboratory is partitioned into several rooms (laboratory is divided into main laboratory, an office, shower, toilet, and kitchen). It had two main doors which were kept closed at time of study. The entire laboratory was under positive pressure and petrochemical vapours were unable to ingress the building. The main laboratory was further divided into main laboratory and storage area (holding room) which was used a storage room for empty and full retained samples.

The main laboratory was directly communicating with the sample holding room. The laboratory was equipped with three extraction systems namely fume hood, two small extraction units on the walls. The main laboratory was equipped several gas chromatographs (GC) equipment and other laboratory equipment capable to conduct required petrochemical fuels analysis. A decanting drum was kept open and placed at one end of the equipment station for decanting superfluous/leftover samples or rinsing testing tubes. The collected samples were kept in fume hood with a sash opened 50%. The fume hood was fully operational at time of the study. The main laboratory had additional two wall mounted extraction systems, one adjacent to the fume hood and the other one opposite the decanting drum. They were also fully operational.

Once the petrol and/or diesel samples were collected, they were transported to the laboratory using a golf club car (GCC). The samples were placed in a dedicated GCC's slot for holding samples during transportation to the laboratory. On arrival at main laboratory, the samples were placed in the fume hood.

The process of analyzing the sample in the GC or laboratory equipment involved rinsing a testing tube with the product to be analyzed three times i.e., a diesel or petrol and thereafter, decanting the leftovers from the rinsing process into the decanting drum. Thereafter, the required volume of sample to be used for analysis was poured into the testing tube and then introduced into the GC or equipment, and then analysis was initiated.

Ten BTEX PID samples to quantify BTEX concentrations in the main laboratory were conducted on the second day whilst the controller and/or laboratory assistant were analysing/verifying fuel samples (petrol and/or diesel). The controller tasked to analyse fuel samples spent about 50% of her shift conducting analysis. Fuels vapours were released during opening of sample bottle and rinsing, decanting, and refilling of the testing tubes/beaker. Petrochemical vapours were continuously liberated from the drum that was kept opened.

About seven hours were spent by laboratory assistant conducting instruments calibration and verifying analysis done by controller. The controller analyzed 12 sets of samples per shift i.e., one set of samples per hour. On average the analysis of samples took about 30 minutes. The controllers had no official tea or lunch break or tea, a tea or lunch were taken in between tasks. The laboratory assistant had an official 30-minute lunch time. The Controller and laboratory assistant wore safety shoes, flame retardant overalls and nitrile gloves.

4.5. BTEX exposure scenario during the removal of strainer (cleaning of plant equipment (the strainer))

The plant equipment was made of number of pipelines and some of pipelines were housing filters (strainers). The pipelines were exposed to an ambient air. As the fuels passes through the pipelines the strainers became clogged up. Once the strainers are blocked a maintenance is triggered to clean the strainers. When the cleaning of plant equipment – clogged up strainers were required, they were carried out by both controllers (inside controller working in control room and the outside controller). Product still trapped in the isolated plant equipment was drained into sump. The pipelines were equipped with control valves and filters (strainers).

The two controllers assisted each other to isolate the line with the equipment that required cleaning. Thereafter, the filter holder (strainer holder) was unbolted, and the strainer was removed from the holder. Then the strainer was taken to the floor of the plant where it was flushed with utility water until all the clogging products were properly removed. The cleaned strainer was then taken back into the holder, bolts were fastened and thereafter, the line was commissioned. The cleaning of plant equipment task took 30 minutes on average to complete and 50 percent of shift. Ten BTEX PID samples to quantify BTEX concentrations during plant equipment cleaning (removal and cleaning of strainer) were carried on the third day whilst the controllers were busy cleaning plant equipment.

PID was mounted on a marked tripod stand with the probe facing the activity at a distance 0.5m from the activity. Measurements were taken at 1.5m during removal of strainer from its holder and at 0.9m when cleaning the strainer on the floor. The positioning of the PID and its probe was used a proxy for the breathing zone for the controllers and used the measured concentration as a proxy for potential inhaled BTEX dose. BTEX emissions were released when strainer was removed, when taking strainer to the floor and flushing the strainer with utility water. The two controllers wore safety shoes, flame retardant overalls and nitrile gloves.

4.6. BTEX emissions at different activity areas

In **Error! Reference source not found.** the average BTEX concentrations and standard deviation per activity area are presented. The average concentration of the BTEX ranged from 3609.2 to 4167.4. The highest average BTEX concentration was measured at laboratory, followed by density huts and the least was measured during cleaning of plant equipment. Whilst the

standard deviation ranged from 98.5 to 486.5, the least was during plant equipment cleaning and highest was at the laboratory.

Results presented in Table 6 are individual BTEX specie pairwise comparison per activity area. Six possible individual BTEX specie pairings were established per activity area. Four out of six individual BTEX specie pairings were found to be statistically significant per activity area.

Table 5: The average of BTEX at the three activity areas (density hut, laboratory, and strainer removal)

BTEX concentrations		
Activity area	Concentration	Standard deviation
	ppm (N=10)	
Density hut	3689.3	385.7
Laboratory	4167.4	486.5
Strainer removal	3609.2	98.5

Table 6: Pairwise comparison per individual activity area

Activity area	Chemical	Concentration (ppm) N=10	Statistically significant difference		
			F-test	P-value	Sig @95
Density hut	Benzene	479.6 ± 50.1	0.219	0.001	Yes
	Toluene	1365.0 ± 142.7			
	Benzene	479.6 ± 50.1	0.920	0.244	No
	Ethylbenzene	442.7 ± 46.3			
	Benzene	479.6 ± 50.1	0.210	0.001	Yes
	Xylene	1401.9 ± 146.6			
	Toluene	1365.0 ± 142.7	0.19	0.001	Yes
	Ethylbenzene	442.7 ± 46.3			
	Toluene	1365.0 ± 142.7	0.973	0.405	No
	Xylene	1401.9 ± 146.6			
	Ethylbenzene	442.7 ± 46.3	0.181	0.001	Yes
	Xylene	1401.9 ± 146.6			
Laboratory	Benzene	542 ± 63.2	0.220	0.001	Yes
	Toluene	1542 ± 180			

	Benzene	542 ±63.2	0.920	0.266	No
	Ethylbenzene	500 ±58.4			
	Benzene	542 ±63.2	0.211	0.001	yes
	Xylene	1584 ±184.9			
	Toluene	1542 ±180	0.19	0.001	Yes
	Ethylbenzene	500 ±58.4			
	Toluene	1542 ±180	0.973	0.406	No
	Xylene	1584 ±184.9			
	Ethylbenzene	500 ±58.4	0.181	0.001	Yes
	Xylene	1584 ±184.9			
Strainer removal	Benzene	469 ±12.8	0.220	0.001	Yes
	Toluene	1335 ±36.5			
	Benzene	469 ±12.8	0.920	0.022	No
	Ethylbenzene	433 ±11.8			
	Benzene	469 ±12.8	0.210	0.001	Yes
	Xylene	1372 ±37.4			
	Toluene	1335 ±36.5	0.19	0.0001	Yes
	Ethylbenzene	433 ±11.8			
	Toluene	1335 ±36.5	0.973	0.192	No
	Xylene	1372 ±37.4			
	Ethylbenzene	433 ±11.8	0.181	0.0001	Yes
	Xylene	1372 ±37.4			

A pairwise comparison on the BTEX emissions was made in three activity areas. For all possible three pairings, there was no statistically significant differences on the BTEX concentration as shown in **Table 7**.

Table 7: Pairwise comparison for three activity areas

Chemical	Activity area	Concentration (ppm) N=10	Statistically significant difference		
			F-test	P-value	Sig @95
BTEX	Density hut	1230 ±100.4			
	Laboratory	1389 ±159.5	0.568	0.149	No
	Density hut	1230 ±100.4			
	Strainer removal	1203 ±70	0.654	0.387	No
	Laboratory	1389 ±159.5			
	Strain removal	1203 ±70	0.323	0.103	No

In **Table 8** presents the percentage contribution of individual BTEX specie per activity area. The xylene was the highest contributor, followed by toluene. The benzene and ethylbenzene were the least contributors respectively. The percentage contribution of individual BTEX specie per activity area remains constant and the same throughout the three activity areas.

Table 8: Total individual component of BTEX per activity area

Pollutant	Activity area	Conc. [ppm] N=10	Contr. %
Density hut	Benzene	479.6 ± 50.1	13
	Toluene	1365.0 ± 142.7	37
	Xylene	1401.9 ± 146.6	38
	Ethyl benzene	442.7 ± 46.3	12
Laboratory	Benzene	542 ± 63.2	13
	Toluene	1542 ± 180	37
	Xylene	1584 ± 184.9	38
	Ethyl benzene	500 ± 58.4	12
Strainer removal	Benzene	469 ± 12.8	13
	Toluene	1335 ± 36.5	37
	Xylene	1372 ± 37.4	38
	Ethylbenzene	433 ± 11.8	12

4.7. Individual BTEX specie average concentration for the different activity area

A bar chart graph was used to visualize individual benzene emissions for the density hut, laboratory and strain remover as shown in **Figure 4**. The highest benzene emissions were at laboratory, followed by density huts and least at the strainer removal.

