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Application of Geographic Information System in the Management of Contaminated Crude Oil Polluted Sites in Ogoni: A Case Study of Ajeokpori, Eleme

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Abstract: *This study investigates the application of Geographic Information Systems (GIS) in effectively managing contaminated soil and groundwater. A comprehensive set of maps is developed, including a topographical survey, groundwater map, hydraulic conductivity map, map of spatial variation in specific storage, transmissivity map, and maps depicting TPH (Total Petroleum Hydrocarbons) and BTEX (Benzene, Toluene, Ethylbenzene, Xylene) levels in both soil and groundwater. By integrating this data within a GIS framework, the study aims to identify areas with elevated levels of TPH and BTEX in soil and groundwater and analyse the relationship between topography, hydraulic conductivity, specific storage, and transmissivity with contaminant migration patterns. Develop a spatial model to predict contamination plumes' potential movement and spread. This GIS-based approach can support informed decision-making for remediation strategies by Prioritizing areas for immediate intervention based on contaminant concentration and potential migration pathways and optimizing the placement of monitoring wells for effective contaminant plume tracking and evaluating the suitability of different remediation techniques based on site-specific characteristics. The findings of this study can be valuable for environmental agencies, remediation contractors, and landowners dealing with contaminated soil and groundwater. The integration of spatial data within a GIS platform provides a powerful tool for comprehensive site assessment, risk evaluation, and the development of effective remediation Action plans (RAP).*

INTRODUCTION

The UN Environment Programme (UNEP) published the results of its 14-month environmental

evaluation in relation to oil pollution in Ogoniland, Nigeria, on 4 August 2011. The assessment identified significant hazards to human health resulting from oil-induced soil and groundwater pollution and provided suggestions for remediating the environment. The report states that the drinking water in at least 10 Ogoni settlements is severely polluted with significant amounts of hydrocarbons, posing a grave risk to human well-being. An assessment of groundwater contamination at 69 sites revealed the presence of a layer of refined oil, measuring 8cm in thickness, floating over the groundwater. This groundwater serves as a source of drinking water for nearby towns (UNEP, 2011).

According to the report, it is projected that a long-term commitment of 25-30 years will be required to address and remediate the contamination in Ogoniland and facilitate a sustainable restoration. Before the clean-up of the creeks, sediments, and mangroves, it is necessary to address the sources of continued contamination, as stated in the report. The report proposes the creation of three new institutions in Nigeria to facilitate the environmental restoration efforts. These include an Ogoniland Environmental Restoration Authority, responsible for implementing the recommendations outlined in the study; an Integrated Contaminated Soil Management Centre, dedicated to treating contaminated soil; and a Centre of Excellence in Environmental Restoration, aimed at fostering knowledge acquisition and providing assistance to other communities affected by oil contamination.

In line with the UNEP report and its recommendations, the Federal Government of Nigeria set up the Hydrocarbon Pollution and Remediation Project in 2014. The objectives of the HYPREP are to (a) develop and initiate a work program aimed at restructuring all hydrocarbon-impacted communities in Nigeria and any matter that the Federal Government may from time to time assign to the HYPREP; (b) undertake a comprehensive assessment of all environmental issues associated with the oil field related activities in Ogoniland including the quantification of impacts; (c) provide helpful guidance data to undertake remediation of. contaminated soil and groundwater in Ogoniland; (d) provide specific recommendations regarding the scope, modalities, and means of remediation of soil and groundwater contamination; (e) technically evaluate alternative technologies to be employed to undertake remediation of contaminated soil and groundwater; (f) provide recommendation for responding to future environmental contamination from oil field operations (HYPREP GAZETTE, 2014).

Among the functions of HYPREP were (1) to investigate and evaluate all Hydrocarbon polluted communities and sites in Nigeria and make recommendations to the Federal Government; (b) to implement the actionable recommendations of the United Nations Environment Programme (UNEP) Report on Environmental Restoration in Niger Delta; and (c) restore communities and sites impacted by Hydrocarbon Pollution in Nigeria and any other matter that the Federal Government may assign to it. The objectives of the HYPREP are to (a) develop and initiate a work program aimed at restructuring all Hydrocarbon Impacted Communities in Nigeria and any matter that the Federal Government may from time to time assign to the HYPREP; (b) undertake a comprehensive assessment of all environmental issues associated with the oil field related activities in Ogoniland including the quantification of impacts; (c) provide helpful guidance data to undertake remediation of. contaminated soil and groundwater in Ogoniland; (d) provide specific recommendations regarding the scope, modalities, and means of remediation of soil and groundwater contamination; (e) technically evaluate alternative technologies to be employed to undertake remediation of contaminated soil and groundwater;:(f)provide recommendation for responding to future environmental contamination from oil field operations; (g) provide recommendations for sustainable environmental management of Ogoniland (HYPREP GAZETTE, 2014).

The site described in this study falls under the semi-complex site, where soil and groundwater are contaminated and far from where people live. Soil contamination in the Niger Delta has become widespread and assumed international concern (UNEP, 2011), affecting local fisher folks and farmers whose economic well-being is dependent on rivers and alluvial fertile soil. There is an increasing concern as large volumes of toxic organic substances continually enter the coastal environment of the Niger Delta (Eregha Irughe, 2009; Linden & Palsson, 2013) through different routes, including leachate and seepage during operations, extraction, transportation, distribution storage, and refining (UNEP, 2011).

Hydrocarbons are common cause of soil contamination and harm vegetation communities. Different technologies, such as soil thermal treatment and washing, have reduced petroleum hydrocarbon soil contamination (Ossai et al., 2020; Al-Ateeqi et al., 2021). However, these methods often tend to be costly and energy-intensive; for these reasons, a Geographic information approach is applied in modelling the contamination and creating a spatial model to forecast the potential movement and expansion of contamination plumes. This approach, which utilizes Geographic Information Systems (GIS), can assist in making well-informed decisions regarding remediation strategies. It accomplishes this by prioritizing areas that require immediate intervention based on contaminant concentration and potential migration routes. Additionally, it optimizes the positioning of monitoring wells to track contaminant plumes effectively and evaluates the appropriateness of various remediation techniques based on site-specific characteristics.

METHODOLOGY

This study demonstrates the application of GIS in managing a contaminated site with elevated levels of TPH and BTEX in both soil and groundwater. The methodology involved the following steps. The study area is Lot 3, Ajeokpori, in Eleme Local Government, Rivers State. The locator map of the study area is shown in Fig. 1.

