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Research Article

GIS Analysis of Organo-Contaminants and Iron Linked to Groundwater and Sediment at Boreholes in Aluu, Delta Region, Nigeria

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Abstract: The source of high fever and gastrointestinal disorders in humans after groundwater consumption in this part of the delta region in Nigeria is unknown. Spatial data engineered by GIS interpretation of organo-contaminants bound to groundwater and borehole sediment provides baseline data and information on the impact of iron and organo-contaminants on groundwater quality in Aluu. A total of 10 water and sediment samples were collected at a depth of 45 m from 10 boreholes within Aluu and analyzed in triplicate. The choice of 45 m implies the occurrence of sediments bearing groundwater for a deep well. A particle size analyzer was used to perform particle size analyses of the air-dried sediments. The American Public Health Association Method (APHA) was used to perform the chemical analysis of the water samples. Here, a liquid-liquid extraction procedure was conducted on the samples using 30 mL dichloromethane (DCM) as the extraction agent. The results were subjected to statistical validation, spatial data and GIS analysis. The textural characteristics possessed a mean grain size from fine sand (2.03) to medium sand (4.3), poorly sorted of 1.45 to 2.1, skewness of near-symmetrical (0.02), meso-kurtic kurtosis of 0.5 to very platy-kurtic of 2.09. Total petroleum hydrocarbon was 0.033 mg/L to 0.88 mg/L, and total hydrocarbon content and iron were 1.65 mg/L to 3.41 mg/L, and 2.98 mg/L-0.48 mg/L respectively. The results of these contaminants bound to sediments and water were above the acceptable limits of the World Health Organization. The ingress of contaminants into the groundwater was significantly controlled by the characteristics of the borehole sediment.

Keywords**:** contaminant indicators, GIS, sediment, organo-contaminant, Niger Delta, total petroleum hydrocarbon, total hydrocarbon content, groundwater

1. Introduction

The concern of residents of Aluu in recent times is the damage to the environment and human health caused by the occurrence of oil spills and migration of organo-contaminants into water courses [1-4]. Water is essential to the sustenance of life in Aluu and access to safe drinking water is crucial for the human health and well-being of this community [5]. The concerns with the state of water in Aluu stem from the high fever and gastrointestinal disorders recorded in the community. Therefore, the impacts of water pollution on humans and the ecosystem coupled with the cost of drinking water treatment has provided a thought-provoking investigation on the study of the spatial data patterns of specific contaminants related to hydrocarbon. The spatial data-GIS model remains a useful tool in water quality

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monitoring. This study is not intended to address all possible water pollutants present in Aluu. Doing so, amounts to a wild investigation of this problem without experimental and other investigation limits; which is deeply expensive.

Water and soil play a crucial role in the migration of contaminants in the food chain. Migration of the contaminant to an aquifer is a function of the mineralogical and textural characteristics of the sediment [1-7]. The highly clayey soil impedes the migration of contaminants and may act as a barrier system. The highly porous and permeable sediment enhances the migration of contaminants into groundwater [8-9]. Iron is a recurring contaminant in groundwater in the Delta region of Nigeria. The occurrence of iron in this region is in two forms, namely in the ferrous and oxidation states. In these forms, they readily associate and dissociate to form complexes in the redox processes; thereby complexing the groundwater quality [10].

Organic contaminants such as total petroleum hydrocarbon (TPH) and total hydrocarbon content (THC) in groundwater in this region are sourced from a crude oil spill. Other sources of hydrocarbon contaminants include polyaromatic hydrocarbons; which constitute a component of the chiral pollutants [11]. Organo-contaminants occur in two states, namely syngenetic, that is, contaminants introduced when sediments are formed and post-syngenetic, that is, contaminants introduced after sediments are formed [12-13]. Either way, organo-contaminant ingress into groundwater is aligned with the textural characteristics of the aquifer material. A highly clayey impervious material slows down the transport of organo-contaminants and acts as a geochemical barrier system. On the other hand, a highly sandy porous and permeable material promotes organo-contaminant transport into the groundwater [14].

Organo-contaminants are the products of anthropogenic activities, including the discharge of waste and petroleum products into water bodies [8-9]. Iron is a recurring contaminant in groundwater found in the delta of River Niger. Organo-contaminants in groundwater in this region are sourced by hydrocarbon in the form of total petroleum hydrocarbon and total hydrocarbon content [9, 12] These organo-contaminants above acceptable limits are harmful to the ecosystem and human health [15]. The presence of a total hydrocarbon content and total petroleum hydrocarbon in drinking water causes a high fever and gastrointestinal disorders [16-18].

Spatial data distribution maps engineered by GIS techniques provide spatial information in tracking the correlation between groundwater quality and borehole sediment characteristics [1, 19]. Spatial data and GIS interpretation provide an understanding of the distribution of contaminants in water and sediment on the chemical and physical properties. The data provides information for regulatory agencies to align with the point and areal source of contaminants within the area for comparative analysis. A spatial data set acts as a baseline for the environmental monitoring of hydrodynamic shifts over time [20-23].

An understanding of the chemical and physical setup of the aquifer material is a prerequisite to information about the transport of organo-contaminants into the aquifer [24]. The grain size distribution, orientation, and cementation are critical sediment characteristics [25-26]. Embedded in these characteristics are parameters of interest such as the mean sorting, skewness and kurtosis [27-28]. In this study, spatial distribution maps have been deployed to provide insight into the impact of borehole sediment characteristics in the ingress of contaminants into groundwater. The novelty of this work has been established and is that hydrocarbon contamination has been observed in frequently used deep wells in Aluu. This contamination is linked to the frequent high fever gastrointestinal disorders in Aluu residents who consumed the well water.

2. Materials and methods

2.1 *Study area and geology*

The Study Area Aluu (Figure 1) is located at the out sketch of the Port-Harcourt metropolitan area in the delta region of Nigeria. The area is within a Latitude of 4.933184 and a Longitude of 6.942646 of the coastal plain of the delta region in Nigeria. The geomorphic delta hosts the geological Benin formation, the Agbada Formation and the Akata formation. The water resources in the region are dominated by distributaries to the River Niger, which empties into the Atlantic Ocean; located on the southern flank of Aluu. Aluu is geomorphologically a low-lying terrain below sea level; elevated to 40 m in the northern section. The low-lying terrain is dominated by perennial flooding which is capacitated by a wetland with an annual rainfall of 2,000-3,000 mm [29]. Excessive rainfall is a characteristic of the tropical rainforest belt of Nigeria. This scenario improves the entry of organo-contaminants into groundwater by infiltration (20).

The wells are located in the Benin Formation, which is overlain by a lateritic aquitard [29-31].

