INVESTIGATING ENVIROMENTAL CONTAMINATION CAUSED BY UNDERGROUND FUEL STORAGE TANKS IN NANSADI AREA

OLIVER SHABA

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DEPARTMENT OF EARTH SCIENCE

DATE: 10TH NOVEMBER, 2023

DISSERTATION APPROVED BY:

SUPERVISOR:

Mr. W. Tchongwe Signature 

ASSESSOR: Signature _____

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I OLIVER SHABA declare that this research study is a product of my own work submitted to Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology. All sources of information used in this correctly cited and referenced, and any assistance rendered has fully acknowledged.

O.SHABA

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ABSTRACT

Incidents involving spills and leakage from underground fuel storage tanks (UFSTs) have the potential to result in soil and groundwater contamination, thereby pose harmful effects to public health and the environment. This research focused on assessing the practicality of employing volatile organic compounds (VOCs), electrical conductivity (EC), and pH as indicators to investigate UFST-related contamination. The geology and geological structure of the area was reviewed, in terms of faults, rock type and soil. Water assessment for VOCs and general water quality parameters were conducted for the quantification of BTEX concentrations, EC, and pH values and also soil assessment was also conducted for BTEX, EC and PH values as indicators in Nansadi Energem Filling station western side of Thyolo district in Malawi. The experimental approach followed in this study included chemical analysis of water samples from underground storage reservoirs and surface water from the river, and also analysis of soil samples. The results showed that both water resources and soil found within the study are not contaminated by hydrocarbons as all values measured are within the Malawi Bureau Standards recommended ranges.

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List of abbreviations

BTEX: Benzene Toluene Ethylbenzene and Xylene

USTs: Underground Fuel Storage Tanks

VOC: Volatile Organic Compound

PAH: Polycyclic Aromatic Hydrocarbon

MTBE: Methyl tert-butyl ether

MERA: Malawi Energy Regulatory Authority

MBS: Malawi Bureau of Standards

PH: Power of Hydrogen

WHO: World Health Organization

TNA: Typically, Nitric Acid

AAS: Atomic Absorption Spectrometry

ICP-MS: Inductively Coupled Plasma Mass Spectrometry

ICP-OES: Inductively Coupled Plasma Optical Emission

GIS: Geographic Information System

CE: Electrical Conductivity

CHAPTER ONE

INTRODUCTION

1.0General background

Petroleum hydrocarbon compounds are refined into many products such as diesel, petrol, paraffin and lubricants. These products are used in Malawi, on daily basis. However, Malawi as developing country, has an increasing number of machines which uses these petroleum products like diesel and petrol. For example, from 2006 to 2015 Malawi has registered 175,208 vehicles of which 70,031 were diesel vehicles and 95,555 were petrol driven vehicles and about 9,622 were motorcycles due to increased number of machines that uses hydrocarbon products has resulted into an increase in number of constructions of underground fuel storage tanks, such as filling station in various area across the country (GoM, 2017).

The construction of these underground fuel storage tanks has both positive and negative effects. In terms of positive effects, it is easy to access fuel in various area across the country for transportation. Not only that but also used for power generation using generators. It can also be used in case of particular for large volume storage. The underground storage has proven to be cost-effective in comparisons with aboveground steel tanks. It is also less fire hazard, another one is that it is more constant storage temperature that led to less energy consumption (Lu, 2010). Finally, it is also safety from vandalism in case they are demonstration in the country. It is very hard to break the underground tanks unlike aboveground tanks (Safety, 2011).

The negative effects of underground fuel storage tanks act as the source of environmental pollution through contamination of groundwater and soil in case there is fuel leakages or spillages. The contaminated water has a lot of effects to the environment. It can harm aquatic life, the hydrocarbon can interfere with organisms' ability to breathe or reproduce and even death (Muthwa, 2020). It can also cause range of health problems like skin irritation, cancer and headache, if hydrocarbon contaminate drinking water (Club, 2005).

The hydrocarbon can also contaminate the soil, if there are leakages. This can lead to breakdown of soil structure, making it less productive to support plant growth which

resulted to less of biodiversity, reduced crop yields (Watkinson, 2013).It can also cause air pollution, if hydrocarbon evaporate into the atmosphere resulting into respiratory problems and other health issue like coughing (Kaplan, 2019).