Data Collection

- A topographical survey was conducted to generate the site's digital elevation model (DEM). See Fig. 2
- Groundwater monitoring wells were installed, and groundwater samples were collected to analyse TPH and BTEX concentrations. See Table 1 and Fig. 3
- Soil samples were collected across the site to determine spatial variations in TPH and BTEX levels. (See Table 3 and Fig 6)

- Additional data layers were obtained, including hydraulic conductivity, specific storage, and transmissivity of the subsurface materials. (See Table 2 and Fig.6).

RESULTS

All collected data was integrated into a GIS platform. A series of thematic maps were created, including a topographical map depicting the site's elevation (See Fig. 2), a Groundwater Map illustrating the spatial distribution of groundwater wells (See Fig. 3), a Hydraulic Conductivity Map showing variations in the subsurface material's ability to transmit water (See Fig. 4) Specific Storage Map representing the volume of water released from the aquifer per unit area and unit decline in the hydraulic head (See Fig. 6). Transmissivity Map depicting the rate at which water can be transmitted through the aquifer thickness (See Fig. 6). Maps illustrating the spatial distribution of TPH and BTEX concentrations in soil and groundwater (See Table 3, Table 4, Fig. 8, Fig. 9, Fig. 10 and Fig. 11).

The thematic maps were overlaid and analysed within the GIS framework. The relationships between topography, hydraulic conductivity, specific storage, transmissivity, and contaminant migration patterns were investigated. Base on the identified relationships, a spatial model was developed to predict the contaminant plume's potential movement and spread.

The GIS analysis results were used to identify areas with elevated contaminant concentrations requiring immediate intervention, analyse potential migration pathways, and prioritize areas based on the predicted movement of contaminant plumes. Optimize the placement of monitoring wells for effective contaminant plume tracking. Evaluate the suitability of different remediation techniques based on site-specific characteristics like contaminant type, depth of contamination, and hydrogeological conditions.