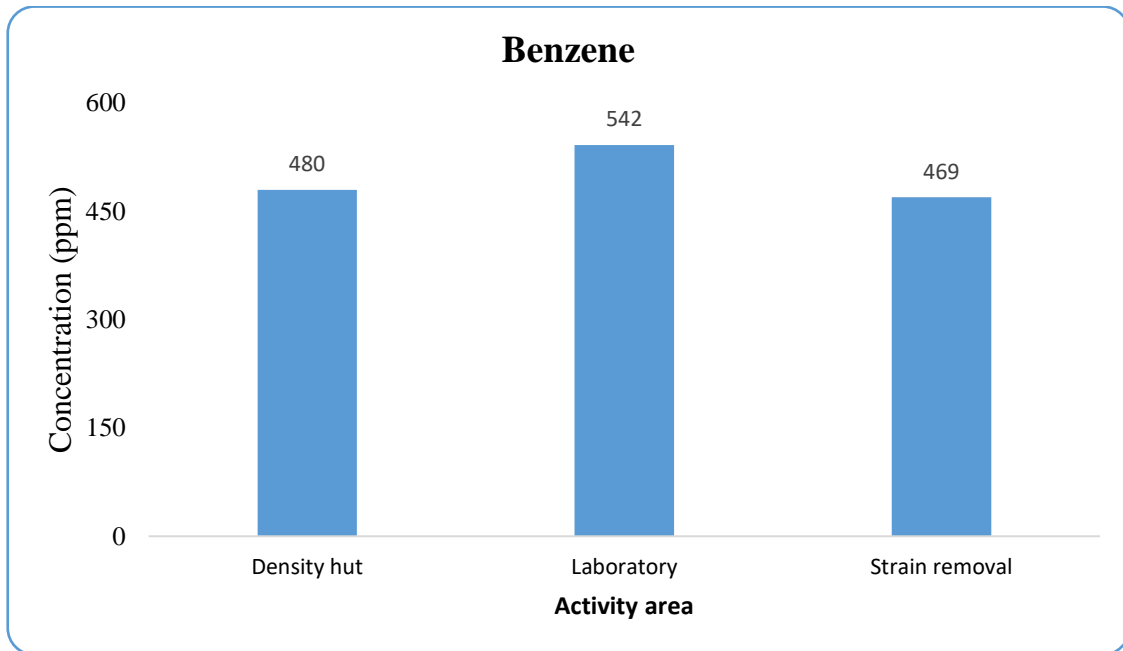


Figure 4: Concentration of benzene per activity area

In **Figure 5** a bar chart graph visualizes toluene concentration for the three activity areas and the highest toluene concentration was at laboratory, followed by density huts and the least was at the strainer removal.

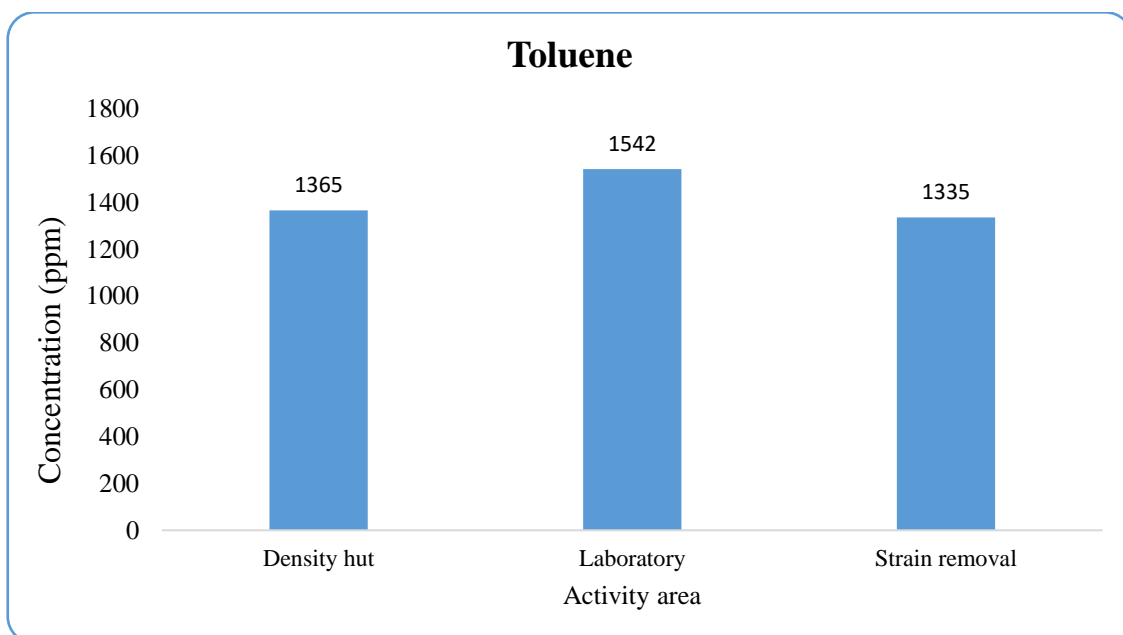


Figure 5: Concentration of Toluene per activity area.

A bar chart graph in **Figure 6**, visualizes ethylbenzene concentration for the three activity areas and the highest toluene concentration was at laboratory, followed by density huts and the least was at the strain removal.

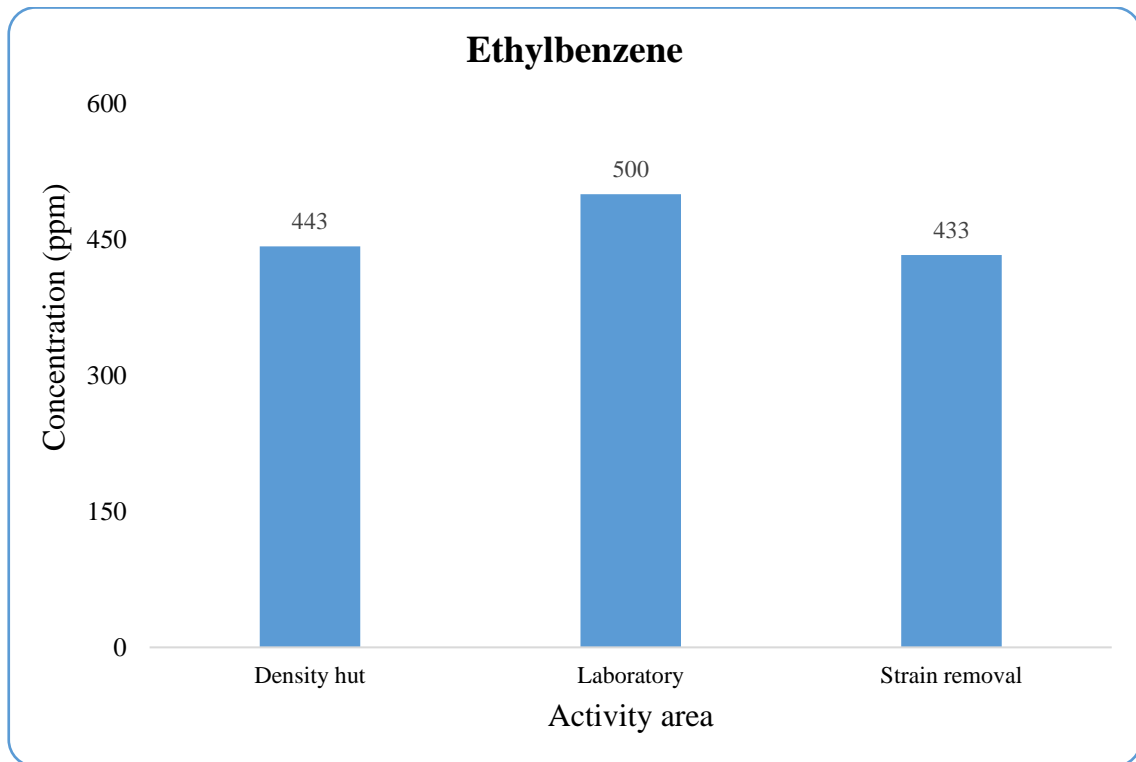


Figure 6: Concentrations of Ethylbenzene per activity area..

A bar chart graph was used to visualize individual xylene emissions for the density hut, laboratory and strain remover as shown in **Figure 7**. The highest xylene emissions were at laboratory, followed by density huts and least at the strainer removal.

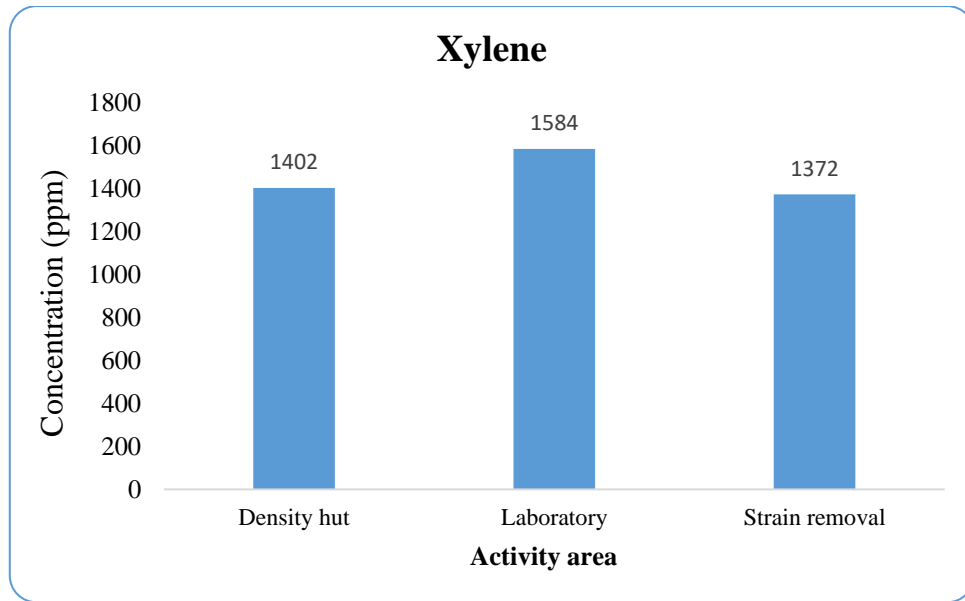


Figure 7: Concentrations of xylene per activity area.

In **Figure 8** represents BTEX bar chart graph in the density huts reflecting individual BTEX specie emissions. Xylene concentration was the highest, followed toluene and the least two species were benzene and ethylbenzene respectively.