1.1. The location of the study area

Energem is one of the oil marketing companies which have many filling stations across the country. The research focused on one the Energem filling station which is located in the area of Nansadi in the Western part of Thyolo district in Malawi. Energem filling station is to the left side of the S150 Goliyati road and left side of railway line, and it is 129.7 meters away from the Luchedza river and Mpaya river. The Energem filling station is surrounded by some houses to west and to south. The geographical coordinates position for Nansadi Energem Filling Station is between 735822m Easting and 8241916m Nothing, where Energem filling station is located. The area is mainly drained by Lucheza river and Mpaya river which is in the western side of the Energem filling station (Figure 1).

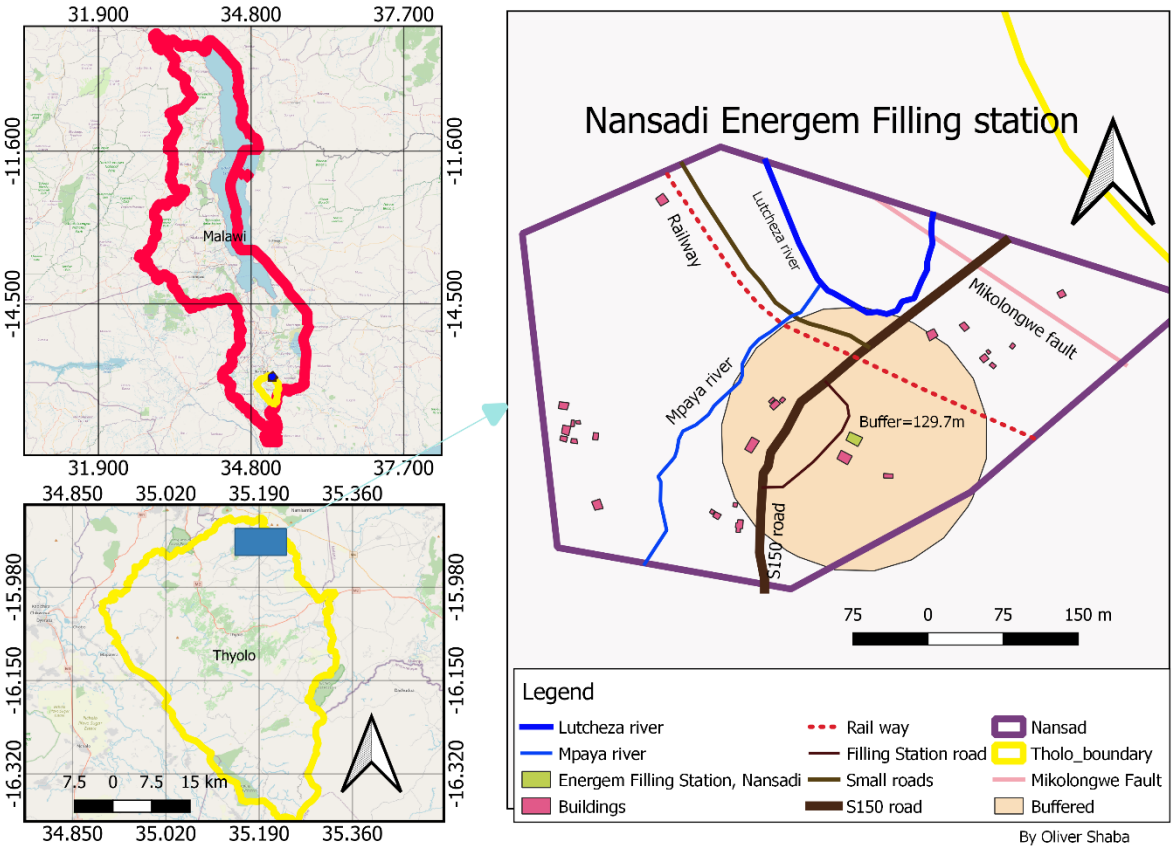


Figure 1: Maps showing location of study area

1.2. Problem Statement

Underground fuel storage tanks, have several positive impacts to social services. They store fuel in various area across the country which is main source of energy to run vehicles, motor cycles and also for power generation using generators. However, they contaminate soil and water especially in the presence of leakages. This resulted to pollution of both soil and water. A lot of studies have been conducted across the globe investigating environmental contamination caused by underground fuel storage tanks. According to the case study on Assessment of soil contamination caused by the underground fuel leakage from selected gas stations in Riyadh, Saudi Arabia (Al, 2018) found that underground storage tanks contaminate large surface area which pose a threat to environment. The research on the Study of contamination by benzene due diesel and gasoline leaks at a gas station in Natal / Brazil (Ramalho et al, 2014) found that benzene contaminate some part of the area which was close to underground storage tanks that were leaking. However, in Malawi there has been no official documented study which investigated environmental contamination caused by underground fuel storage tanks. Lack of knowledge on such studies put the life of people at risk of using contaminated water and soil especially where there are leakages. Therefore, this research aims at investigating environmental contamination caused by underground fuel storage tanks on the environment in Nansadi area.

1.3. Main objective and Specific Objectives

1.3.1 Main objective.

The main research is to investigate the contamination caused by underground fuel storage tanks to the environment in Nansadi area.

1.3.2 Specific objectives

To achieve the main objective of this research, the following specific objectives were considered:

- ✓ To review geology of the study area.
- ✓ To analyse the presence of hydrocarbon in groundwater.
- ✓ To analyse the presence of hydrocarbons in soil. .

1.4. Research questions

This research seeks to address the following questions:

- ✓ What is the general geology of the area?
- ✓ Is the soil around the at Nansadi area contaminated by hydrocarbons from underground fuel storage tanks?
- ✓ Is the water around the Nansadi area contaminated by hydrocarbons from underground fuel storage tanks?

1.5. Significance of Study