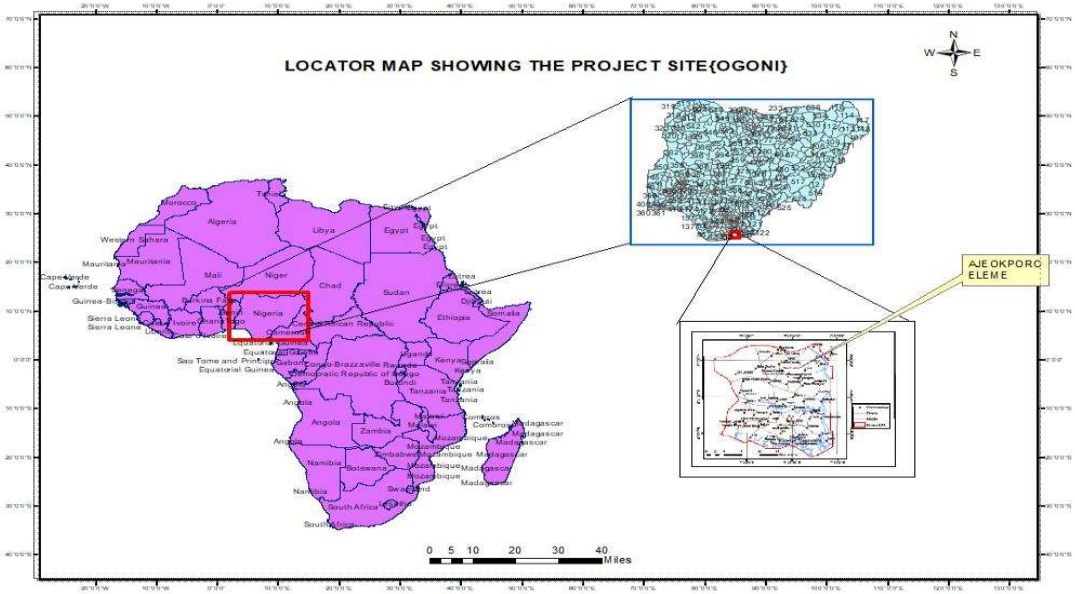


Fig.1: Study Area Map

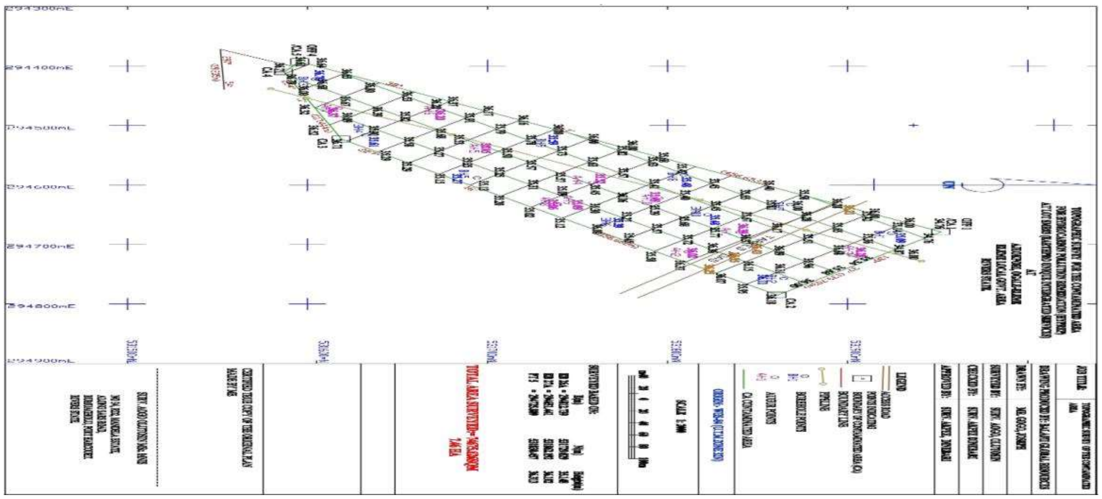


Fig. 2: Topographic Survey of the area

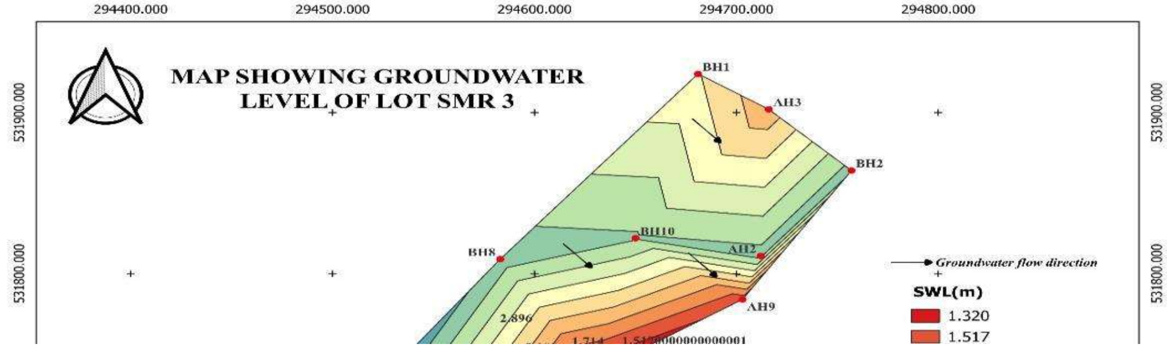


Fig 3: Map showing Groundwater elevation

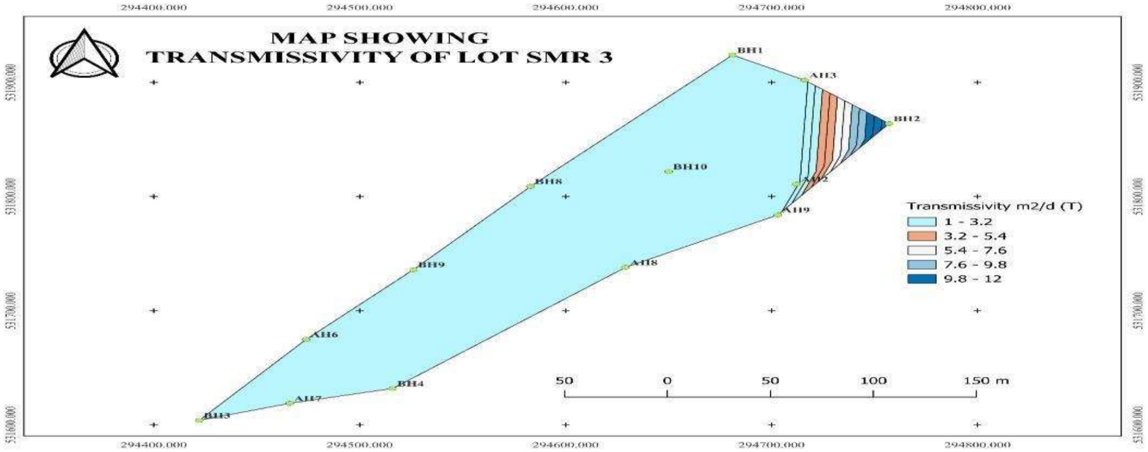


Fig 4: Spatial variation in aquifer transmissivity

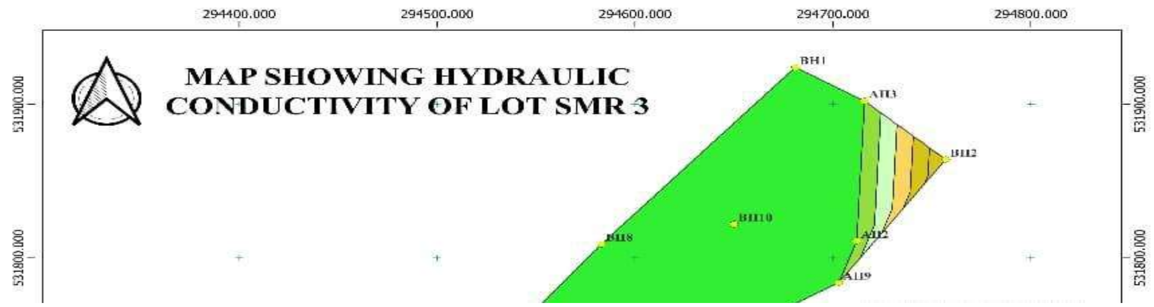


Fig. 5: Spatial Variation in Aquifer hydraulic conductivity (m/day)