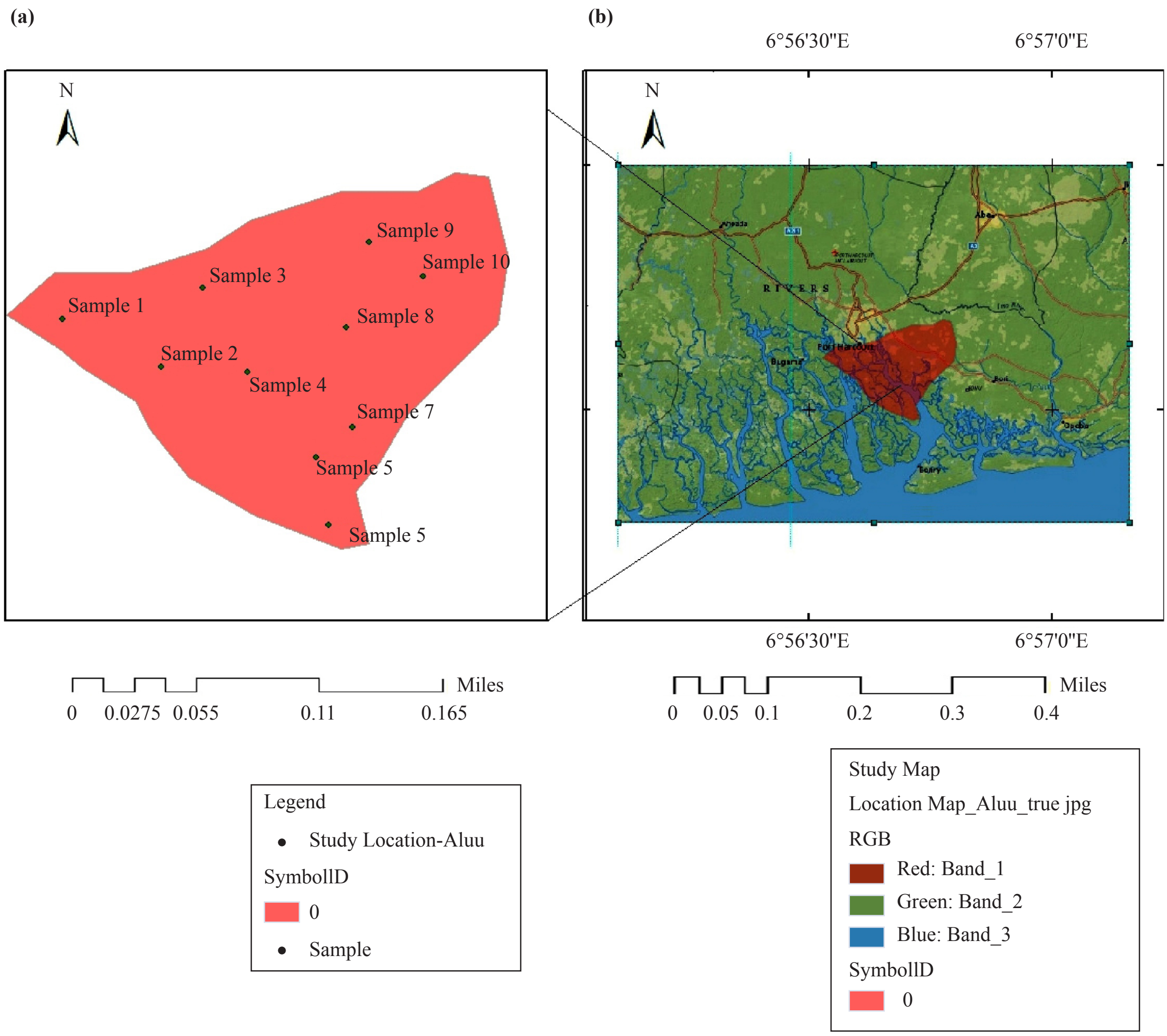


Figure 1. a) Location and b) study map of Aluu

2.2 *Scope and limitations of the study*

The quality of groundwater is influenced by the infiltration of contaminants from the surface environment to the subsurface. There are several parameters listed by the World Health Organization which influence the quality of groundwater. Let it be known that this study is not intended to exhaust the list provided by international and regional agencies. Rather, the specific issue of groundwater contamination by hydrocarbon pollutants in the study area has been a concern of Aluu residents. It was an attempt to satisfy their curiosity and request that led to the investigation of hydrocarbon ingress into the most widely used wells in Aluu.

The quality of surface water, especially river basins and streams, is controlled by seasonal variations as reported by [32]. However, the preliminary results of the deep-well water study in Aluu do not reflect statistically significant changes in groundwater quality with changing seasons. This scenario has been reported by [33] for groundwater samples studied during four different seasons.

2.3 *Sample collection and analytical techniques*

A total of 10 water and 10 sediment samples were collected from 10 wells at a depth of 45 m and analyzed in triplicate for organo-contaminant characteristics. The selection of the borewells followed the design provided by [34]. In this design, the selection of boreholes for groundwater quality investigation was random and was based on the frequent use of the borehole for water supply. The sample collections were done in triplicate in a standard field format. A 45 m depth was chosen for deep wells because shallow wells of 18.6 m are ordinarily prone to greater contaminant ingress. To prevent photo-oxidation, the extracted sediment samples were tightly sealed in a black polythene container and the extracted water was stored in sample bottles. For the determination of pH, total petroleum hydrocarbon, total hydrocarbon content and iron in groundwater, the water in the core samples were drained for 24 hours in sample bottles and sealed for laboratory analysis. The water samples were subjected to chemical analyzes for organo-contaminants and pH as an organo-contaminant indicator. The American Public Health Association (35) Method (APHA) was followed to perform the chemical analysis of the water samples. Here, sediment samples were analyzed following the liquid-liquid extraction procedure. For a start, 30 mL of dichloromethane (DCM) was used for extraction.

2.4 *Particle size and experimental studies*

At the end of the water extraction, the air-dried and sieved sediments were deployed for size analysis of particle. For particle size analysis, sediment samples were air-dried and transferred to a Gilson ASTM test sieve particle size analyzer (Model SS-34, United Kingdom) for segregation into fractions [36]. Procedurally, extracted sediment and water samples were deployed for analysis of chemical and physical characteristics. The analyses included pH, TPH, THC and iron (Fe). For pH, the required standards were prepared and used in the measurement. Standard suspensions required were prepared and used to analyze pH (Orion Model 290 pH meter, United Kingdom).

For TPH resolution, water extracted in a 1L flask was transferred to a 500 mL funnel of separation. An extraction solvent of 1 M dichloromethane of 50 mL was used. The content was shaken strongly for 5 mins and allowed to settle for the organic layer to separate. The organic layer was mixed with 5 g of anhydrous sodium sulfate and made up to 250 mL. This extraction was repeated three times and the concentrate made up to 10 mL was evaporated at room temperature. The concentrated extract concentrate was oven-dried to dryness at 110 °C to compute TPH.

For THC determination, water extracted in a 1L flask was transferred into a 500 mL funnel of separation. Consequently, 5 mL of 1 M sulfuric acid was used for acidification and the content reacted for 3 mins with 25 mL of n-hexane. The organo-layer was allowed to settle out of the solution. The content was extracted into a 250 mL timed distillation flask and deployed to a reflux condenser attached to it. The reflux technique was applied to generate 10 mL. The THC was computed using a pre-weighted flask shortly after the solvent was evaporated to dryness. All analyses were triplicated in a standard laboratory format as provided [4].