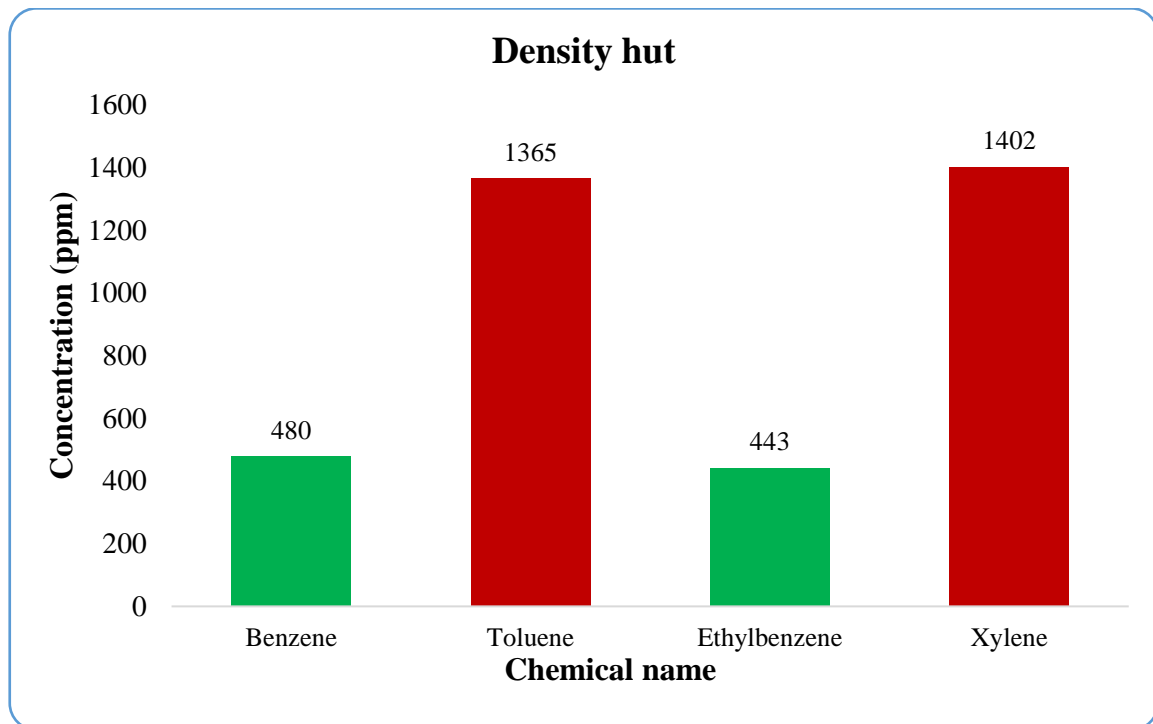


Figure 8: Concentrations of individual components for BTEX at the Density hut.

A bar chart graph was used to visualize individual BTEX specie emissions for the laboratory as shown in **Figure 9**. The highest was xylene emissions, followed by toluene and the least emissions were benzene and ethylbenzene respectively.

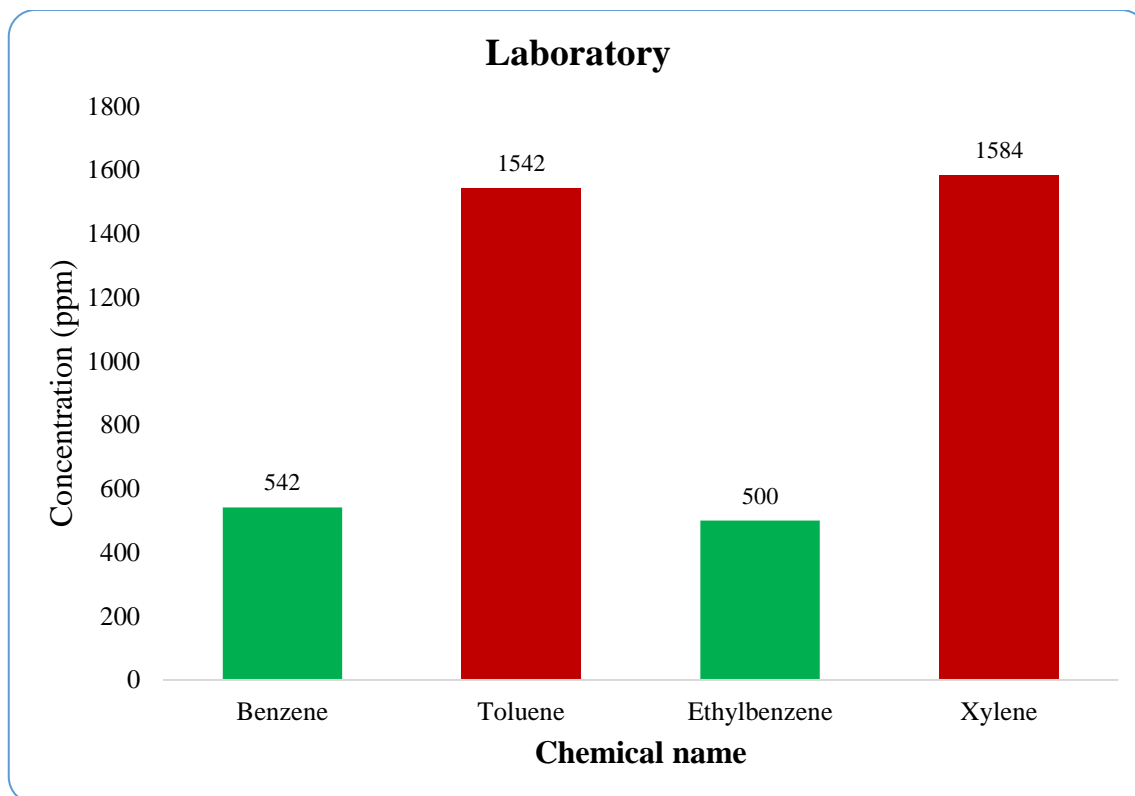


Figure 9: Concentrations of individual components for BTEX at the Laboratory.

In **Figure 5** a bar chart graph visualizes individual BTEX specie during cleaning of plant equipment (strainer removal). The highest individual BTEX specie was xylene and followed by toluene, the benzene and ethylbenzene species had the least emissions respectively.

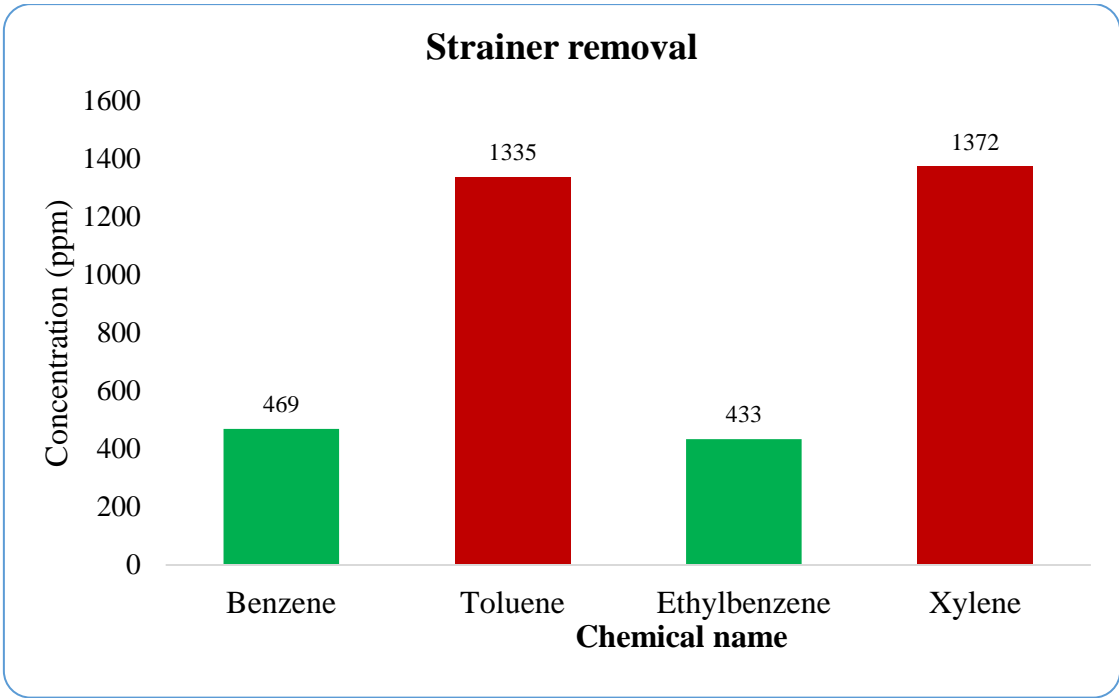


Figure 10: Concentrations of individual components for BTEX at Strainer removal.

Results in **Table 9** are presenting the BTEX concentrations for the all the activity areas. The chronic daily intake, exposure duration, the chronic daily period for over 25 years period, the chronic daily intake adjusted, cancer risk and hazard quotient were calculated. The cancer risk scores for benzene, and hazard quotient for toluene, ethylbenzene, and xylene (TEX) were found to be far above their reference values respectively. This denotes a high probability of developing carcinogenic and non-carcinogenic health effects for the exposed depot workers.