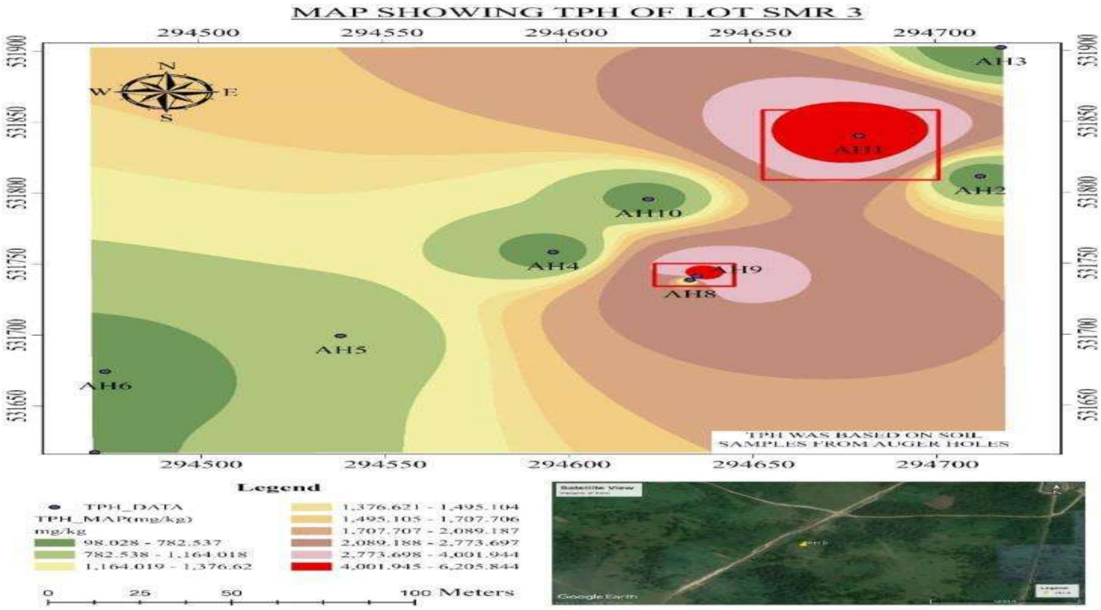


Fig. 6: Map showing the TPH level

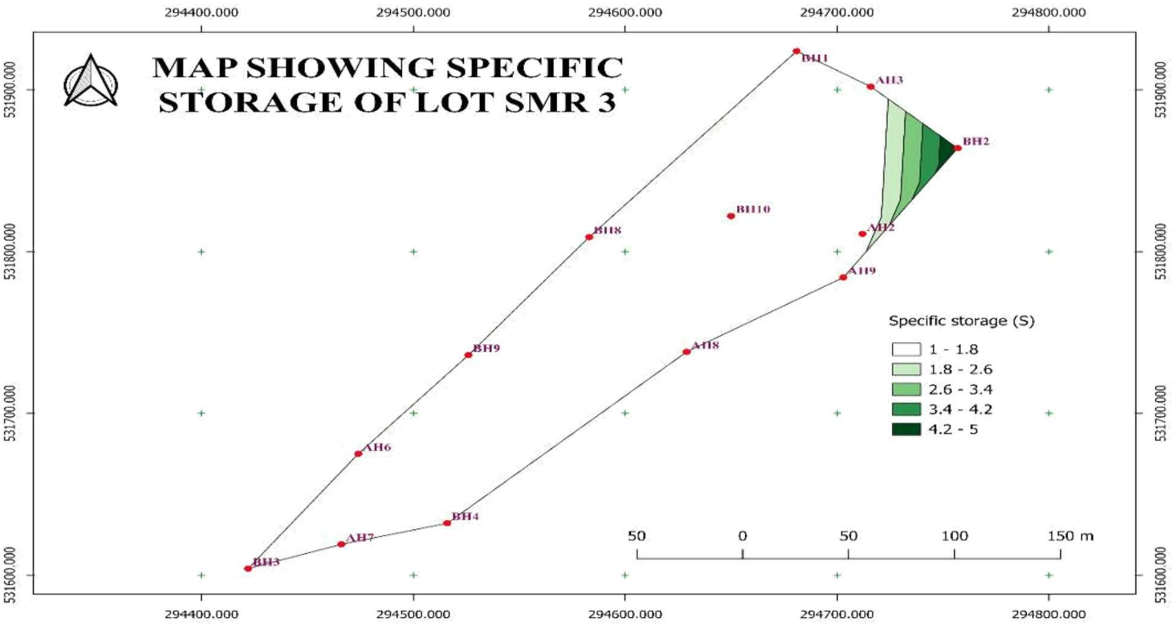


Fig. 7: Spatial Variation in Specific Storage

Spatial Distribution of TPH in Soil Samples

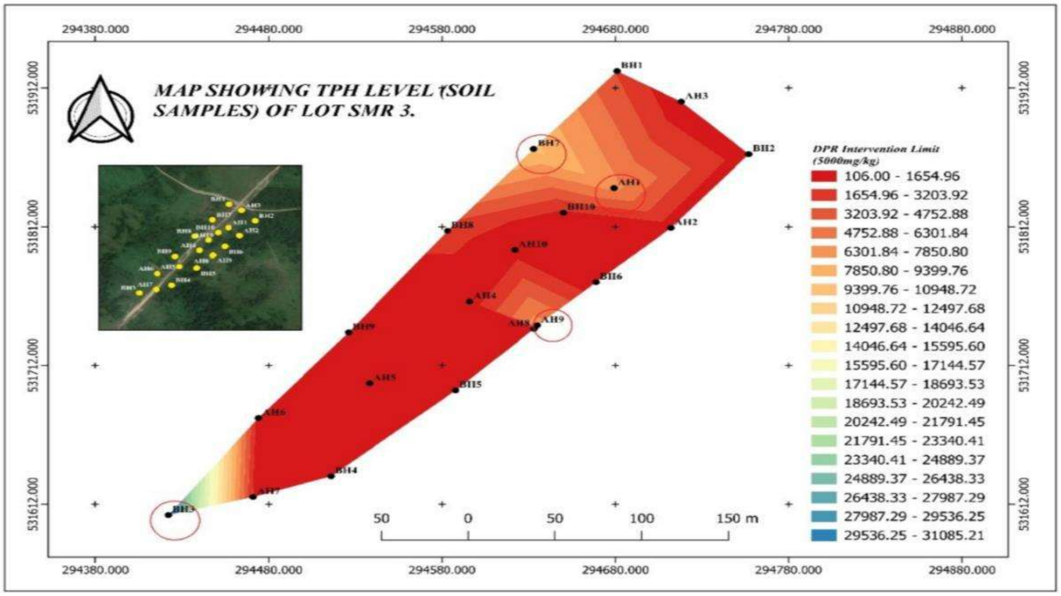


Fig. 8: Map showing the TPH in soil samples

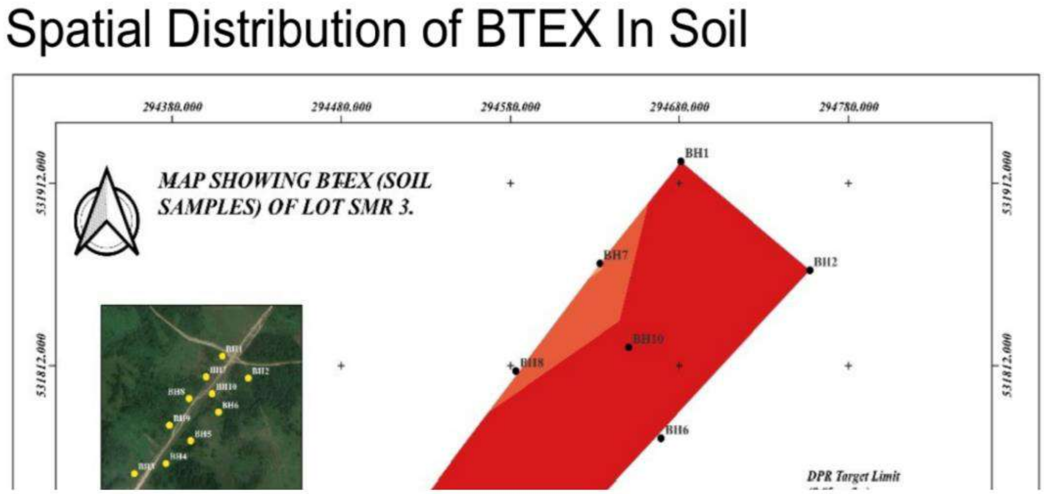