For Fe determination using (Perkin Elmer AAS PinAAcle 9, Canada) (37), The extracted water samples were digested in a fume hood using 1 M nitric acid solution. Blanks and standard solutions of 0.5 mg/L, 1 mg/L, 5 mg/L and 10 mg/L were prepared and used for AAS runs. These water samples were filtered and made up to 100 mL and deployed to the AAS for the analysis of total Fe [37]. Sigma Aldrich United Kingdom provided high-quality consumables for the analyses [38].

2.5 *Spatial data and GIS analysis*

For the preparation of the location map of Aluu, a shapefile was prepared using Google Map Pro. The GPS coordinates used for the exercise were obtained from fieldwork. The National Geographic World Map is the base map [19]. For Spatial distribution map preparation, an Excel data sheet of the parameters was prepared and converted to GIS spatial GIS tables. These tables were saved as shapefiles for the inverse distance-weighted interpolation in 3D deployment and raster analysis [19].

3. Results

3.1 *Scope and limitations of the study*

Borehole sediment assessed for the mean, sorting coefficient, skewness and kurtosis, provided a range of results (Table 1). The sediment is described as medium to fine sand (non-segregated as a sand fraction), poorly sorted, near-symmetrical to asymmetrical in skewness, and meso-kurtic to platy-kurtic in kurtosis. The textural characteristics of the sand fractions using equations 1-4 are mean (4.90-1.20), sorting coefficient (2.30-1.45), skewness (-0.62-0.57), and kurtosis (2.09-0.51)

$$\text{The mean was calculated using; Mean } (\text{GM}) = \frac{\phi 16 + \phi 50 + \phi 84}{3} \tag{1}$$

$$\text{The sorting coefficient D} = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 + \phi 5}{6.6} \tag{2}$$

$$\text{Skewness } (\text{GSK}) = \frac{\phi 84 + \phi 16 - 2(\phi 50)}{2(\phi 84 - \phi 16)} + \frac{\phi 95 + \phi 5 - 2(\phi 50)}{2(\phi 95 - \phi 5)} \tag{3}$$

$$\text{Kurtosis } (\text{K}) = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)} \tag{4}$$

Table 1. Textural characteristics of Aluu Non-segregated Sediment

Borehole Number	Borehole depth (m)	Mean (GM)	Sorting coefficient (GSD)	Skewness (GSK)	Kurtosis (K)	Borehole Characteristics Particle Sizes
1	45	4.3	1.70	0.57	1.035	Sand fraction
2	45	4.43	1.51	-0.62	0.96	Sand fraction
3	45	2.86	2.30	-0.04	0.49	Sand fraction
4	45	3.23	2.17	0.032	0.57	Sand fraction
5	45	4.3	1.94	-0.7	0.9	Sand fraction
6	45	4.9	1.45	-0.4	2.09	Sand fraction
7	45	3.96	1.97	-0.6	0.83	Sand fraction
8	45	2.97	2.07	0.02	0.63	Sand fraction
9	45	1.20	2.1	0.17	1.10	Sand fraction
10	45	2.03	2.1	0.55	0.51	Sand fraction

3.2 *Statistical validation of textural and chemical characteristics*

The results and statistics deployed to analyze particle size control of contaminants are provided (Table 2 and Table 3). There is an observation that 0.44 mg/L and 0.78 mg/L of TPH are domiciled in the medium and sand fractions with a deviation of 0.094 and 0.13 mg/L respectively. Again, these groups were affected by 5 samples with a mean difference of 0.036 mg/L between the groups. The difference indicates that the sand fraction possesses a 0.036 higher concentration than the medium sand fraction. Therefore, the result validates the sample mean at a 95% confidence level.

Table 2. Descriptive statistics of TPH, THC and Fe contaminants in sand fractions of the boreholes

	Group Statistics				
	Grain sizes " Medium sand" and "Fine sand"	N	Mean	Std. Deviation	Std. Error Mean
TPH Contaminant concentration (mg/L)	Medium sand	5	0.31	0.094	0.042
	Fine sand	5	0.26	0.13	0.058
THC Contaminant concentration (mg/L)	Medium sand	5	2.83	0.27	0.12
	Fine sand	5	2.35	0.65	0.29
Fe Contaminant Concentration (mg/L)	Medium sand	5	0.88	0.12	0.10
	Fine sand	5	0.96	0.13	0.11

Table 3. Physicochemical characteristics of borehole sediment and groundwater

Borehole Number	Media	Borehole GPS Readings (Decimal Degrees)		Average of Parameters			
45 m Depth	45 m Depth	Latitude	Longitude	pH	TPH	THC	Fe
				Not Applicable	mg/L	mg/L	mg/L
1	Water	4.935068	6.942646	6.95 ± 0.02	0.17 ± 0.02	1.62 ± 0.02	0.42 ± 0.02
	Medium sand			6.63 ± 0.02	0.67 ± 0.02	2.48 ± 0.02	0.60 ± 0.02
	Fine Sand			6.86 ± 0.02	0.88 ± 0.02	2.86 ± 0.02	0.48 ± 0.02
2	Water	4.934633	6.943551	5.60 ± 0.02	0.45 ± 0.02	1.34 ± 0.02	0.45 ± 0.02
	Medium sand			7.63 ± 0.02	0.64 ± 0.02	3.41 ± 0.02	0.56 ± 0.02
	Fine Sand			6.95 ± 0.02	0.87 ± 0.02	2.75 ± 0.02	0.60 ± 0.02
3	Water	4.935352	6.943932	6.87 ± 0.02	0.28 ± 0.02	1.71 ± 0.03	0.45 ± 0.02
	Medium sand			7.02 ± 0.02	0.36 ± 0.02	3.06 ± 0.03	2.50 ± 0.02
	Fine Sand			6.92 ± 0.02	0.76 ± 0.02	2.35 ± 0.03	2.98 ± 0.02

Table 3. (cont.)