This study tries to reveal information about the environmental of the study area whether the presence of underground fuel tanks of Nansadi Energem Filling Station have led to contamination of soil and water sources. This information is so helpful to both community, government and regulatory authorities to understand the specific challenges and risks associated with underground fuel storage tanks in Nansadi area as well other areas. This would enable the authorities to develop targeted policies, regulations and guidelines to ensure that the underground fuel storage tanks should be source of contaminating the environment. The findings would also help directly the Energem oil company guiding it to adopt best practices to prevent contamination incidents, ensuring compliance with regulations and protecting their reputation and business operations. The study will also provide a foundation for further studies and investigations in similar regions and other areas. The findings can be used by researchers, academicians and students to deepen their understanding of environmental contamination, groundwater management, and sustainable urban development. The results of the study would also help in filling lack of environmental data as one of the challenges singled out in Malawi Vision 2063 under environmental sustainability for conservation of environmental. The results will help authorities in data driven decision making when establishing and certification of filling station development in Malawi.

CHAPTER TWO

LITERATURE REVIEW

2.1. General geology of the study area

The Thyolo area is one of the diverse reliefs. Elevation ranges from 53m above sea level at Chiromo to 1462 at the summit of Thyolo Mountain (Carter, 1973). Three physiographic zones recognized are the shire valley plain, the Thyolo fault scarp zone, which forms the eastern boundary of the southern section of Malawi rift valley and the Thyolo highlands. The zones are overshadowed by Ridge of Thyolo Mountain (Carter, 1973). The Thyolo highlands represent a mind tertiary erosion surface, slightly titled away from the rift valley escarpment and failing gradually to approximately 610m to the southern of Luchenza. The surface however is not uniform and there is significant variation in relief. Only in the extreme northeast does the surface approaches that of plateau characterized by only slight dissection. In that area it is mantled by widespread and generally thick residual soils (Carter, 1973). The Thyolo fault scarp zone dominates the eastern side of the shire valley and defines the faulted and dissected southwestern margin of the Thyolo highlands surface. It comprises a number of discontinuous topographic steps that reflects complex history of post Stromberg rift faulting. Thyolo is dominated by metamorphic rocks of igneous origin. The most dominating metamorphic rocks are, gneiss and schist, but also it consists of quartzite metamorphic rock and some igneous rocks such as dolerite (Walker, 1949).

2.2. Geological factors consideration when constructing UFSTs

Geology plays a fundamental role in determining the permeability of subsurface materials. Permeability refers to the ability of rocks or soils to allow the movement of fluids, such as fuel contaminants. Geologic formations with high permeability, such as fractured bedrock or porous sedimentary layers, can facilitate the migration of leaked fuel from storage tanks, allowing it to spread more quickly and over greater distances. Conversely, low-permeability formations, such as clay layers, can act as barriers, slowing down the movement of contaminants and reducing their migration potential (Sheng et al, 2019).