Spatial Distribution of BTEX In Soil

Fig 9: Map showing the Spatial Distribution of BTEX in Soil

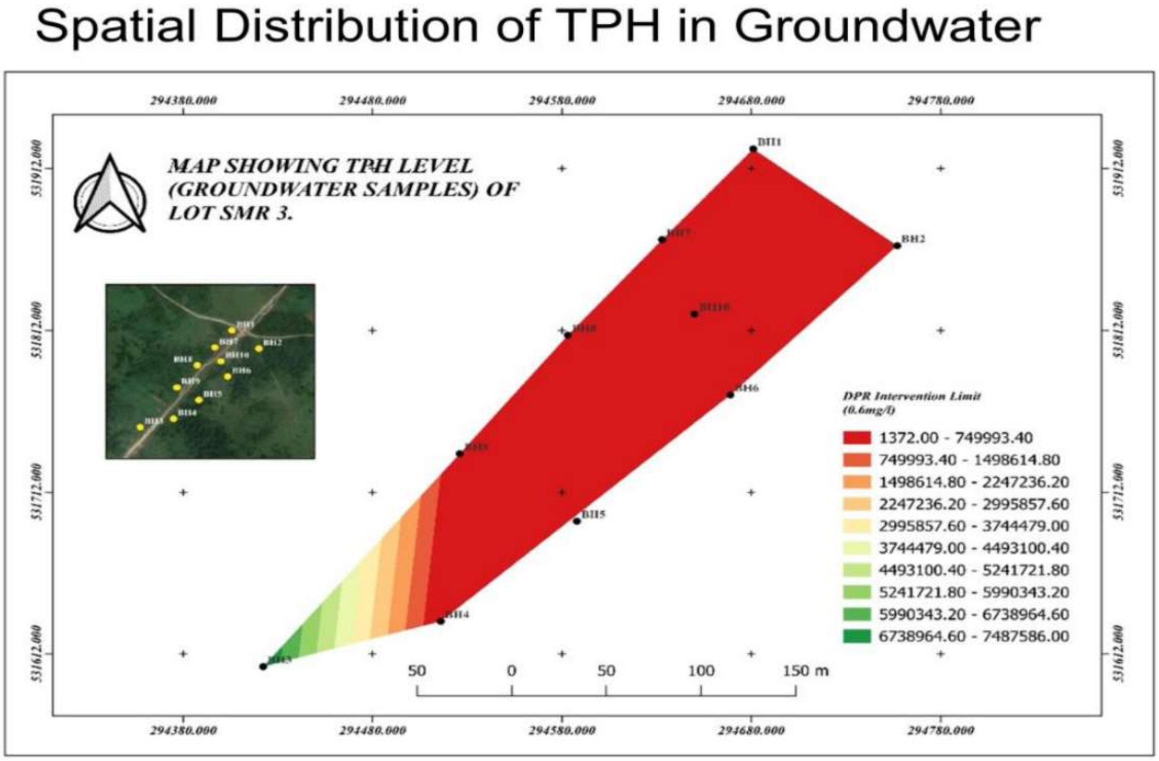

Spatial Distribution of TPH in Groundwater

Fig 10: Map showing the Spatial Distribution of TPH in Groundwater

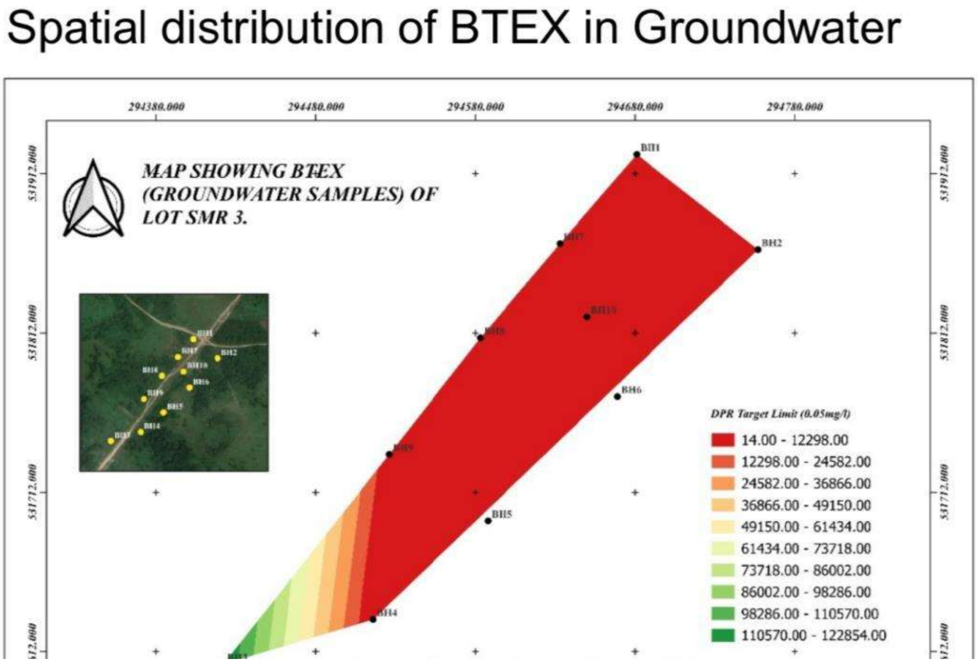
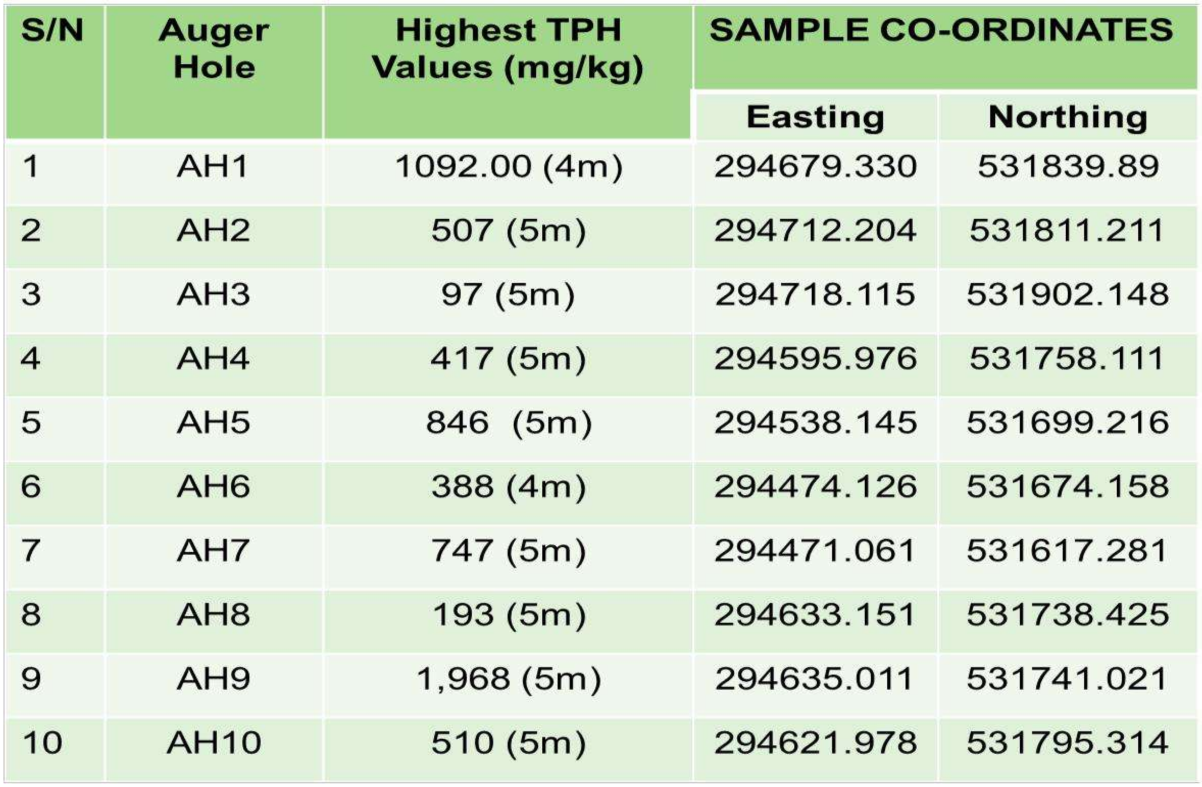