Borehole Number	Media	Borehole GPS Readings (Decimal Degrees)		Average of Parameters			
45 m Depth	45 m Depth	Latitude	Longitude	pH	TPH	THC	Fe
				Not Applicable	mg/L	mg/L	mg/L
4	Water	4.934585	6.94434	7.18 ± 0.02	0.096 ± 0.03	1.43 ± 0.02	0.65 ± 0.01
	Medium sand			7.02 ± 0.02	0.095 ± 0.03	1.87 ± 0.02	1.4 ± 0.01
	Fine Sand			6.92 ± 0.02	0.64 ± 0.03	1.65 ± 0.02	1.43 ± 0.01
5	Water	4.933806	6.944972	5.65 ± 0.02	0.033 ± 0.00	1.96 ± 0.01	0.45 ± 0.02
	Medium sand			6.83 ± 0.02	0.054 ± 0.00	2.44 ± 0.01	1.34 ± 0.02
	Fine Sand			6.8 ± 0.02	0.80 ± 0.01	3.34 ± 0.01	1.24 ± 0.02
6	Water	4.933184	6.945083	6.85 ± 0.02	0.053 ± 0.002	0.61 ± 0.02	1.88 ± 0.02
	Medium sand			7.82 ± 0.02	0.196 ± 0.02	0.84 ± 0.02	2.42 ± 0.02
	Fine Sand			7.6 ± 0.02	0.76 ± 0.02	0.78 ± 0.02	2.98 ± 0.02
7	Water	4.934078	6.945304	5.64 ± 0.01	0.54 ± 0.01	1.40 ± 0.01	1.42 ± 0.02
	Medium sand			8.05 ± 0.01	0.72 ± 0.01	0.13 ± 0.01	1.65 ± 0.02
	Fine Sand			7.86 ± 0.01	0.87 ± 0.01	0.14 ± 0.01	2.33 ± 0.02
8	Water	4.934992	6.945254	7.85 ± 0.01	0.1 ± 0.00	0.11 ± 0.02	1.05 ± 0.02
	Medium sand			7.82 ± 0.01	0.37 ± 0.01	0.124 ± 0.02	1.62 ± 0.02
	Fine Sand			7.60 ± 0.01	0.54 ± 0.01	1.10 ± 0.02	2.37 ± 0.02
9	Water	4.935779	6.945455	5.76 ± 0.02	0.50 ± 0.02	0.86 ± 0.02	1.34 ± 0.02
	Medium sand			5.44 ± 0.02	0.60 ± 0.02	1.66 ± 0.02	2.60 ± 0.02
	Fine Sand			5.35 ± 0.02	0.55 ± 0.02	2.80 ± 0.02	2.96 ± 0.02
10	Water	4.935464	6.945957	8.32 ± 0.02	0.66 ± 0.01	1.08 ± 0.03	1.24 ± 0.02
	Medium sand			8.05 ± 0.02	0.70 ± 0.01	1.84 ± 0.03	2.35 ± 0.05
	Fine Sand			7.86 ± 0.02	1.10 ± 0.01	2.00 ± 0.03	2.59 ± 0.02
(39) Acceptable limits for water and sediment				6.5-8.5	0.01-0.3 mg/L	0.01-0.3 mg/L	0.3 (water)-10 (sediment) mg/L

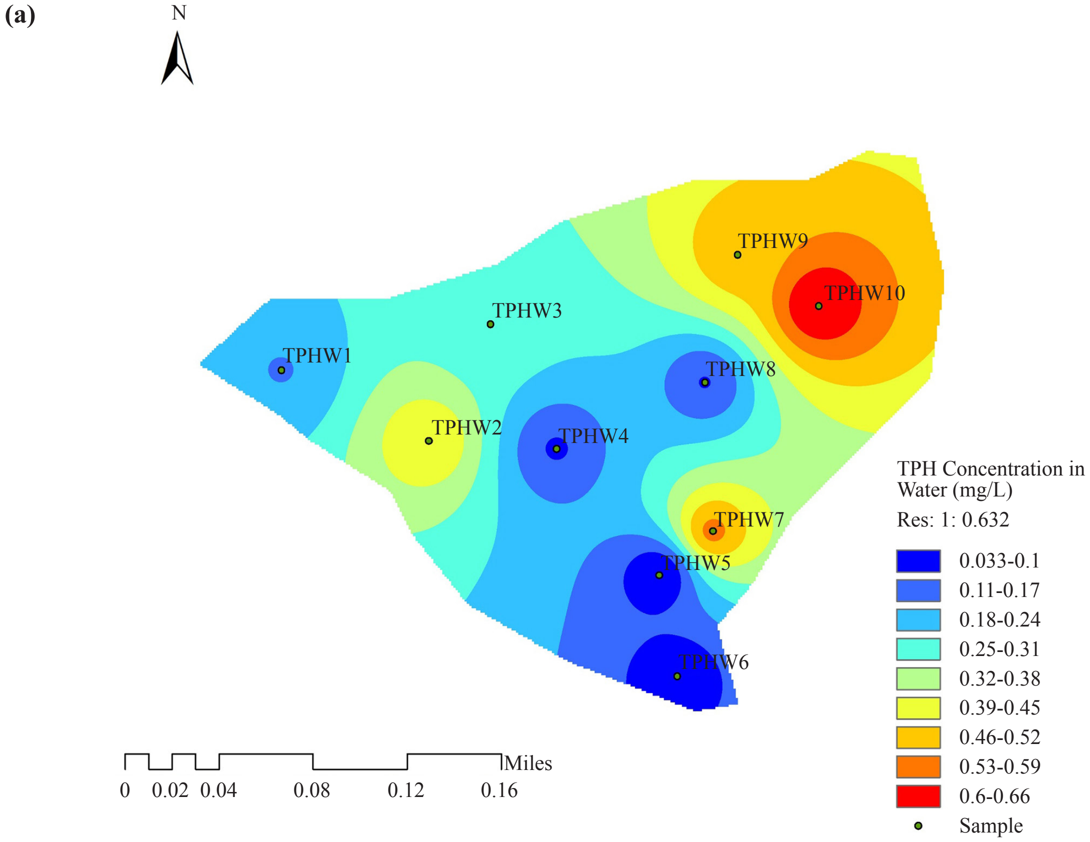
Source: Authors (2022)

The statistics of the t-test used to analyze the contaminants by the particle size of the sediment show that the mean concentration of THC engineered by the medium and fine sand fractions was 1.79 mg/L and 1.98 mg/L with a deviation of 0.27 mg/L and 0.65 mg/L respectively. These groups were affected by 5 samples. Therefore, a mean difference of 0.19 mg/L was observed between the medium and fine sand groups. This difference was dominated by THC with 0.19 mg/L. With a 95% confidence interval (CI), the t-test could suggest that the mean difference supports the validity of the sample means as true estimates of the population mean.

The mean Fe concentration engineered by medium and fine sand fractions was 0.88 mg/L and 0.99 mg/L with a deviation of 0.12 mg/L and 0.13 mg/L from the mean. Again, these groups were affected by 5 samples with a mean difference of 0.11 mg/L between the medium and fine sand groups. Therefore, the result validates the sample mean at a 95% confidence level.

There is a fluctuation in the values of the pH ranging from 7.63 in medium sand to 5.60 in water. The pH of the water ranges from 7.18 to 5.60. The TPH ranges from 0.97 mg/L in fine sand to 0.033 mg/L in water. The THC ranges from 3.41 in medium sand to 0.61 mg/L in water. The Fe content ranges from 2.98 mg/L in fine sand to 0.42 mg/L in water. in water. Therefore, fluctuation exists in all cases for the parameters investigated.