Table 9: Carcinogenic and non – carcinogenic risks for male and female controllers, and laboratory workers (chemist and laboratory assistant)

Area	Pollutant	CDI year mg/Kg/day	ED	CDI _{25 year} mg/Kg/day	CDI _{adj.} mg/Kg/day	CR	HQ
Density huts	Benzene	0.913	0.66	100.38male 89.89female	45.8 x 10 ⁻¹ male 36.8 x 10 ⁻¹ female	13 x 10 ⁻² 10 x 10 ⁻²	N/A
Laboratory	Benzene	1.03 and/or 1.09	0.74 and/or 0.83	112.54male 100.78female	51.4 x 10 ⁻¹ male 41.2 x 10 ⁻¹ female	14 x 10 ⁻² 11 x 10 ⁻²	N/A
				126.23male 113.04female	57.6 x 10 ⁻¹ male 46.2 x 10 ⁻¹ female	16 x 10 ⁻² 13 x 10 ⁻²	N/A
Strainer removal	Benzene	0.89	0.64	97.33male 87.16female	4.44 x 10 ⁻¹ male 3.56 x 10 ⁻¹ female	12 x 10 ⁻³ 10 x 10 ⁻³	N/A
Density huts	Toluene	2.60	1.88	285.92male 256.05female	1.31 x 10 ^{male} 1.05 x 10 ^{female}	N/A	9.17 6.3
Laboratory	Toluene	2.94 and/or 3.11	2.12 and/or 2.38	322.42male 288.73female	1.47x 10 ^{male} 1.18 x 10 ^{female}	N/A	10.29 7.08
				361.20male 324.14female	1.65 x 10 ^{male} 1.33 x 10 ^{female}	N/A	11.55 7.98
Strainer removal	Toluene	2.55	1.84	279.83male 250.60female	1.28 x 10 ^{male} 1.03 x 10 ^{female}	N/A	8.96 6.18
Density huts	Ethylenebenzene	0.97	0.51	76.04male 68.10female	34.7 x 10 ⁻¹ male 27.9 x 10 ⁻¹ female	N/A	12.15 8.37
Laboratory	Ethylenebenzene	1.10 and/or 1.16	0.79 and/or 0.89	120.15male 107.59female	54.9 x 10 ⁻¹ male 44.0x 10 ⁻¹ female	N/A	19.22 13.2
				135.35male 121.21female	61.8 x 10 ⁻¹ male 49.3 x 10 ⁻¹ female	N/A	21.63 14.88
Strainer removal	Ethylenebenzene	0.95	1	104.94male 93.97female	61.8 x 10 ⁻¹ male 49.6 x 10 ⁻¹ female	N/A	21.63 14.88

Density huts	Xylene	2.60	1.88	285.92 male 256.05 female	1.31 x 10 ⁻¹ male 1.05 x 10 ⁻¹ female	N/A	4.59 3.15
Laboratory	Xylene	2.94 and/or 3.11	2.12 /or 2.38	322.42 male 288.73 female	14.7 x 10 ⁻¹⁰ male 1.18 x 10 ⁻¹⁰ female	N/A	51.45 3.54
				361.20 male 324.14 female	1.65 x 10 ⁻¹⁰ male 1.33 x 10 ⁻¹⁰ female	N/A	577.5 399.00
Strainer removal	Xylene	2.54	1.83	278.31 male 249.24 female	1.27 x 10 ⁻¹ male 1.02 x 10 ⁻¹ female	N/A	444.5 306.00

This chapter discusses the study results for three activity areas then compared against one another. The descriptive and inferential statistical results and physical layouts for the three activity areas and their potential contributions to the measured BTEX concentrations. The chapter ends with the discussion of the strengths and limitations of the study, recommendations, conclusion and are discussed both activity areas and compounds of BTEX and the significance of the study.

5. DISCUSSION AND CONCLUSION

5.1. Synopsis of study findings

This study provides data about measured BTEX concentrations in three activity areas at petrochemical depot in Heidelberg. The study aimed to characterize the three exposure scenarios in the activity areas. The study found that the BTEX concentrations in all three activity areas exceeded the 8-hour time-weighted average which confirmed the null hypothesis of the study.

5.1.1 BTEX concentrations in three activity areas

Figure 5 – 11 present summaries of BTEX concentrations measured in three activity areas at petrochemical depot in Heidelberg. Highest BTEX concentrations were measured at laboratory, followed by density huts and the least was measured during the removal of the strainer (plant equipment cleaning). The BTEX concentrations were found to be high in the activity areas. The activity areas (exposure scenarios) served as direct sources for the BTEX vapours. The activity areas were in the microenvironment and in the breathing zone of the worker (receptor).

The average benzene concentrations measured in three activity areas ranged from 469ppm to 542ppm, and the highest benzene concentration was measured at laboratory, followed by density huts and the least was measured during plant equipment clean (strainer). The highest benzene concentration was found to be 542 times higher than the current South African Occupational Exposure Limits of 1ppm.

Whilst average toluene concentrations measured ranged from 1335pm to 1542pm; the highest toluene concentration was measured at the laboratory and was found to be more than 30 times above the South African Occupational Exposure Limits of 50ppm, this was followed by density huts and the least measured was during plant equipment cleaning.

Whilst average ethylbenzene concentrations measured ranged from 433ppm to 500ppm; the highest was measured at laboratory, this was followed the density huts and least was measured during plant equipment cleaning and was found to be 5 times more than the South African Occupational Exposure Limits of 100ppm.

Whilst average xylene concentrations measured ranged from 1372ppm to 1584ppm, the highest was measured at laboratory. This was followed by density huts and the least was measured during plant equipment cleaning and found to be more than 15 times above the South African Occupational Exposure Limits of 100ppm. All the measured BTEX compounds were found to be above their respective South African Occupational Exposure Limits. The high concentrations of BTEX measured in three activity areas were expected, given by virtue that BTEX has a high vapour pressure and this property makes BTEX easily airborne and this is also inline with individual BTEX composition in the fuels.

The laboratory had highest BTEX concentrations compared to the other two activity areas. The measured BTEX concentration findings in this study are inline and support and complement other studies (63, 89-91) who found that the BTEX concentrations were significantly higher in workers in the petrochemical depot working environment. Further supported by petrochemical depot workers study found an elevated phenol level in their urine due to the exposure to petrol vapours during the filling activities as compared to the controlled group that was not exposed (92). Similarly, another study found that service station attendants, street vendors and office workers were exposed to BTEX, the service station attendants were exposed to high levels of benzene and whilst the street vendors and office workers were exposed to high levels of toluene as compared to the levels that service attendants were exposed to (93). Another study found that workers in gasoline station exposed to an ambient air were exposed to benzene and toluene concentrations that were five times higher than in enclosed parking garages (91). In another study in a working environment settings Toluene, ethylbenzene and xylene (TEX) were found to be in compliance with the European Occupational Exposure Standard, yet benzene concentration was found to be in excess of the Occupational Exposure Limits (94). Contrary, to other studies in the petrochemical sector that found workers were exposed to low BTEX concentrations but still developed chronic conditions such as cancers (15, 95, 96).

The lower BTEX emissions measured during the cleaning of strainer was attributed to plant equipment being exposed to ambient air which assisted with the BTEX emissions dilution. Although, the BTEX concentrations were lower compared to the other two activity areas i.e.,

laboratory and density huts, but they were still well above the South African Occupational Exposure limits for each individual compound for the BTEX. Whilst the higher BTEX concentrations measured in two activity areas can be attributed to the main activities that were carried out by controller and/or laboratory assistant at time of the study. In addition, the following may have also contributed to high BTEX levels measured at laboratory and density huts:

5.1.2 Laboratory

It was completely closed and did not allow ingress of fresh air or the escape of the generated BTEX emissions from petrochemical samples and analytic activities. In addition, activities such as rinsing and decanting of superfluous analyte into the decanting drum also contributed to BTEX emissions as well as the drum that was kept open.

The vapours were extracted by the fume hood and two wall mounted extraction systems. However, the two wall mounted extraction systems were not properly positioned to extract BTEX emissions being liberated by activities and opened drum. Hence, they were not effective in extracting all BTEX emissions in the laboratory. The lack of natural ventilation and the ineffective mechanical ventilation in the laboratory contributed to the high BTEX concentrations measured in the laboratory. This is further supported by a similar study also found that diesel station workers were exposed to high BTEX emissions due to the lack of both mechanical and natural ventilation in the depot (89).

5.1.3 Density huts

It was partially opened due to the door which was kept open, and this allowed vapours to escape and fresh air to ingress which passively diluted the BTEX concentrations during sample collections. Although the door was kept open the natural ventilation was not good enough to remove all the BTEX emissions in the density huts. If both side windows were opened, they could have assisted in allowing the BTEX emissions to escape. The current opening is one direction and if the wind direction is towards the opened door high accumulation of BTEX emissions in the density huts are expected. Additionally, the following activities contributed to high BTEX emissions i.e., rinsing and decanting superfluous samples into the decanting area, and the density measuring jars/jugs that were kept open.

5.2. Statistical analysis of BTEX concentrations in the three activity areas (Density huts, laboratory, and strainer removal)

A summary of the statistical results for BTEX concentrations in three activity areas at Heidelberg are presented in Table 5, 6, 7 & 8 **Error! Reference source not found.** The

average of BTEX concentration for density huts (N = 10) was 3689.3ppm and standard deviation was 385.7. The average of BTEX concentration for laboratory (N = 10) was 4167.4ppm and standard deviation was 486.5. The average of BTEX concentrations for density huts (N = 10) was 3609.2ppm and standard deviation was 98.5. Pairwise was done per activity area. In all three activity areas, six pairings were possible to establish per activity area and the six pairings are benzene and toluene, benzene and ethylbenzene, benzene and xylene, toluene and ethylbenzene, toluene and xylene, and ethylbenzene and xylene. Out of the six possible pairings, four were found to be statistically significant ($p < 0.05$ in each case). The following were the pairings that were found to statistically significant per activity area: benzene and toluene, benzene and xylene, toluene and ethylbenzene, and ethylbenzene and xylene. Two pairings were found not be statistically significant and were benzene and ethylbenzene, and toluene and xylene ($p > 0.05$ in each case).