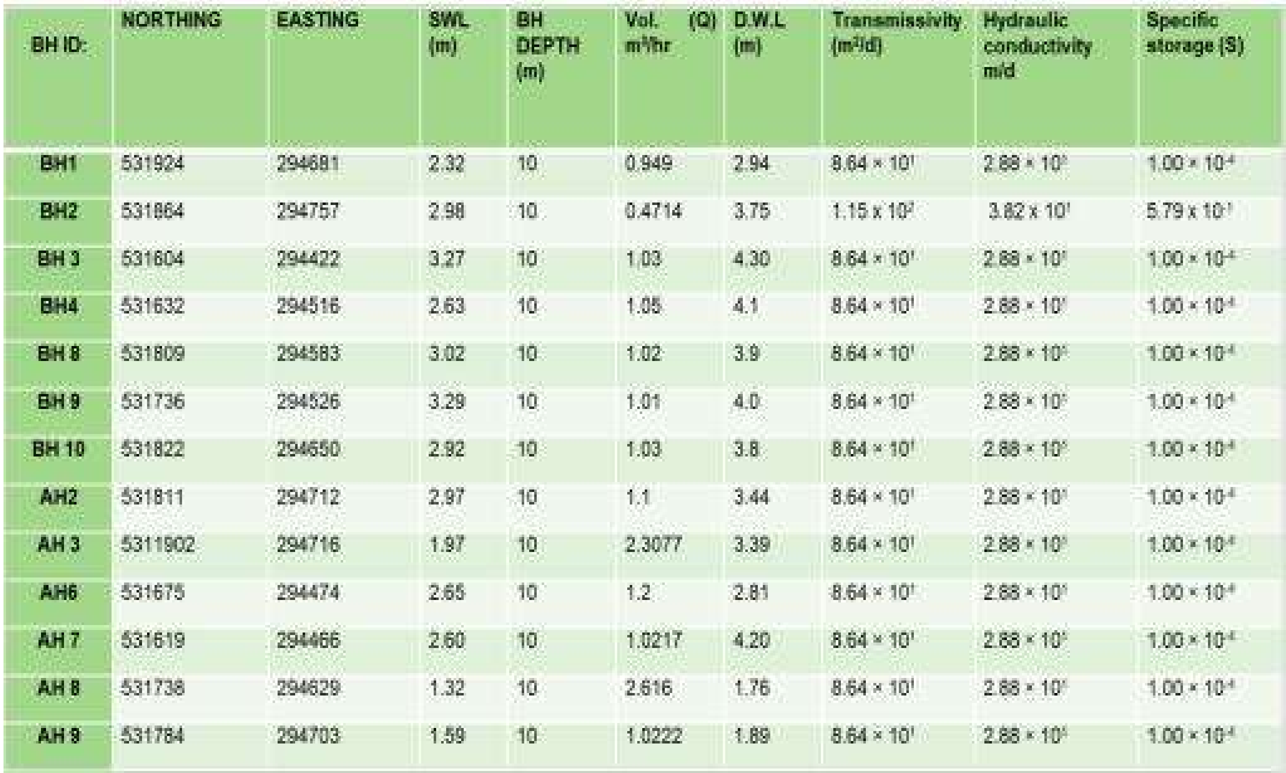
Fig. 11: Map showing the Spatial Distribution of TPH in Groundwater

Table 1: Soil test results from Augor holes



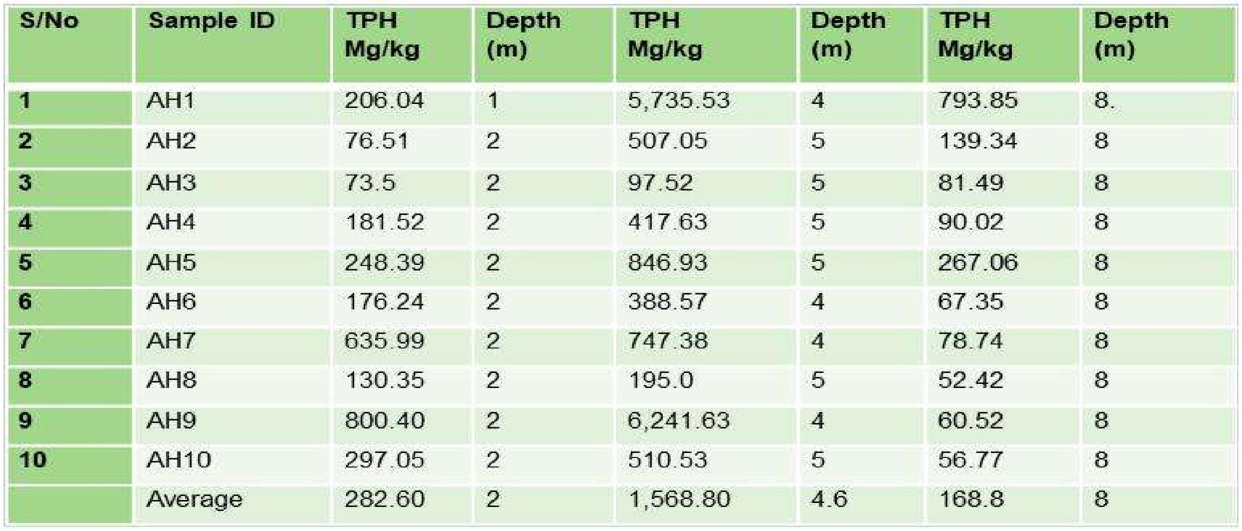
S/N	Auger Hole	Highest TPH Values (mg/kg)	SAMPLE CO-ORDINATES	
			Easting	Northing
1	AH1	1092.00 (4m)	294679.330	531839.89
2	AH2	507 (5m)	294712.204	531811.211
3	AH3	97 (5m)	294718.115	531902.148
4	AH4	417 (5m)	294595.976	531758.111
5	AH5	846 (5m)	294538.145	531699.216
6	AH6	388 (4m)	294474.126	531674.158
7	AH7	747 (5m)	294471.061	531617.281
8	AH8	193 (5m)	294633.151	531738.425
9	AH9	1,968 (5m)	294635.011	531741.021
10	AH10	510 (5m)	294621.978	531795.314