3.3 *Spatial distribution and GIS data analysis*



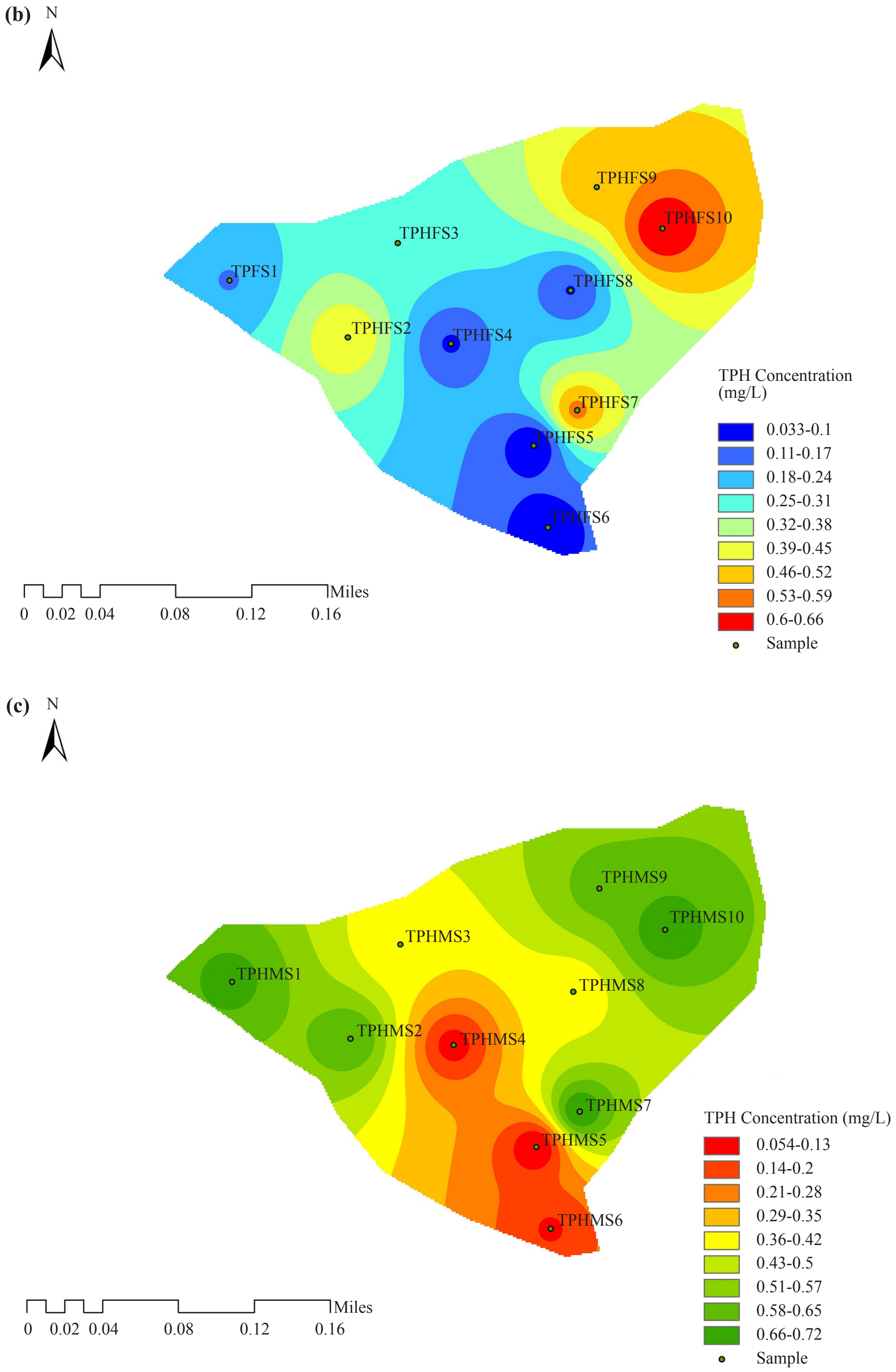
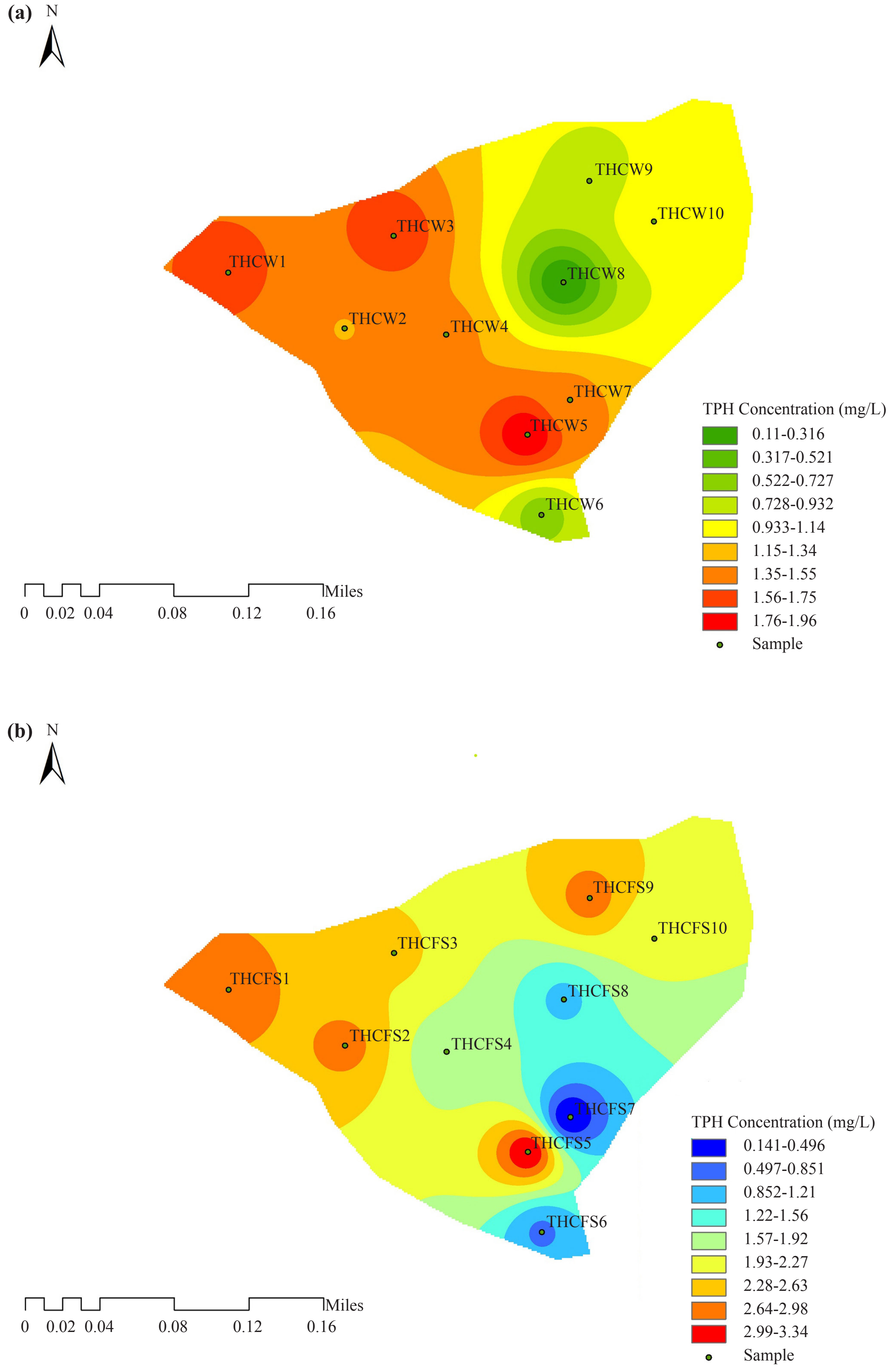