Pairing of three activity areas against one another, three possible pairings were established i.e., density huts and laboratory, density huts and strainer removal, and laboratory and strainer removal. All three pairings were found not to be statistically significant ($p > 0.05$ in each case). The percentage of contribution of individual component of the BTEX per activity area was found to be identical in all activity areas i.e., benzene 13%, toluene 37%, ethylbenzene 12 % and xylene 38%. This was expected based on fuel composition in South Africa and the fact that fuels are blended. The homogenous distribution of BTEX in the fuels was expected given the fact that the fuels came from a single source (shipped via pipeline from the refineries) and composition of individual petrochemicals are relative constant.

5.2.1 *Potential Health Risk Analysis for BTEX*

The results presented in Table 9 depicts the carcinogenic and non-carcinogenic risks for BTEX exposure at petrochemical depot in Heidelberg for controller and/or laboratory assistant both male and female when working at three activity areas. The average life expectancy and weight for both male and female controller and/or laboratory assistant were considered when calculating the CDI_{adj} . In Table 9. The cancer risk for benzene exposure was determined using an equation (5) shown under Table 4 and data in Table 4 and while the non-carcinogenic health effects of toluene, ethylbenzene, and xylene (TEX) were determined by calculating a hazard quotient using an equation (6) shown under Table 4 and also data in Table 4.

According to US EPA, a cancer risk score greater than 1×10^{-4} indicates a potential for the exposed individual to the develop cancer. The following were cancer risk score for the

following activity areas: The cancer risk was determined to be 13×10^{-2} (male) and 10×10^{-2} (female), 14×10^{-2} (male) and 11×10^{-2} (female), 16×10^{-2} (male) and 13×10^{-2} (female), 12×10^{-3} (male) and 10×10^{-3} (female) for the workers in the density huts, laboratory, strain remover (plant equipment cleaning) respectively.

In all exposure scenarios (male and female) the cancer risk was found to be higher than the acceptable risk levels of $1E^{-4}$. There were 13 males and 10 females in the population of 100 controllers who will be likely to develop cancer when working density huts environment. In the laboratory work environment, 14 males and 11 females in a population of 100 controllers were likely to develop cancer, whereas 16 males and 13 female laboratory workers were likely to develop cancer in a population of 100 laboratory workers, and during plant equipment cleaning 12 males and 10 female controllers were likely to develop cancer in a population of 1000.

Therefore, the potential of developing cancer is heightened by working in the laboratory and density huts. The risk of number of employees who will likely develop cancer is reduced when doing plant equipment cleaning. In all three activity areas cancer risk for males were higher than female counterparts. This finding indicates that males are more vulnerable than females even though the exposure concentration is the same. This is contrary to the study findings which found that females were more vulnerable to develop cancer due to exposure to BTEX from domestic coal burning (13). The higher number of males who were likely to develop cancer in all the activity areas were influenced by two factors i.e., males have a shorter average life expectancy and higher average body weight versus their females' counterparts.

A hazard quotient was used to determine the non-carcinogenic health effects, a hazard quotient of greater than 1 was used as a reference value. A value greater than 1 denoted a higher possibility that depot workers will get health effects from the exposure to the TEX. The hazard quotient for males ranged from 4.59 to 577.5, the highest hazard quotient was more than 577 times above the HQ reference value. The lowest was at density huts for xylene and highest was at laboratory for chemist for xylene. The hazard quotient for females ranged 3.15 to 399.00, the highest hazard quotient was more than 399 times above the HQ reference value. The lowest was at density for xylene and the highest was at laboratory for laboratory assistant.

From the results, both males and females had a hazard quotient far above 1 which means health effects arising from TEX exposure are anticipated. This is further enhanced by

additives effects which like to target common organs such a central nervous system (67). The males were found to be more vulnerable to develop the non-carcinogenic effects. The higher number of males who were likely to develop the non-carcinogenic effects in all the activity areas were influenced by the fact that- males have a higher average body weight versus their females' counterparts. These findings do not support and confirm other findings from studies where the hazard quotient for TEX was found to be below 1 (13, 30).

5.3. Study limitations

The individual information used in the risk assessment are the average person default values. The introduction of average person default values presents a limitation on this study as it well known that human being is not the same and there is no average person in South Africa even in the entire world. Workers vary from one another due to their uniqueness, genetic makeup (the biological make-up), gender, vulnerability, and environmental factors. These factors may affect the breathing rate, the adaptation, the weight and the life expectancy of each individual worker and the manner they could respond to BTEX exposure.

The study assumed that the concentrations in near field breathing zone of the worker represent internal and absorbed dose of the worker not considering personal protective equipment, body defense mechanism and the metabolism of the BTEX. These factors may either enhance or reduce the available internal and absorbed dose. The study used a shift system that was invoked by outbreak of the Covid-19 virus which might not applicable once the outbreak has passed or brought under control. Therefore, the outcome of the risk assessment has this inherent limitation.

Due to limited funds, only data for area sampling was used as a proxy for workers' exposure to BTEX. The study did not use a weather monitoring station to obtain meteorological data which are important for the behavior and dispersion of VOC's including BTEX especially during plant equipment cleaning which was directly exposed and influenced by prevailing ambient environmental conditions. Due to this limitation the measured BTEX concentrations are not correlated with meteorological data such as wind speed, wind direction, humidity, and temperature.

The data was only collected in spring and the other three seasons were not covered, this was due to time constraints and limited funds. It is anticipated that BTEX emissions will remain relatively constant throughout the year, however, a possibility exists that there might inter

seasonal variations especially the activities that are performed outdoor could be influenced by environmental conditions. Despite the study limitations, it has shown that depot workers are overexposed to BTEX in a petrochemical depot and the exposure could lead to carcinogenic effects and while non-carcinogenic effects were found to be more likely to develop as well.

5.4. Study strengths

This is the first study to characterize exposure scenarios and to conduct in depth risk assessment for BTEX in the specific petrochemical depot. It has demonstrated that workers are exposed to BTEX concentrations when carryout their tasks in the activity areas. It has given management an opportunity to understand and appreciate the role of task-based activities in the overall depot workers 'exposure to BTEX per activity area.

Now policy makers have opportunity to influence and direct the design and construction of petrochemical depot to prevent workers' exposure to BTEX emissions when carryout their tasks. Secondly, the petrochemical depot management have an opportunity to modify tasks by introducing specific task-based engineering controls to either prevent or minimize workers' exposure to BTEX emissions when performing tasks.

5.5. Future research and recommendations

Future studies conducting exposure and risk assessment to BTEX in the inland petrochemical depot network are necessary since this study was focused and confined to the one depot.

The future study could run both personal and area sampling in petrochemical depot covering the four seasons of the year. The personal will assist in the estimation BTEX concentration in the breathing zone. This may further correlate the area and personal BTEX concentrations per activity area. Breathing zone concentration is suggested to be an accurate estimation of how much the receptor is exposed to relative to ambient and indoor concentration.

Furthermore, future studies could cover the other routes of intake for the BTEX as this study was confined to inhalation. The possibility of VOCs /BTEX emissions changing from being airborne to water and soil compartments and its unintended impacts to the communities and farming activities.

5.6. Recommendations

The following recommendations are made to assist management of depot to control employees' exposure to BTEX emissions per activity area.

5.6.1 *Density huts*

The practicality of introducing a vapour recovery system on workbenches to extract the VOCs generated during sample collection and from density measuring jugs should be investigated or alternatively, the introduction of an online fuels and density analysis should be investigated or the practicality of introducing sample bombs to collect fuel samples should be investigated. Keep the windows opened to promote an ingress of fresh air and allow BTEX emissions to escape. A practicality of introducing a controlled mechanical ventilation to blow vapours away from the breathing zone of the depot workers should be investigated.

5.6.2 *Laboratory*

The practicality of automating or modifying the GC equipment in the laboratory to be able to conduct an online petrochemical analysis to control employees' exposure should be investigated. The tasks that require rinsing of testing tubes with fuels, refilling of the testing tubes, and discarding of superfluous samples should be performed under controlled conditions, the practicality of introducing a vapour recovering system to control vapours emissions should be investigated. The current practice of keeping the decanting drum open should be discontinued to prevent the accumulation of vapours in the laboratory or alternatively, it should be kept under a vapour recovery system. The practicality of keeping the retained fuel samples under the vapour recovery system in the laboratory storage should also be investigated. The fume hood and two extraction units should be serviced on a regular basis.

5.6.3 *Cleaning of plant equipment (strainer removal)*

The practicality of automating the removal and lifting the strainer to be cleaned to increase the distance between the strainer and receptors (controllers) should be investigated. The practicality of putting the clogged-up strainer in degreaser bath to remove and clean the strainer with the view of automating the task to prevent employees 'exposure to VOC emissions.

5.6.4 *Recommendations applicable to all activity areas*

Employees exposed to BTEX including the other petrochemicals should undergo a risk-based medical surveillance program including biological monitoring to evaluate the efficacy

of the existing controls and as part of a preventative medical surveillance program. Provide information, instruction, and training at regular interval about: - petrochemicals (BTEX) that employees are potentially exposed to at workplace and duties of persons who are likely to be exposed to VOCs vapour. The names and potential harmfulness of the BTEX at the workplace and the employees who are likely to be exposed. Significant findings of the BTEX exposure assessment (an occupational health risk assessment survey). Information on how to access the relevant safety data sheets and information that each part of an SDS provides. The work practices and procedures that must be followed for the use, handling, storage, transportation, spillage, and disposal of samples, in emergency situations, as well as for good housekeeping and personal hygiene. The necessity of personal exposure air sampling, biological monitoring, and medical surveillance; The need for engineering controls and how to use and maintain them. The need for personal protective equipment, including respiratory protective equipment, and its use and maintenance. The precautions that must be taken by an employee to protect themselves against health risks associated with exposure, including wearing and using protective clothing and respiratory protective equipment. The necessity, correct use equipment, maintenance and potential of safety facilities and engineering control measures provided. Supervisor/Line Manager must give written instructions of the procedures to be followed in the event of spillages, leakages, or any similar emergency situations to employees. Once the aforementioned information, instruction and training have been provided, enforce the wearing of the prescribed PPE including ABEK respirator and no employee should be allowed to enter and remain in respiratory zone without the prescribed PPE and respiratory protection equipment (ABEK respirator).