Soil types and Containment, Geologic variations in soil types can impact the containment of leaked fuel. Some soils, such as coarse-grained sands and gravels, tend to have higher permeability, allowing contaminants to spread more easily. In contrast, finer-grained soils like clays have lower permeability and can serve as barriers, limiting the vertical and lateral movement of contaminants. Understanding the soil characteristics in proximity to underground fuel storage tanks is crucial for assessing the potential for contamination and designing appropriate containment measures (Kenneth et al, 2012).

Natural Hazards, Geology also plays a role in assessing the susceptibility of underground fuel storage tanks to natural hazards such as earthquakes, landslides, or faults. Areas with known seismic activity or unstable geological conditions may require additional engineering considerations and design measures to ensure the tanks can withstand potential ground movements or disruptions (GoM, 2017).

2.3 Causes of underground fuel storage tanks leakages

There are a number of factors that cause underground fuel tanks to be leaking to contaminate the surrounding.

2.3.1 Corrosion: Over time, fuel tanks corrode due to the interaction of the stored fuels with the tank materials (Figure 2). Corrosion weakens the tank structure, leading to cracks and holes that allow fuel to leak into the surrounding soil. The most common way for contamination to happen is through leaks from the storage tanks. These liquids can then seep through the soil and reach the groundwater, contaminating it (Naik et al, 2014).



Excavated USTs

Figure 2: Showing corroded underground fuel tanks (EPA, 2001)

2.3.2 Improper Maintenance: Lack of proper maintenance, inspection, failure to follow proper installation procedures of piping systems and corrosion protection measures for the tanks can lead to structural failures and leaks. Over time, the tanks might develop weak points that allow fuel to escape, which result to these liquids to seep into the surrounding soil and reach groundwater through leaching (EPA, 2001).

2.3.3 Physical Impact or External Damage; Damage to the tank from physical impact or other external factors can also cause UST leaks. This can include damage from vehicle traffic, construction activities, or natural disasters such as floods or earthquakes. When leakage happens, these liquids can the seep into the surrounding soil and reach groundwater results to contamination.

2.4 Dangerous chemicals leak from underground fuel storage tanks

Underground storage tanks can hold substances such as gasoline, diesel and other toxic substances. Gasoline and diesel consist of an intricate mixture of numerous compounds. In the event of tank leakage (Figure 3), a significant portion of these

pollutants have the ability to swiftly migrate through the nearby soil, rapidly polluting substantial amounts of groundwater and infiltrating surface water bodies like lakes and rivers (Club, 2005). Hydrocarbons leaked from the underground fuel storage tanks can contain some toxic substances (Table 1).