Figure 2. a) Spatial TPH data map for water in Aluu; b) Spatial TPH data map for fine sand in Aluu; c) Spatial TPH data map for medium sand in Aluu
Source: Authors (2022)


(a)
N
THCW1
THCW2
THCW3
THCW4
THCW5
THCW6
THCW7
THCW8
THCW9
THCW10
0 0.02 0.04 0.08 0.12 0.16 Miles
TPH Concentration (mg/L)
0.11-0.316
0.317-0.521
0.522-0.727
0.728-0.932
0.933-1.14
1.15-1.34
1.35-1.55
1.56-1.75
1.76-1.96
Sample
(b)
N
THCFS1
THCFS2
THCFS3
THCFS4
THCFS5
THCFS6
THCFS7
THCFS8
THCFS9
THCFS10
0 0.02 0.04 0.08 0.12 0.16 Miles
TPH Concentration (mg/L)
0.141-0.496
0.497-0.851
0.852-1.21
1.22-1.56
1.57-1.92
1.93-2.27
2.28-2.63
2.64-2.98
2.99-3.34
Sample

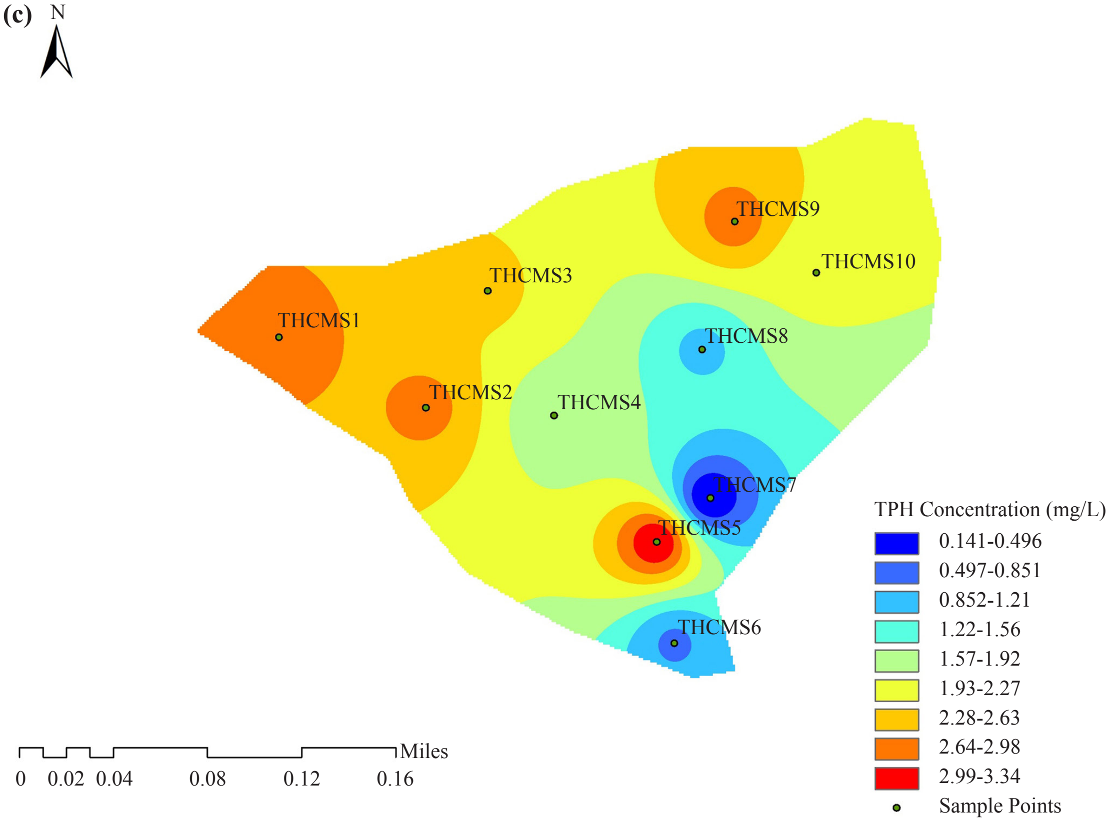
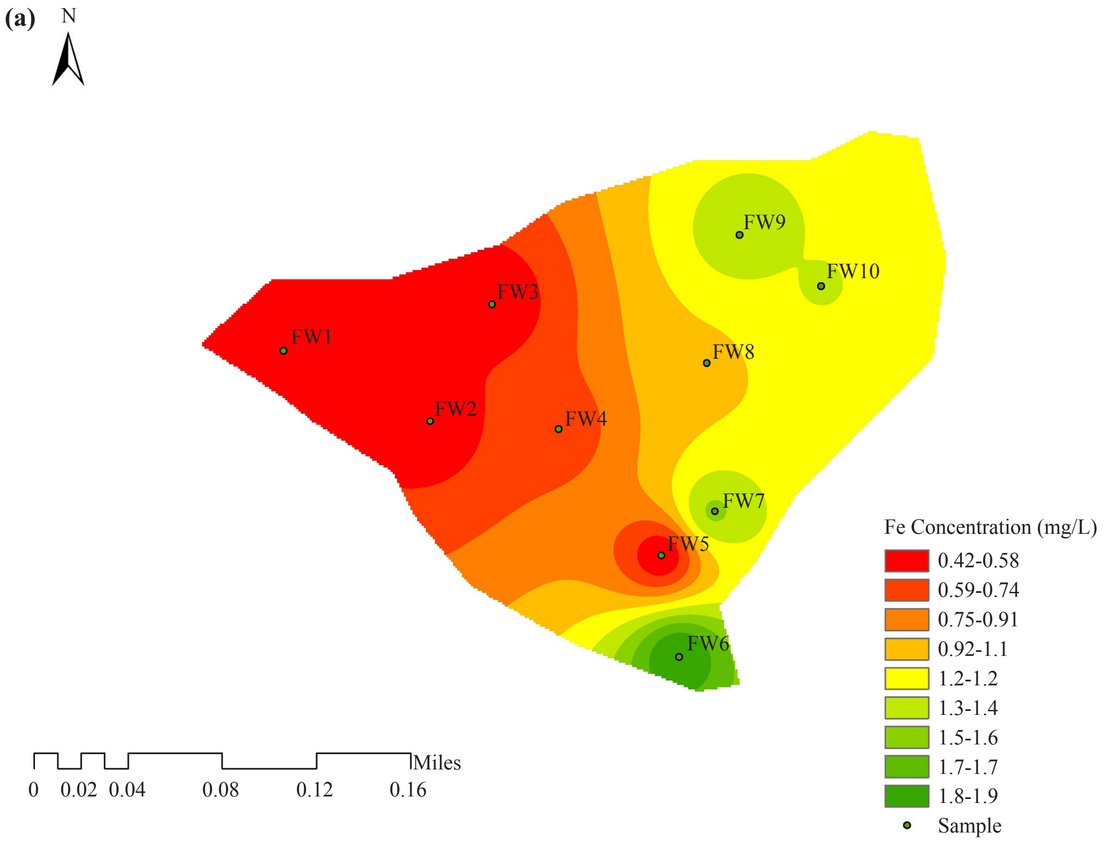
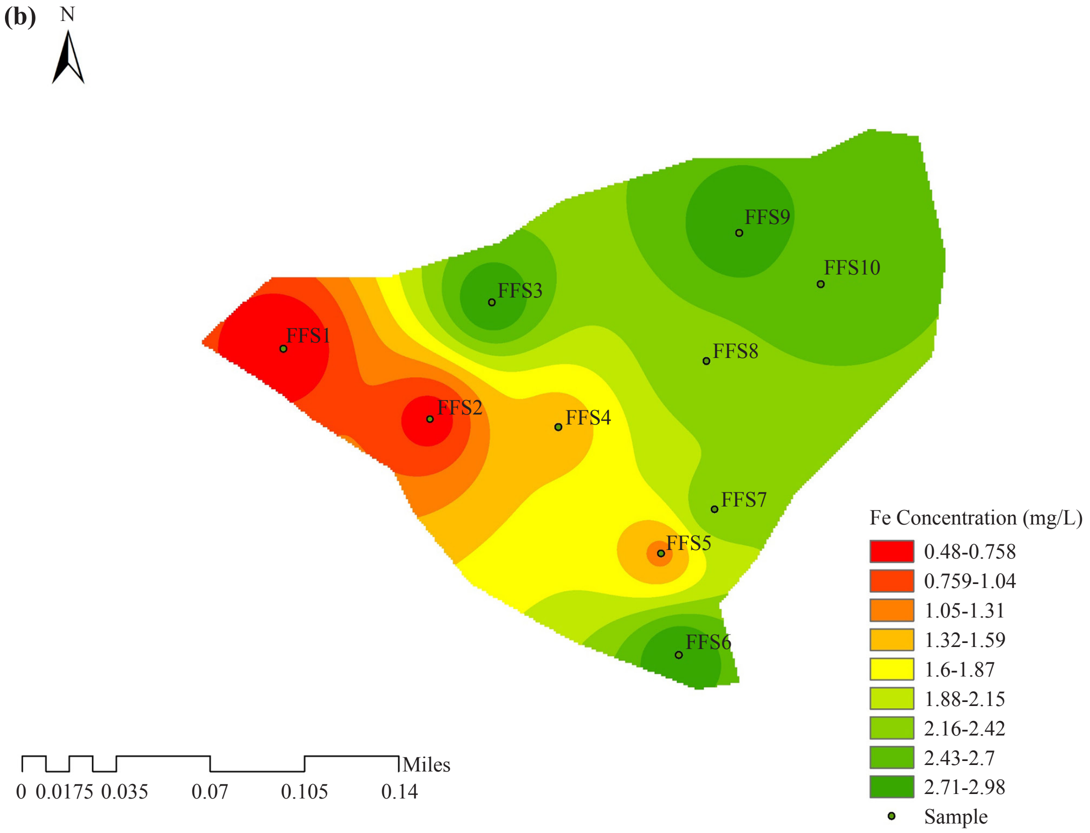