Table 2: Aquifer Hydraulic Properties



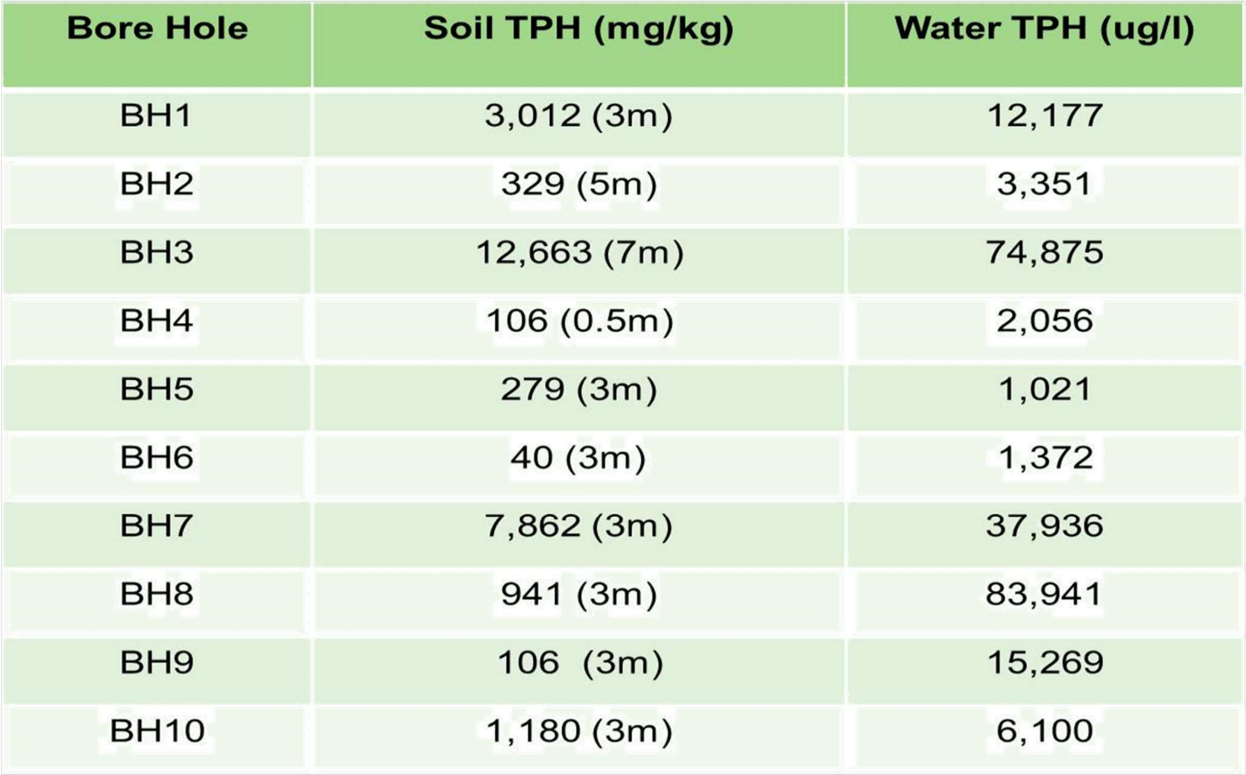
BH ID:	NORTHING	EASTING	SWL (m)	BH DEPTH (m)	Vol. (Q) m³/hr	D.W.L (m)	Transmissivity (m^2/d)	Hydraulic conductivity m/d	Specific storage (S)
BH1	531924	294681	2.32	10	0.949	2.94	8.64×10^1	2.88×10^1	1.00×10^{-4}
BH2	531864	294757	2.98	10	0.4714	3.75	1.15×10^2	3.82×10^1	5.79×10^{-1}
BH 3	531604	294422	3.27	10	1.03	4.30	8.64×10^1	2.88×10^1	1.00×10^{-4}
BH4	531632	294516	2.63	10	1.05	4.1	8.64×10^1	2.88×10^1	1.00×10^{-4}
BH 8	531809	294583	3.02	10	1.02	3.9	8.64×10^1	2.88×10^1	1.00×10^{-4}
BH 9	531736	294526	3.29	10	1.01	4.0	8.64×10^1	2.88×10^1	1.00×10^{-4}
BH 10	531822	294650	2.92	10	1.03	3.8	8.64×10^1	2.88×10^1	1.00×10^{-4}
AH2	531811	294712	2.97	10	1.1	3.44	8.64×10^1	2.88×10^1	1.00×10^{-4}
AH 3	5311902	294716	1.97	10	2.3077	3.39	8.64×10^1	2.88×10^1	1.00×10^{-4}
AH6	531675	294474	2.65	10	1.2	2.81	8.64×10^1	2.88×10^1	1.00×10^{-4}
AH 7	531619	294466	2.60	10	1.0217	4.20	8.64×10^1	2.88×10^1	1.00×10^{-4}
AH 8	531738	294629	1.32	10	2.616	1.76	8.64×10^1	2.88×10^1	1.00×10^{-4}
AH 9	531784	294703	1.59	10	1.0222	1.89	8.64×10^1	2.88×10^1	1.00×10^{-4}

Table 3:TPX and BTEX value in soil and groundwater



S/No	Sample ID	TPH Mg/kg	Depth (m)	TPH Mg/kg	Depth (m)	TPH Mg/kg	Depth (m)
1	AH1	206.04	1	5,735.53	4	793.85	8.
2	AH2	76.51	2	507.05	5	139.34	8
3	AH3	73.5	2	97.52	5	81.49	8
4	AH4	181.52	2	417.63	5	90.02	8
5	AH5	248.39	2	846.93	5	267.06	8
6	AH6	176.24	2	388.57	4	67.35	8
7	AH7	635.99	2	747.38	4	78.74	8
8	AH8	130.35	2	195.0	5	52.42	8
9	AH9	800.40	2	6,241.63	4	60.52	8
10	AH10	297.05	2	510.53	5	56.77	8
	Average	282.60	2	1,568.80	4.6	168.8	8

Table 4: Impact depth of Soil and water from Borehole



Bore Hole	Soil TPH (mg/kg)	Water TPH (ug/l)
BH1	3,012 (3m)	12,177
BH2	329 (5m)	3,351
BH3	12,663 (7m)	74,875
BH4	106 (0.5m)	2,056
BH5	279 (3m)	1,021
BH6	40 (3m)	1,372
BH7	7,862 (3m)	37,936
BH8	941 (3m)	83,941
BH9	106 (3m)	15,269
BH10	1,180 (3m)	6,100