5.7. Conclusion and significant

This study made an effort to quantify BTEX concentrations in three activity areas namely density huts, laboratory and during the cleaning of plant equipment (strainer removal) in petrochemical depot at Heidelberg. From the results of this study, it may be concluded that the three activity areas are a significant source of BTEX emissions in the depot. The results showed highest constant BTEX concentrations in the three activity areas over the 12 hours shift.

The BTEX emissions were generated by activities that were performed by the depot workers. Highest BTEX concentrations were measured at laboratory, followed by density huts and the least was measured during the removal of the strainer. The lack of effective vapour recovery system and natural ventilation in the laboratory and in density huts also contributed

to the high BTEX concentrations measured on these areas. Individual BTEX component results measured in the three activity areas indicated concentrations which were far above the occupational exposure limits for individual BTEX. For instance:

- The average benzene concentrations measured in three activity areas ranged from 469ppm to 542ppm. The highest benzene concentration was found to be 542 times higher than the current South African Occupational Exposure Limits of 1ppm.
- The average toluene concentrations measured ranged from 1335ppm to 1542ppm and was found to be more than 30 times above the South African Occupational Exposure Limits of 50ppm.
- The average ethylbenzene concentrations measured ranged from 433ppm to 500ppm; the highest was found to be 5 times above the South African Occupational Exposure Limits of 100ppm.
- The average xylene concentrations measured ranged from 1372ppm to 1584ppm, the highest was found to be more than 15 times above the South African Occupational Exposure Limits of 100ppm

The study tried to utilize a near field breathing zone BTEX concentration as averaged over for 12-hour shift for tasks performed by depot workers both male and female (controllers and laboratory assistants) in the three described activity areas to estimate the potential carcinogenic and non-carcinogenic health effects. In the density huts the cancer risk was 12 and 10 for males and females respectively in 100 population of controllers; at laboratory for a population of 100 controllers, it was found to be 14 and 13 males and females respectively, for a population of 100 laboratory workers, it was found to be 15 and 12 for males and females respectively.

Whilst during plant equipment cleaning, it was found in a population of 100 controllers, 12 males and 9 females respectively were at risk of developing cancer. In all the activity areas more males were found to be more likely to develop cancer, this denotes that male are vulnerable as compared to female's counterpart.

Whilst the health risk assessment for toluene, ethylbenzene and xylene was done through calculating the hazard quotient. It was found to be well above the reference value of 1. Again, more males were also likely to develop non-carcinogenic health effects. This also denotes that more males were prone to develop the non-carcinogenic health effects.

5. REFERENCES

1. International Labour Office – Geneva: ILO. Exposure to hazardous chemicals at work and resulting health impacts: A global review 2021.
 2. International Labour Office – Geneva: ILO. Promoting a safe and sustainable petrochemical and chemical industry in China
Petrochemical and Chemical OHSE Forum. 2008.
 3. 2013 ILO. The prevention of occupational diseases. 2013.
 4. NEWSLETTER O. OSHE Workplace Accident Survey Report: There were 1088 workers casualties in workplace accident from January to June 2015; Transport, Garments, Construction and Agriculture Workers in peak. OSHE NEWSLETTER. 2015 MAY -JUNE 2015.
 5. Wolkoff P. Volatile organic compounds. *Indoor Air, Suppl.* 1995;3:1-73.
 6. Rad HD, Babaei AA, Goudarzi G, Angali KA, Ramezani Z, Mohammadi MM. Levels and sources of BTEX in ambient air of Ahvaz metropolitan city. *Air Quality, Atmosphere & Health.* 2014;7(4):515-24.
 7. McKenzie LM, Witter RZ, Newman LS, Adgate JL. Human health risk assessment of air emissions from development of unconventional natural gas resources. *Science of the Total Environment.* 2012;424:79-87.
 8. Loewenson R. Southern Africa: Trends and Policy Issues.
 9. Rezazadeh Azari M, Naghavi Konjin Z, Zayeri F, Salehpour S, Seyedi M. Occupational exposure of petroleum depot workers to BTEX compounds. *International Journal of Occupational and Environmental Medicine.* 2012;3(1):39-44.
 10. Lee S, Chang M. Indoor and outdoor air quality investigation at schools in Hong Kong. *Chemosphere.* 2000;41(1-2):109-13.
 11. Guo H, Lee S, Li W, Cao J. Source characterization of BTEX in indoor microenvironments in Hong Kong. *Atmospheric Environment.* 2003;37(1):73-82.
 12. Hazrati S, Rostami R, Farjaminezhad M, Fazlzadeh M. Preliminary assessment of BTEX concentrations in indoor air of residential buildings and atmospheric ambient air in Ardabil, Iran. *Atmospheric environment.* 2016;132:91-7.
 13. Masekameni M, Moolla R, Gulumian M, Brouwer D. Risk Assessment of Benzene, Toluene, Ethyl Benzene, and Xylene Concentrations from the Combustion of Coal in a Controlled Laboratory Environment. *International journal of environmental research and public health.* 2019;16(1):95.
 14. Masih A, Lall AS, Taneja A, Singhvi R. Inhalation exposure and related health risks of BTEX in ambient air at different microenvironments of a terai zone in north India. *Atmospheric environment.* 2016;147:55-66.
 15. Keretsetse GS, Laubscher P, Du Plessis J, Pretorius P, Van Der Westhuizen F, Van Deventer E, et al. DNA damage and repair detected by the comet assay in lymphocytes of African petrol attendants: a pilot study. *Annals of occupational hygiene.* 2008;52(7):653-62.
 16. Schneider P, Gebefügi I, Richter K, Wölke G, Schnelle J, Wichmann H-E, et al. Indoor and outdoor BTX levels in German cities. *Science of the Total Environment.* 2001;267(1-3):41-51.
 17. Infante PF. The IARC October 2009 evaluation of benzene carcinogenicity was incomplete and needs to be reconsidered. *American journal of industrial medicine.* 2011;54(2):157-64.
 18. Agents Classified by the IARC Monographs, Volumes 1–123 [Internet]. 2019 [cited 1 MAY 2019]. Available from: <https://monographs.iarc.fr/wp-content/uploads/2018/09/ClassificationsAlphaOrder.pdf>.
 19. Rattanajongjitrakorn P, Prueksasit T. Temporal variation of BTEX at the area of Petrol station in Bangkok, Thailand. *APCBEE procedia.* 2014;10:37-41.
 20. Ekpenyong CE, Davies K, Daniel N. Effects of gasoline inhalation on menstrual characteristics and the hormonal profile of female petrol pump workers. *Journal of Environmental Protection.* 2013;4(08):65.
-

21. Sutic I, Bulog A, Sutic I, Pavisic V, Mrakovcic-Sutic I. Changes in the concentration of BTEX (benzene, toluene, ethylbenzene, m/p-xylene and o-xylene) following environmental and occupational exposure to vapors. *Changes*. 2016;2(10).
 22. Le Ha VT. Preliminary assessment of BTEX concentrations indoor and outdoor air in residential homes in Hanoi, Vietnam. *Vietnam Journal of Science and Technology*. 2017;55(4C):78.
 23. Durmusoglu E, Taspinar F, Karademir A. Health risk assessment of BTEX emissions in the landfill environment. *Journal of hazardous materials*. 2010;176(1-3):870-7.
 24. Wentworth GR, Aklilu Y-a, Landis MS, Hsu Y-M. Impacts of a large boreal wildfire on ground level atmospheric concentrations of PAHs, VOCs and ozone. *Atmospheric Environment*. 2018;178:19-30.
 25. Pénard-Morand C, Annesi-Maesano I. Air pollution: from sources of emissions to health effects. *Breathe*. 2004;1(2):108-19.
 26. Zheng H, Kong S, Xing X, Mao Y, Hu T, Ding Y, et al. Monitoring of volatile organic compounds (VOCs) from an oil and gas station in northwest China for 1 year. *Atmospheric Chemistry and Physics*. 2018;18(7):4567-95.
 27. Sun J, Shen Z, Zhang L, Zhang Y, Zhang T, Lei Y, et al. Volatile organic compounds emissions from traditional and clean domestic heating appliances in Guanzhong Plain, China: Emission factors, source profiles, and effects on regional air quality. *Environment international*. 2019;133:105252.
 28. Atkinson R, Arey J. Atmospheric degradation of volatile organic compounds. *Chemical reviews*. 2003;103(12):4605-38.
 29. Naidoo S, Piketh SJ, Curtis C. Quantification of emissions generated from domestic burning activities from townships in Johannesburg. *Clean Air Journal= Tydskrif vir Skoon Lug*. 2014;24(1):34-41.
 30. Borhani F, Noorpoor A. Cancer risk assessment Benzene, Toluene, Ethylbenzene and Xylene (BTEX) in the production of insulation bituminous. *Environmental Energy and Economic Research*. 2017;1(3):311-20.
 31. Kimemia D, Annegarn H. An urban biomass energy economy in Johannesburg, South Africa. *Energy for Sustainable Development*. 2011;15(4):382-7.
 32. Louis LM, Kavi LK, Boyle M, Pool W, Bhandari D, De Jesús VR, et al. Biomonitoring of volatile organic compounds (VOCs) among hairdressers in salons primarily serving women of color: A pilot study. *Environment International*. 2021;154:106655.
 33. Zhong L, Batterman S, Milando CW. VOC sources and exposures in nail salons: a pilot study in Michigan, USA. *International archives of occupational and environmental health*. 2019;92(1):141-53.
 34. Acharya SR, Moon DH, Shin YC. Assessment of VOCs, PM10, and Formaldehyde Exposure in the Hair Salons of South Korea. *Journal of Environmental Health and Sustainable Development*. 2020.
 35. Pytel K, Marcinkowska R, Zabiegała B. Investigation on air quality of specific indoor environments—spa salons located in Gdynia, Poland. *Environmental Science and Pollution Research*. 2020:1-19.
 36. Okonkwo U, Orji I, Onwuamaeze I. Environmental impact assessment of petrol and gas filling stations on air quality in umuahia, Nigeria. *Global Journal of Engineering Research*. 2014;13(1):11-20.
 37. Hooftman N, Oliveira L, Messagie M, Coosemans T, Van Mierlo J. Environmental analysis of petrol, diesel and electric passenger cars in a Belgian urban setting. *Energies*. 2016;9(2):84.
 38. Franck H-G, Stadelhofer JW. Production and uses of benzene derivatives. *Industrial Aromatic Chemistry*: Springer; 1988. p. 132-235.
 39. Loomis D, Guyton KZ, Grosse Y, El Ghissassi F, Bouvard V, Benbrahim-Tallaa L, et al. Carcinogenicity of benzene. *The Lancet Oncology*. 2017;18(12):1574-5.
 40. Marcus WL. Chemical of current interest-benzene. *Toxicology and industrial health*. 1987;3(1):205-66.
 41. Ozokwelu ED. Toluene. *Kirk-Othmer Encyclopedia of Chemical Technology*. 2000.
-