Figure 3. a) Spatial THC data map for water in Aluu; b) Spatial THC data map for fine sand in Aluu; c) Spatial THC data map for medium sand in Aluu

Source: Authors (2022)

Based on geographic location, the concentrations of TPH bound to water are highest (0.6-0.66 mg/L) in the north eastern portion of Aluu and lowest (0.033-0.1 mg/L) in the southern portion of the same (Figure 2a). Fine sand TPH is highest (1.1 mg/L) in the eastern North Aluu section, with the lowest concentration (0.54-0.6 mg/L) concentration occurring near these wells (Figure 2b). The TPH bound to medium sand dominated (0.66-0.72 mg/L) in the eastern, North Western and Western sections of Aluu (Figure 2c). The concentration of THC bound to groundwater was dominated (1.76-1.96 mg/L) in the northern west and southern sections of Aluu (Figure 3a). Also, the THC bound to fine sand occurs highest (2.99 mg/L-3.34 mg/L) in the Southern transect of Aluu compared to the lowest concentration (0.144 mg/L-0.48 mg/L) at the South Eastern section of the same (Figure 3b). It should be noted that THC in medium sand dominates (3.22 mg/L-3.41 mg/L) in the western part of Aluu compared to the lowest concentration (1.65 mg/L-1.85 mg/L) which occurred in the eastern and eastern parts of Aluu. Again, the Fe concentration bound to water dominates (1.89 mg/L-1.99 mg/L) in the Southern section of Aluu as opposed to the lowest concentration (0.42 mg/L-0.758 mg/L) found at the North Western and Western sections of the same location (Figure 4a). Furthermore, Fe in fine sand dominates (2.71 mg/L-2.98 mg/L) the Southern, North Eastern, Eastern and Northern sections of Aluu as opposed to the lowest concentration (0.48 mg/L-0.758 mg/L) found at the North Western flank of the same location (Figure 4b). Finally, Fe in medium sand dominates (2.71 mg/L-2.98 mg/L) the Southern section of the area of study when compared to the lowest concentration (0.45 mg/L-0.73 mg/L) found in the North Western and western sections of the location of study (Figure 4c).


(a)
N
FW1
FW2
FW3
FW4
FW5
FW6
FW7
FW8
FW9
FW10
Fe Concentration (mg/L)
0.42-0.58
0.59-0.74
0.75-0.91
0.92-1.1
1.2-1.2
1.3-1.4
1.5-1.6
1.7-1.7
1.8-1.9
Sample
Miles
0
0.02
0.04
0.08
0.12
0.16


(b)
N
FFS1
FFS2
FFS3
FFS4
FFS5
FFS6
FFS7
FFS8
FFS9
FFS10
Fe Concentration (mg/L)
0.48-0.758
0.759-1.04
1.05-1.31
1.32-1.59
1.6-1.87
1.88-2.15
2.16-2.42
2.43-2.7
2.71-2.98
Sample
Miles
0
0.0175
0.035
0.07
0.105
0.14