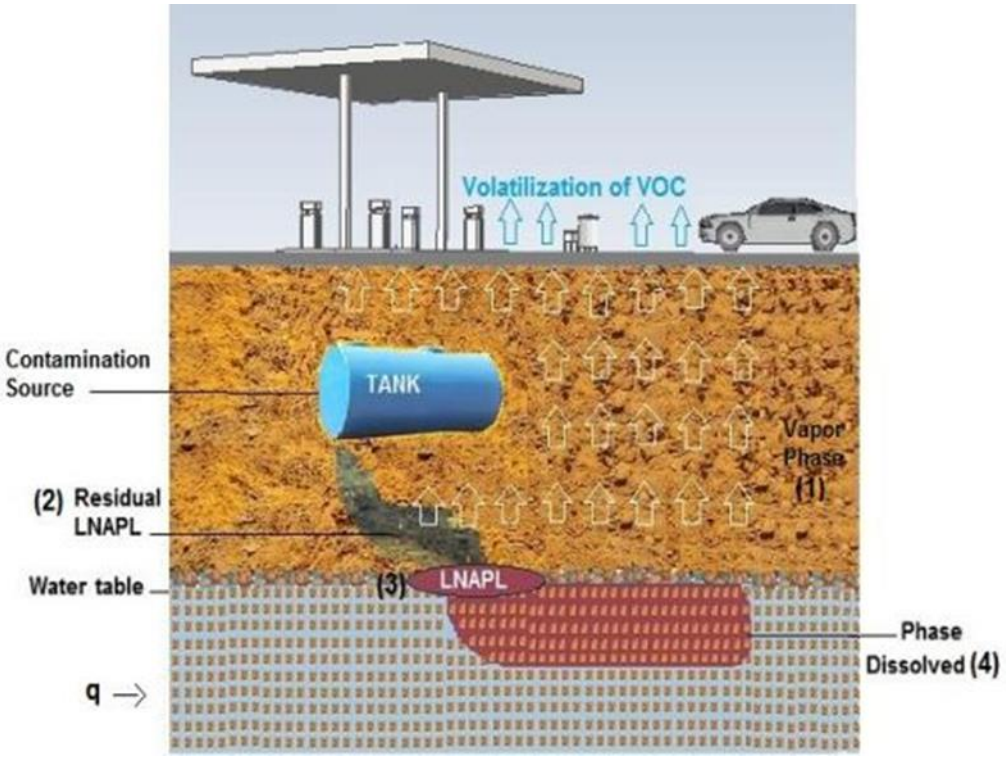


Figure 3: Showing the leakage of underground fuel storage tank (Ramalho et al, 2014)

Table 1: Indicating toxic substances release from UFSTs (CLUB, 2005)

Toxic Substance	Pollutant Class	From	Mobility in Soil
Benzene	VOC 1	Gasoline and other petroleum substances	High
Toluene	VOC 1	Gasoline and other petroleum substances	High with other chemicals in gas.
MTBE	Oxygenate	Gasoline	High with other chemicals in gas

Xylenes	VOC 1	Gasoline and other petroleum substances	Moderate
Naphthalene	PAH 2	Gasoline and other petroleum substances	High in sandy soils
1,2 Dichloroethane	VOC 1	Leaded gasoline	Very high to high
Ethylbenzene	VOC 1	Gasoline and other petroleum substances	Moderate

2.5 Negative impacts of petroleum products on soil and water

Underground fuel storage tanks can pose environmental risks if not properly managed. Petroleum products, such as gasoline, diesel and oil can have significant impacts on water and soil if they are released from storage tanks as discussed below.

2.5.1 Groundwater contamination. Petroleum products can contaminate groundwater if they are released from underground storage tanks. This can result in the contamination of drinking water supplies and other sources of groundwater, posing significant health risks to humans and wildlife (Al, 2014).

2.5.2 Soil contamination: Petroleum products can contaminate the soil if they are spilled or leaked, making it unsuitable for plant growth. This can have a significant impact on agricultural land and natural habitats (Valeria et al, 2006).

2.5.3 Toxicity to wildlife: Petroleum products are toxic to many forms of wildlife, including fish, amphibians, birds, and mammals. Exposure to petroleum products can cause reproductive problems, developmental issues, and other health problems in wildlife (Xue et al, 2019).

CHAPTER THREE

METHODOLOGY

3.1 Type of data

Both primary and secondary data were used in this study. Primary data mainly included results of samples analysed in the laboratory whereas secondary data was mainly the geological information obtained from Geological Survey Department.

3.2 Data collection

3.2.1 Reviewing geology of the study area

The secondary data was collected from the geological survey in Zomba District to review the geology information of the study area in terms of the faults, rock type and soil of area, through geological bulletin of Thyolo and other literature reviews.

3.2.2 Water sampling

Water samples were collected from the river closed to the Energem filling station at the point where the filling station makes right angle to the river was marked as an upstream going downward as downstream. Water samples were collected at point 1 at upstream of the river then going down for 50 meters point 2 and 50 meters downstream again at point 3. The samples were collected from the rivers, deeper wells and boreholes (Appendices 1-3) closed to filling station. The method used to collect water sample was grabbing sampling. The materials used were clean plastic bottles, plastic container and 5-liter plastic bottle. Each bottle was labelled to represent the information of particular point where sample was collected.

3.2.3 Soil sampling

Soil samples were collected from same the points where water samples were also collected. Soil samples were also collected around the filling station by digging one-meter-deep hole using a hole, shovel and peak. The collected samples were put in clean plastic papers and more information about each particular sampling point was recorded.

3.3 Data analysis

3.3.1. Water and soil samples analysis

Water samples were analyzed for hydrocarbon chemical parameters (Toluene, Ethylbenzene and Xylene (BTEX)), pH and electrical conductivity at Malawi Bureau Standard laboratory in Blantyre.