42. Franck H-G, Stadelhofer JW. Production and uses of toluene derivatives. *Industrial Aromatic Chemistry*: Springer; 1988. p. 236-64.
 43. Fishbein L. An overview of environmental and toxicological aspects of aromatic hydrocarbons II. Toluene. *Science of the total environment*. 1985;42(3):267-88.
 44. Chu P, Landis ME, Le QN. Production of ethylbenzene. Google Patents; 1994.
 45. Keller N, Maksimova NI, Roddatis VV, Schur M, Mestl G, Butenko YV, et al. The catalytic use of onion-like carbon materials for styrene synthesis by oxidative dehydrogenation of ethylbenzene. *Angewandte Chemie International Edition*. 2002;41(11):1885-8.
 46. Yang W, Wang Z, Sun H, Zhang B. Advances in development and industrial applications of ethylbenzene processes. *Chinese Journal of Catalysis*. 2016;37(1):16-26.
 47. Franck H-G, Stadelhofer JW. Production and uses of xylene derivatives. *Industrial Aromatic Chemistry*: Springer; 1988. p. 265-90.
 48. Keretsetse GS, Laubscher PJ, Du Plessis JL, Pretorius PJ, Van Der Westhuizen FH, Van Deventer E, et al. DNA damage and repair detected by the comet assay in lymphocytes of african petrol attendants: a pilot study. *Ann Occup Hyg*. 2008;52(7):653-62.
 49. Rafiee A, Delgado-Saborit JM, Sly PD, Amiri H, Hoseini M. Lifestyle and occupational factors affecting exposure to BTEX in municipal solid waste composting facility workers. *Science of the Total Environment*. 2019;656:540-6.
 50. Milazzo MJ, Gohlke JM, Gallagher DL, Scott AA, Zaitchik BF, Marr LC. Potential for city parks to reduce exposure to BTEX in air. *Environmental Science: Processes & Impacts*. 2019;21(1):40-50.
 51. Hun DE, Corsi RL, Morandi MT, Siegel JA. Automobile proximity and indoor residential concentrations of BTEX and MTBE. *Building and Environment*. 2011;46(1):45-53.
 52. Wheeler AJ, Wong SL, Khoury C, Zhu J. Predictors of indoor BTEX concentrations in Canadian residences. *Health reports*. 2013;24(5):11-7.
 53. Montero-Montoya R, López-Vargas R, Arellano-Aguilar O. Volatile organic compounds in air: sources, distribution, exposure and associated illnesses in children. *Annals of global health*. 2018;84(2):225.
 54. Salama KF, Omer EO, Zafar M. Assessment of BTEX concentration around fuel station in Eastern Province Kingdom of Saudi Arabia. *International Journal of Environmental Health Engineering*. 2021;10(1):2.
 55. Dehghani MH, Baghani AN, Fazlzadeh M, Ghaffari HR. Exposure and risk assessment of BTEX in indoor air of gyms in Tehran, Iran. *Microchemical journal*. 2019;150:104135.
 56. Miri M, Shendi MRA, Ghaffari HR, Aval HE, Ahmadi E, Taban E, et al. Investigation of outdoor BTEX: Concentration, variations, sources, spatial distribution, and risk assessment. *Chemosphere*. 2016;163:601-9.
 57. Plog BA, Niland J, Quinlan P. *Fundamentals of industrial hygiene*: National Safety Council Ithaca, NY; 1996.
 58. Wang T, Bo P, Bing T, Zhaoyun Z, Liyu D, Yonglong L. Benzene homologues in environmental matrixes from a pesticide chemical region in China: occurrence, health risk and management. *Ecotoxicology and environmental safety*. 2014;104:357-64.
 59. López E, Schuhmacher M, Domingo JL. Human health risks of petroleum-contaminated groundwater. *Environmental science and pollution research*. 2008;15(3):278-88.
 60. Fayemiwo O, Moothi K, Daramola M. BTEX compounds in water–future trends and directions for water treatment. *Water Sa*. 2017;43(4):602-13.
 61. Smith MT. Advances in understanding benzene health effects and susceptibility. *Annual review of public health*. 2010;31:133-48.
 62. Marć M, Zabiegała B, Namieśnik J. Application of passive sampling technique in monitoring research on quality of atmospheric air in the area of Tczew, Poland. *International Journal of Environmental Analytical Chemistry*. 2014;94(2):151-67.
 63. Moolla R, Curtis CJ, Knight J. Assessment of occupational exposure to BTEX compounds at a bus diesel-refueling bay: A case study in Johannesburg, South Africa. *Science of the Total Environment*. 2015;537:51-7.
 64. international Labour Office – Geneva: ILO. World Day for safety and health at work
-

28 April 2014. 2014.

65. Alli BO. Fundamental principles of occupational health and safety Second edition. Geneva, International Labour Organization. 2008;15:2008.
 66. Heever DJSDDvd. Occupational Hygiene: The Science, Volume 1. 2014 ed. Bloemfontein: Sun Media Bloemfontein 2014.
 67. Occupational Health and Safety Act 85 of 1993 & Regulations, (March 2017).
 68. Reed S, Pisaniello D, Benke G. Principles of Occupational Health and Hygiene: An introduction: Routledge; 2020.
 69. Cooper C. Energy and transport issues for Gauteng, South Africa. *Journal of Energy in Southern Africa*. 2007;18(2):11-5.
 70. Transnet Pipelines 2019 [cited 2019 01 may 2019]. Available from: <https://www.transnet.net/InvestorRelations/AR2018/TPL.pdf>.
 71. New National Multi-Purpose Pipeline 2019 [Available from: <https://www.transnet.net/AboutUs/Pages/NMPP.aspx>].
 72. Fayemiwo O, Daramola M, Moothi K. BTEX compounds in water–future trends and directions for water treatment. *Water SA*. 2017;43(4):602-13.
 73. Boffetta P, Jourenkova N, Gustavsson P. Cancer risk from occupational and environmental exposure to polycyclic aromatic hydrocarbons. *Cancer Causes & Control*. 1997;8(3):444-72.
 74. Tunsaringkarn T, Prueksasit T, Kitwattanavong M, Siriwong W, Sematong S, Zapuang K, et al. Cancer risk analysis of benzene, formaldehyde and acetaldehyde on gasoline station workers. *Journal of Environmental Engineering and Ecological Science*. 2012;1(1):1.
 75. Xiong F, Li Q, Zhou B, Huang J, Liang G, Zhang L, et al. Oxidative Stress and Genotoxicity of Long-Term Occupational Exposure to Low Levels of BTEX in Gas Station Workers. *Int J Environ Res Public Health*. 2016;13(12).
 76. Ziramba E. Price and income elasticities of crude oil import demand in South Africa: A cointegration analysis. *Energy Policy*. 2010;38(12):7844-9.
 77. Wabiri N, Amusa H. Quantifying South Africa's crude oil import risk: A multi-criteria portfolio model. *Economic modelling*. 2010;27(1):445-53.
 78. Adendorf C, Khulu V, Emuze F. Investigating an effective supply chain for a refinery in a regulated petroleum sector. *TD: The Journal for Transdisciplinary Research in Southern Africa*. 2012;8(2):189-99.
 79. Kunene O, Allopi D. Impact of road and railway traffic at the Port of Durban: freight & forwarding. *Transport World Africa*. 2010;8(4):20-3.
 80. Kunene OM. Investigation on road infrastructure, traffic and safety within the Port of Durban 2013.
 81. Maroun W, Garnett R. The Transnet pipeline case study. *Emerald Emerging Markets Case Studies*. 2014;4(7):1-11.
 82. Health USEPAOo, Group EAEA. Exposure factors handbook: Exposure Assessment Group, Office of Health and Environmental Assessment, US ...; 1989.
 83. Moolla R, Curtis C, Knight J. Occupational exposure of diesel station workers to BTEX compounds at a bus depot. *International journal of environmental research and public health*. 2015;12(4):4101-15.
 84. Kitwattanavong M, Prueksasit T, Morknoy D, Tunsaringkarn T, Siriwong W. Health risk assessment of petrol station workers in the inner city of Bangkok, Thailand, to the exposure to BTEX and carbonyl compounds by inhalation. *Human and Ecological Risk Assessment: An International Journal*. 2013;19(6):1424-39.
 85. Pautz M. Is there a reason for South Africa to have a positive outlook towards 2020?: industry overview and analysis. *Civil Engineering= Siviele Ingenieurswese*. 2015;2015(v23i11):24-31.
 86. Holding AA, Ground BBN, Zone DD, Site IIA, Municipality LLL, Municipality LL. SDA Strategic Development Area SDF Spatial Development Framework WCW Water Care Works.
 87. Honeywell RSb. MniRAE 3000 User's Guide. 2014.
 88. WORLDHEALTHRANKINGS
live longer live better [Internet]. World Life Expectancy Partner. 2019 [cited 25 August 2019]. Available from: <https://www.worldlifeexpectancy.com/south-africa-life-expectancy>.
-