DISCUSSION

The Digital Elevation Model depicted through the Topographic survey map (Fig. 2) shows the water flow direction on the study area's surface. This indicates that the water flows south-easterly in the study area. The hydrogeological configuration of the groundwater elevation corroborates this. Static water levels depicting groundwater elevation show a groundwater flow direction of south-east, as shown in Fig. 3. These maps represent the Earth's surface features, including the elevation and contour lines of the terrain. They provide a basis for understanding the surface elevation, which influences the recharge and flow of groundwater. The direction of groundwater flow is determined by the hydraulic gradient, which is the slope of the water table or potentiometric surface. Groundwater flows from areas of higher elevation and pressure to areas of lower elevation and pressure, following the path of least resistance. Topographic maps and grid levelling data help determine the hydraulic gradient, and hydrogeological studies provide insights into the permeability and porosity of the aquifer materials, which influence flow direction. Topographic maps provide the initial framework for understanding surface

elevation, grid levelling refines this data, hydrogeological studies offer insights into subsurface characteristics, and these elements help determine groundwater elevation and flow direction in an aquifer (Braun and Ramage, 2020) see Fig. 2 and 3.

The relationship between the spatial variation in aquifer transmissivity, groundwater elevation, flow direction, and the transport of oil pollution and contaminants within soil and groundwater involves several key aspects: Aquifer transmissivity (T) is a measure of how much water can be transmitted horizontally through a unit width of the aquifer. It is the product of the aquifer's hydraulic conductivity (K) of the aquifer material and the saturated thickness (b). See Fig.4 and

5. The test holes have the same aquifer depth, aquifer thickness and tend to possess the same aquifer characteristics.

Hydraulic conductivity values range between 2.88 × 101 m/day to 3.82 X 101 m/day, classifying as fast and depicting medium sand aquifer medium-coarse materials that can easily transmit groundwater flow and aid contaminant flow in the aquifer system. The groundwater flow velocity was determined as a product of the hydraulic gradient and conductivity. An average value of 0.634m/s was obtained for the site.

Transmissivity can vary spatially due to changes in the geological materials, aquifer thickness, and other factors. High transmissivity indicates regions where water (and contaminants) can move more efficiently, while low transmissivity indicates restricted flow. The water table or potentiometric surface often represents the groundwater level in an aquifer. Groundwater flows from areas of high elevation (high hydraulic head) to low elevation (low hydraulic head). The flow direction is influenced by the hydraulic gradient, which is the slope of the water table or potentiometric surface (Maliva, 2016), The spatial variation diagram is shown in Figure 4. Aquifer transmissivity indicates a range of 8.64 × 101 – 1.15 × 101 m2/d in all the sampled locations. Spatial variation in aquifer transmissivity shows an increase in a north-easterly direction (Fig. 4), which is corroborated by the trend of variation of specific storage of the subsurface aquifers shown in Fig. 7 and Table 2

The direction of groundwater flow determines the path contaminants will take. Contaminants will move toward groundwater flow, potentially impacting wells, springs, and other water resources downstream.

Changes in the flow direction due to seasonal variations, pumping, or other factors can alter the contaminant pathways. Areas with high transmissivity will have more significant and faster groundwater flow, enhancing the spread of contaminants in the direction of the hydraulic

gradient. Flow direction, influenced by the topography and hydraulic gradient, dictates the primary pathways for contaminant transport. Groundwater elevation can affect the saturation of soil and the direction of contaminant movement. Higher elevations typically contribute to recharge areas, while lower elevations can discharge areas where contaminants might emerge. (Gonçalves, 2024)

Seasonal fluctuations in groundwater elevation can change contaminant transport patterns, potentially spreading pollutants differently throughout the year. High transmissivity aquifers facilitate excellent contaminant dispersion due to increased flow velocities and broader pathways (Sethi & Molfetta, 2019)

Low transmissivity aquifers might limit dispersion, resulting in higher concentrations of contaminants in localized areas. Soil properties, such as porosity and permeability, also play a critical role in contaminant transport. Highly permeable soils can enhance the movement of contaminants, while less permeable soils can act as barriers. In summary, the spatial variation in aquifer transmissivity, groundwater elevation, and flow direction are critical factors in understanding the transport of oil pollution and other contaminants within soil and groundwater. High transmissivity areas facilitate faster and broader dispersion of pollutants, while flow direction, dictated by the hydraulic gradient, determines the contaminant pathways. Groundwater elevation and soil properties further influence the movement and concentration of contaminants, impacting both the extent and severity of pollution. Effective oil pollution management and remediation require a comprehensive understanding of these interrelated factors. (Sethi and Molfetta, 2019)

The relationship between aquifer transmissivity, specific storage, and contaminant transport is complex and interdependent. High transmissivity facilitates faster and broader contaminant dispersion, while high specific storage can buffer changes in contaminant concentrations. Low transmissivity restricts contaminant movement, potentially leading to higher local concentrations, and low specific storage can cause rapid contaminant release with changes in groundwater levels. Understanding these relationships is critical for predicting contaminant behaviour, designing remediation strategies, and assessing contamination risks.

Hydrogeological factors, including groundwater elevation, topography, aquifer transmissivity, specific storage, and hydraulic conductivity, govern the transport of TPH and BTEX contaminants in soil and groundwater. High transmissivity and hydraulic conductivity facilitate rapid contaminant spread, while specific storage influences the rate and extent of contaminant.

release. Groundwater elevation and topography determine the flow directions and pathways for contaminant migration. Understanding these interrelationships is crucial for assessing contamination risks and designing effective remediation strategies.

Integrating all the results, Augur points 1,5,7and 9 have higher TPH in soil, see Fig. 6 while Borehole (BH) 3,7 and 9 have higher TPH and BTEX values in the groundwater, see Table 3, Fig 6, 8.9.10 and 11. By applying GIS to this analysis, I have developed a spatial model to predict the movement and spread of contamination plumes by integrating hydraulic conductivity, specific storage, and transmissivity with contaminant migration patterns. This GIS-based approach supports informed decision-making for remediation strategies by Prioritizing areas for immediate intervention based on contaminant concentration and potential migration pathways and optimizing the placement of monitoring wells for effective contaminant plume tracking and evaluating the suitability of different remediation techniques based on site-specific characteristics.

CONCLUSION

The findings of this study will be valuable for environmental agencies, remediation contractors, and landowners dealing with contaminated soil and groundwater. Integrating spatial data within a GIS platform provides a powerful tool for comprehensive site assessment, risk evaluation, and the development of effective Remediation Action Plans (RAP).

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