BTEX compounds were analyzed using gas chromatography. Samples were mixed with hexane solvent in order to separate the BTEX from the samples. To ensure quality of the data produced, quality measures control which included running calibration standards, duplicate samples, blanks, and standard reference materials were considered. Then the BTEX results were compared with the standard ones of Malawi Bureau Standard.

3.3.2 Power of hydrogen (PH)

Power of hydrogen for both water and soil samples were measured using pH meter. The pH meter was calibrated using standard pH buffer solutions (pH4, pH7 and pH10) to ensure accurate measurements. Electrodes for pH meter were immersed in water samples as well as in soil slurry (soil samples) to record pH. The pH results were then compared with the standard ones from MBS to determine whether the underground water and soil in the study area are contaminated by hydrocarbons.

3.3.3. Electric Conductivity

Electric conductivity (EC) for both water samples was measured using EC meter. The EC results were also compared with the MBS in order to determine the presence of hydrocarbons in samples,

3.4. Study limitation

There are some of challenges which faced during conducting this research some of them were as follows; Improper collections of samples due to sand mining along the rivers, the geology of the area does not favour transmission of fluid flow due to think residual soil, lack of fault along the buffered zones and presence hard rock such gneiss, the filling station is not old enough, Lack of enough money to drill holes for samples collection.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Geology of the study area and its impact on hydrocarbons movement

Secondary data from the geology survey show that Thyolo fault scarp zone dominates the eastern side of the shire valley and defines the faulted and dissected southwestern margin of the Thyolo highlands surface. Nansadi area has Mkolongwe faults which is outside the buffered zone of Energem filling station and it is about 180-200 meters away from the filling station. The area is dominated by metamorphic rocks (gneisses) of igneous origin (Figure 4). These metamorphic rocks are hard and strong making the area less permeable to fluids movement. The area has also thick residual soils. So, geology of study area show there would be less movement of hydrocarbons in case there are fuel leaks from the underground fuel storage tanks as the area is less permeable due presence of thick residual soils and hard metamorphic rocks, the gneisses.