89. Moolla R, Curtis CJ, Knight J. Occupational exposure of diesel station workers to BTEX compounds at a bus depot. *International journal of environmental research and public health*. 2015;12(4):4101-15.
 90. Salem E, El-Garawani I, Allam H, Abd El-Aal B, Hegazy M. Genotoxic effects of occupational exposure to benzene in gasoline station workers. *Industrial health*. 2018;56(2):132-40.
 91. Soldatos AP, Bakeas EB, Siskos PA. Occupational exposure to BTEX of workers in car parkings and gasoline service stations in Athens, Greece. *Fresenius Environmental Bulletin*. 2003;12(9):1064-70.
 92. HEIN R, AUNG BT, LWIN O, Zaidi S. Assessment of occupational benzene exposure in petrol filling stations at Rangoon. *The Annals of occupational hygiene*. 1989;33(1):133-6.
 93. Romieu I, Ramirez M, Meneses F, Ashley D, Lemire S, Colome S, et al. Environmental exposure to volatile organic compounds among workers in Mexico City as assessed by personal monitors and blood concentrations. *Environmental Health Perspectives*. 1999;107(7):511-5.
 94. Mihajlović V, Grba N, Sudi J, Eichert D, Krajinović S, Gavrilov MB, et al. Assessment of Occupational Exposure to BTEX in a Petrochemical Plant via Urinary Biomarkers. *Sustainability*. 2021;13(13):7178.
 95. Glass DC, Schnatter AR, Tang G, Irons RD, Rushton L. Risk of myeloproliferative disease and chronic myeloid leukaemia following exposure to low-level benzene in a nested case-control study of petroleum workers. *Occupational and environmental medicine*. 2014;71(4):266-74.
 96. Xiong F, Li Q, Zhou B, Huang J, Liang G, Zhang Le, et al. Oxidative stress and genotoxicity of long-term occupational exposure to low levels of BTEX in gas station workers. *International journal of environmental research and public health*. 2016;13(12):1212.
-

PLAGIARISM DECLARATION



PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I Richard John Mdlalose (Student number: 600722) am a student registered for the degree of Master Public Health in Occupational Hygiene in the academic year 2022.

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that the work submitted for assessment for the above degree is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.
- I have included as an appendix a report from "Turnitin" (or other approved plagiarism detection) software indicating the level of plagiarism in my research document.

Signature: RJMdlalose

Date: 29 July 2022

RESEARCH ETHICS CLEARANCE CERTIFICATE

UNIVERSITY OF THE
WITWATERSRAND
JOHANNESBURG



R14/49 Mr Richard John Mdlalose

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M200120 MED19-11-149

NAME: Mr Richard John Mdlalose
Principal Investigator)
DEPARTMENT: School of Public Health
Transnet, Petrochemical Depot, Heidelberg, Gauteng


PROJECT TITLE: Exposure and risk assessment of Benzene, Toluene
Ethyl Benzene and Xylene (BTEX) in a petrochemical
depot at Heidelberg, South Africa

DATE CONSIDERED: 31/01/2020

DECISION: Approved unconditionally

CONDITIONS:

SUPERVISOR: Dr Daniel Masekameni

APPROVED BY: 
Dr C Penny, Chairperson, HREC (Medical)

DATE OF APPROVAL: 14/09/2020

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office Secretary in Room 301, Third floor, Faculty of Health Sciences, Philip Tobias Building, 29 Princess of Wales Terrace, Parktown, 2193, University of the Witwatersrand. I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to the Committee. **I agree to submit a yearly progress report.** The date for annual re-certification will be one year after the date of convened meeting where the study was initially reviewed. In this case, the study was initially reviewed May and will therefore be due in the month of May each year. Unreported changes to the application may invalidate the clearance given by the HREC (Medical).

Principal Investigator Signature

Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

DATA CAPTURING SHEET

1. APPENDIX A: QUESTIONNAIRE

Questionnaire for exposure assessment of Benzene, Toulene, Ethyl Benzene and Xylene (BTEX) in a petrochemical depot at Heidelberg, South Africa

Workers' data

1. How many shifts are there in a day (24 hours) from Monday to Thursday?
 - a) Three shifts of 8 hours
 - b) Two shifts of 12 hours
 - c) One straight shift of 9 hours
 2. How many shifts are there in a day (24 hours) from Friday to Sunday?
 - a) Three shifts of 8 hours
 - b) Two shifts of 12 hours
 - c) One straight shift of 9 hours
 3. How many days do you get as an off day per month?
 - a) Two days
 - b) Eight days
 - c) Four days
 4. How many leave days do you take per year?
 - a) 28 days
 - b) 15 days
 - c) 23 days
 5. How many days you spend on training away from depot per year?
 - a) 10 days
 - b) 5 days
 - c) 15 days
 6. What time the tank controller from Monday to Thursday spends per shift on tank dipping?
 - a) An hour
 - b) 45 minutes
 - c) Two hours
 7. What time the outside controllers from Monday to Thursday spends per shift on pig launching or receiving?
-

- a) One hour
 - b) Two hours
 - c) Four hours
8. What time the quality controller from Monday to Thursday spends per shift on sample collection and analysis?
- a) 5 hours
 - b) 6 hours
 - c) 7 hours
9. What time the laboratory assistant from Monday to Thursday spends in testing facility per day cleaning, analyzing, verifying, calibrating and maintain equipment?
- a) 4 hours
 - b) 5 hours
 - c) 7 hours
10. What time the outside controllers spends per month on cleaning plant equipment?
- a) 8 hours
 - b) 9 hours
 - c) 12 hours
11. What time the controller in-charged of plant operations from Monday to Thursday spends per shift in the control room?
- a) 7 hours
 - b) 6 hours
 - c) 4 hours
12. What time tank controller from Friday to Sunday spends per day on tank dipping?
- a) An hour
 - b) 45 minutes
 - c) Two hours
13. What time outside controllers from Friday to Sunday spend per day on pig launching or receiving?
- a) One hour
 - b) Two hours
 - c) Four hours
14. What time quality controller from Friday to Sunday spends per day on sample collection and analysis?
- a) 6 hours
-

b) 8 hours

c) 11 hours

15. What time the controller in-charged of plant operations from Friday to Sunday spends per day in the control room?

a) 12 hours

b) 10 hours

c) 7 hours

2. APPENDIX B: CHECKLIST

1. Checklist for exposure assessment

Yes = Y and No = N

- (a) Do they have work instruction or standard operating procedure (SOP) for tasks? Y/N
 - (b) Were you trained on the SOP? Y/N
 - (c) Are you aware of potential exposure to hazardous chemical substances? Y/N
 - (d) Were they trained on the work instruction? Y/N
 - (e) Were trained on what they are potential exposed to? Y/N
 - (f) What training was given on precautionary measures that are required to adhere to, including personal protective equipment? Y/N
 - (g) Are they provided with personal lockers and washing facility for contaminated PPE? Y/N

 - (h) Are they provided with shower facilities? Y/N
 - (i) Are they provided with eating (dining and breakfast) and toilet facilities? Y/N
 - (j) Are they allowed to eat and smoke in the plant? Y/N
2. Where are you storing clean personal clothing and PPE (overalls, booth, safety glasses, hearing protectors, gloves, respiratory protection equipment)?
- i. PPE locker with partitions for personal clothes and PPE
 - ii. PPE locker with no partitions PPE and personal clothing are mixed with dirty PPE
 - iii. No storage PPE and personal clothing
3. Where are you storing dirty PPE?
- i. Dirty PPE locker
 - ii. No provision is made for employees
 - iii. In my personal bag
4. Who washes/cleans dirty PPE such as overalls and booth?
- i. No laundry facilities provided by employer, employees take contaminated PPE for cleaning and washing at home.
-

- ii. Employer has contracted a supplier who does laundry, contaminated PPE are stored in a dirty room ready to be collected by the supplier for laundry.
- iii. Once PPE are contaminated/dirty are disposed of and employees are issued with new PPE

5. How are they disposing off contaminated PPE?

- i. Waste management procedure is followed
- ii. No procedure available and contaminated PPE is disposed of together with general waste
- iii. Contaminated PPEs is disposed of at home.

6. Observations on the day of the survey

Weather patterns

- i. Sunny and clear
- ii. Partial cloudy
- iii. Partial cloudy and raining
- iv. Cloudy but with no rain
- v. Cloudy and raining
- vi. Partial cloudy and raining
- vii. Windy and raining
- viii. Windy with no rain
- ix. Cold and windy with rain
- x. Cold and windy with no rain
- xi. Dry, windy, and hot
- xii. Hot day
- xiii. Cold day

Season of the year

- i. Spring
 - ii. Summer
 - iii. Autumn
 - iv. winter
-

Windy speed

- i. < 5 m per second
- ii. > 5 m per second

Humidity level

- i. < 50%
- ii. 50% to 70%
- iii. >71%

Plant conditions

- i. Plant is operating at full capacity – 100%
- ii. Plant is operating at 50% capacity
- iii. Plant is operating at 25% capacity
- iv. The entire plant is not operational /decommissioned

Utilization of PPE and compliance

- i. Workers wearing the required PPE correctly.
 - ii. Workers were issued with correct PPE but not worn
 - iii. Workers wearing required PPE but incorrectly
 - iv. Workers were not issued with required PPE.
 - v. Correct and required PPE worn by workers but the PPE is defective.
-