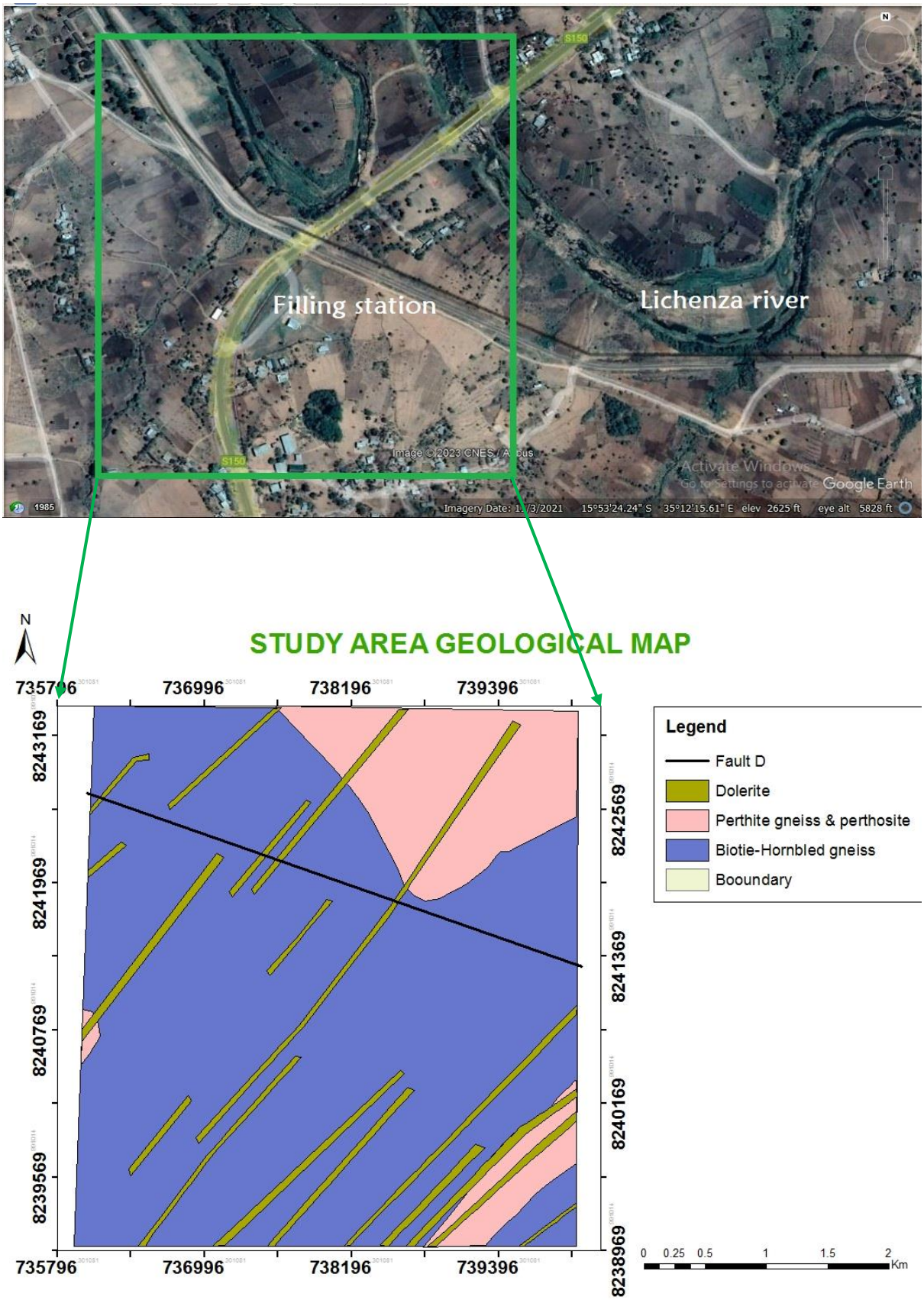


Figure 4: Geological map of the study area

4.2 Water analysis results

Water samples analysed for the following parameters Benzene Toluene, Ethylbenzene, and Xylene (BTEX), pH for water samples and electrical conductivity, and the results are presented in Tables 2, 3 and 4.

Table 2: Table results for BTEX

NO OF SAMPLE	MBS RECOMMENDED	COLLETECTED RESULTS AFTER TEST	UNITS
A	Nil	Nil	UG/L
B	Nil	Nil	UG/L
C	Nil	Nil	UG/L
D	Nil	Nil	UG/L
E	Nil	Nil	UG/L

Benzene, Toluene, Ethylbenzene, and Xylene (BTEX)

Benzene, Toluene, Ethylbenzene, and Xylene, collectively known as BTEX, are group of volatile organic compounds (VOCs) commonly found in petroleum-based products like gasoline and diesel. These substances are not linked in petroleum pollution or contamination but are frequently used as indicators in environmental assessments to identify petroleum contamination. When petroleum products are accidently released into the environment, for instance through fuel spills, storage tanks leaks or unintended discharges, BTEX compounds may be present in resulting to contamination. BTEX compounds are volatile and can easily turn into vapor, allowing them to move through the air, soil and groundwater. This high mobility means they can spread away from the pollution source. If petroleum product leak from underground storage tanks, BTEX compounds can contaminate both the soil and groundwater. They can dissolve in the groundwater and travel with its flow,

potentially impacting nearby drinking water wells and surface water bodies. So according to the results BTEX results (Table 2) show that there is no contamination of petroleum products like diesel and petrol.

Table 3: Results table for water pH

NUMBER OF SAMPLE	MBS RECOMMENDED	COLLECTED RESULTS	UNITS
A	6.5-8.5	6.5	PH UNITS
B	6.5-8.5	7.1	PH UNITS
C	6.5-8.5	6.9	PH UNITS
D	6.5-8.5	8	PH UNITS
E	6.5-8.5	7.7	PH UNITS

The presence of hydrocarbons in water can lead to changes in the water's pH. When hydrocarbons are found in water, they can undergo reactions with oxygen, resulting in the formation of organic acids. These organic acids have the potential to decrease the water's pH, making it more acidic. The pH scale, which ranges from 0 to 14, designates 7 as neutral. Any pH value below 7 indicates acidity, while a pH value exceeding 7 signifies alkalinity. Consequently, when hydrocarbons cause a drop-in water pH, it can have detrimental effects on aquatic life and other organisms reliant on the water's pH level. According to the results from the table from the laboratory shows that water is not contaminated by petroleum compounds from the underground fuel storage tank unless further study must conduct.

Table 4: A table showing EC results

NUMBER OF SAMPLES	MBS RECOMMENDED	RESULTS COLLECTED	UNITS
A	70-150	140	MS/M
B	70-150	152	MS/M
C	70-150	130	MS/M
D	70-150	1oo	MS/M
E	70-150	99	MS/M

The presence of hydrocarbon compounds in water leads to a reduction in water's electrical conductivity because hydrocarbons, which are organic compounds consisting solely of carbon and hydrogen atoms, are nonpolar and incapable of dissociating in water, thus failing to generate ions that facilitate electrical conduction. According to the results from the Malawi Bureau of Standards (Table 4) is slightly increase in value of conductivity in some of the samples and other sample are within the range with the recommended ones from the MBS. This shows that there is no contamination caused by hydrocarbon compounds, this can show that there little or no leakage of underground fuel storage tanks unless further study must be conducted.

4.3 Soil analysis results

Five soil samples were analysed for pH, EC and BTEX compounds and the results are presented in Tables 5, 6 and 7 below.

Table 5: Soil pH results

NUMBER OF SAMPLE	MBS RECOMMENDED	COLLECTED RESULTS	UNITS
A	6.5-8.5	6.5	PH UNITS
B	6.5-8.5	7.1	PH UNITS
C	6.5-8.5	6.9	PH UNITS
D	6.5-8.5	8	PH UNITS
E	6.5-8.5	7.7	PH UNITS

According to the results from Table 5, from the laboratory of Malawi Bureau of Standards shows that soil is not contaminated by petroleum compounds from the underground fuel storage tank, by comparing the collected results with the recommend of MBS unless further study must be conducted.

Table 6: Soil samples EC results

NUMBER OF SAMPLES	MBS RECOMMENDED	RESULTS COLLECTED	UNITS
A	70-150	140	MS/M
B	70-150	152	MS/M
C	70-150	130	MS/M
D	70-150	1oo	MS/M
E	70-150	99	MS/M

According to the results from the Malawi Bureau of Standards (Table 6) shows that there is slightly increase in value of conductivity in some of the samples and other sample are within the range with the recommended ones from the MBS. This shows that there is no contamination caused by petroleum products like Diesel and Petrol. This means that there is little or no leakage of underground fuel storage tanks unless further study must be conducted.

Table 7: BTEX compounds results for soil samples

NO OF SAMPLE	MBS RECOMMENDED	COLLETECTED RESULTS AFTER TEST	UNITS
A	Nil	Nil	UG/L
B	Nil	Nil	UG/L
C	Nil	Nil	UG/L
D	Nil	Nil	UG/L
E	Nil	Nil	UG/L

The BTEX results (Table 7) show that there is no presence of petroleum products in the soil sample. This means that soil is not contaminated by hydrocarbons which might have leaked from the underground fuel storage tanks of Nansadi Filling Station.

CHAPTER FIVE

CONCLUSSION AND RECOMMENDATIONS

5.1 Conclusion

The research results through both water and soil samples analysis show no evidence that the study area is contaminated by hydrocarbons from the underground fuel storage tanks of Nansadi Energem filling station. Chemical parameters such as pH, electric conductivity and BTXE results are within the recommended range of MBS. The results imply that the Nansadi Energem filling station underground fuel storage tanks are not leaking to cause contamination. This is case since the filling station was recently constructed whereby the tanks are yet to start corroding and the piping system is still intact to cause fuel leakage. The geology of the study area does not favour transmission of fluids which can come due tanks leakages or improper installation of pipe system. The study area is dominated by metamorphic rock such as biotie-hornbeld gneisses, thick residual soils and less faulted making it less permeable for hydrocarbons in case there is fuel leakage.

5.2 Recommendations

Due to some challenges experienced in this study, the following are recommendations made:

- ✓ Similar study should be conducted in the same study area with proper tools to collect recommended samples from drill holes. There were no enough resources for drilling during the study.

- ✓ Similar study should be done in areas with old filling stations since in such areas there are possibility of having corroded underground fuel tanks causing fuel leakage to the surrounding. The filling station considered in this study was recently constructed and chances for fuel leakage are minimal as the piping system and underground tanks are still in good condition.

- ✓ Similar study should be done in areas where the geology favour movement of hydrocarbons from underground fuel tanks once there is leakage. The area under study is less permeable due to its geology.

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Appendices

Below are some of the figures 5-7 which shows some of activities during sampling