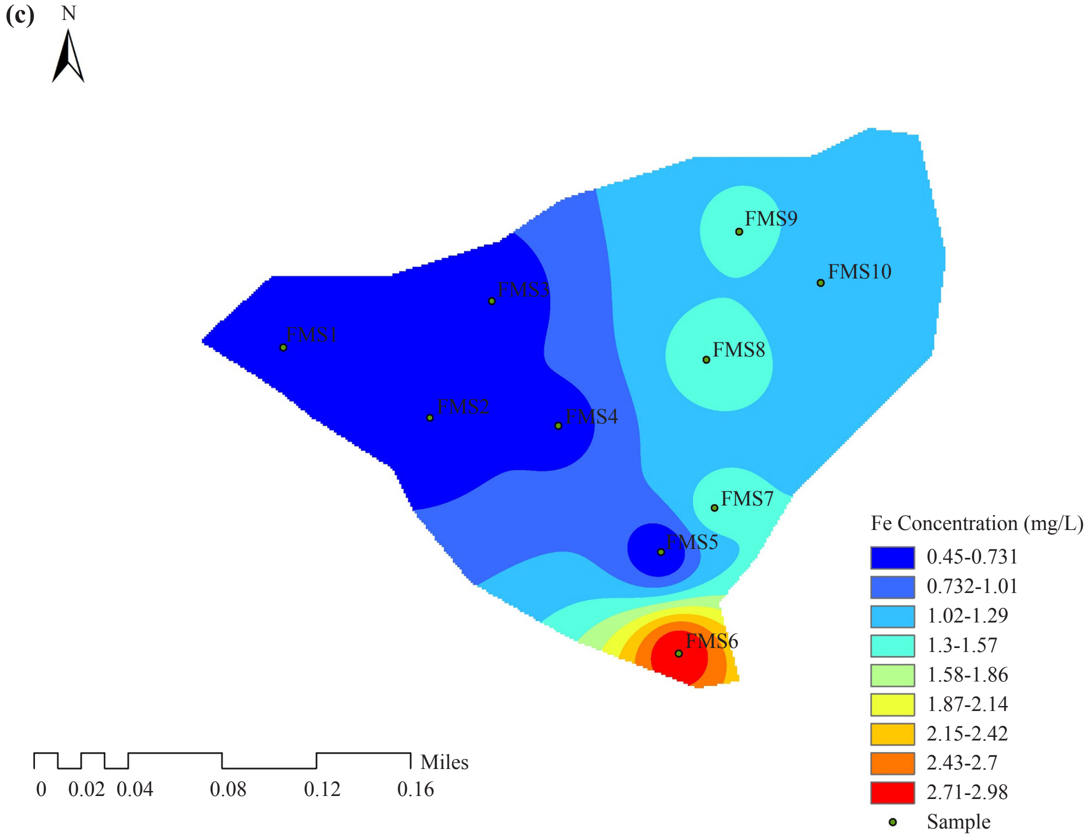


Figure 4. a) Spatial Fe data map for water in Aluu; b) Spatial Fe data map for fine sand in Aluu; c) Spatial Fe data map for medium sand in Aluu
Source: Authors (2022)

4. Discussion

The pH in some water and sediment remains below the acceptable limits established by the World Health Organization. There is an alignment with records provided elsewhere in a similar contaminated deltaic environment. There are reported cases of lower pH values for water and sediment pH in a similar deltaic environment [40]. The textural characteristics of the borehole sediments based on the mean, sorting coefficient, skewness, and kurtosis indicate medium to fine sand. These sediments are poorly sorted and negatively skewed in grain size. The kurtosis indicates sediment grains are very leptokurtic to platykurtic. These features indicate deposition in a high-energy environment. There was not sufficient time for the grain sorting process.

The pH of the contaminant indicates the presence of organic contamination in the soils and groundwater. The TPH, THC and Fe in both water and sediment are above the acceptable limits set by the World Health Organization [39]. Water treatment in the Niger Delta region of Nigeria is centered on the reduction of iron to acceptable limits. This understanding is due to the brown colouration of groundwater in the presence of high iron content. Previous studies have shown little attention to the cause of high fever and gastrointestinal disorders in humans after consuming well water in this region [41]. This study has sourced TPH, THC and Fe as the main groundwater organo- and inorganic contaminants and pollutants in the region. The water and sediment accommodate higher TPH, THC and Fe content above the acceptable limits provided by the World Health Organization. At 95% CI, there exists strong statistical evidence that the behaviour of the TPH, THC and Fe in this region is related to the presence of medium and fine sand, which creates a permeable porous aquifer. This aquifer allows the migration of pollutants into groundwater. These dominant textural characteristics in the borehole section in deltaic environments have been reported previously [42].

The treatment of water in the Niger delta in Nigeria is based on bacterial elimination and the reduction of iron to acceptable limits without recourse to other important contaminants. The attention of Environment Agencies and water companies is usually drawn to the brown colouration experience. Therefore, minimal effort is given to understanding the effect of organo-contaminants in groundwater.

Iron in the water and sediment remains higher than the acceptable limits provided by regional and international regulators. Therefore, the Fe content reported herein is comparable to those reported in some contaminated sections of the delta region in Nigeria [43]. This high Fe content may be aligned with the presence of iron-fixing bacteria brought in during sediment deposition. It may also be due to the high affinity of Fe to the sand fractions of the sediment. The heterogeneous configuration of the aquifer may explain the erratic distribution of Fe in the region.

Spatial data distribution study using GIS techniques is not readily available in the delta region of Nigeria. However, non-3D studies reveal similar patterns of differences and erratic occurrence of organo-contaminant and iron distribution between sample locations. The organo-contaminant and iron point sources are not detectable using GIS techniques. However, previous studies of surface water and sediments revealed the occurrence of organo-contaminants above acceptable limits. The total iron in surface water and surface sediment is usually below acceptable limits due to the oxidation of ferrous iron to the ferric state. The distribution pattern of contaminants in the groundwater is dictated by the textural characteristics of the borehole sediments. The distribution pattern of single contaminants is influenced by the nature of anthropogenic activities in the landscape. Here, the crude oil spill has significantly altered the geochemical landscape of Aluu to the point that sections with active oil spills support higher concentrations of hydrocarbon contamination. As a concept, if contaminant migration is not texturally controlled, single contaminants would be distributed evenly within the sediment and groundwater. However, this ideal state of distribution does not exist in the sediment and groundwater of Aluu. Therefore, differences exist in the geochemical competitive capability of the single iron and hydrocarbon contaminants for space in groundwater and the sediment. The textural barrier impeding this free migration of contaminants has provided a template for this study; while the geochemical barrier supporting the distribution would form a template for further studies.

Therefore, in comparison with similar articles provided [20, 42], uncontrollable disposal of hydrocarbon products and crude oil discharge into the watersheds in Aluu accounts for the infiltration of organo-contaminants into the groundwater.

5. Conclusion

Herein, the baseline characteristics of organo-contaminants and Fe impressed into groundwater have been established. The high fever and gastrointestinal disorders in humans are critical reasons for this study. In this scene, Fe and organo-contaminant ingress into the groundwater has been tracked. As a prelude, standard laboratory procedures were deployed for textural and physicochemical characterization. The distribution pattern of contaminants in the groundwater and borewell sediments is dictated by the textural characteristics of the borewell sediments and the nature of anthropogenic activities in the landscape. The textural characteristics of the segregated sediments provided a route for the transport of the contaminant into the groundwater.

Therefore, spatial data and GIS analysis were used to provide baseline data and information on characterized borehole water and sediments impacted by organo-contaminants and Fe. This study investigated the characterization of borehole sediment and the impact of organo- contaminants and Fe in Aluu. The TPH, THC and Fe content are above the acceptable limits provided by the World Health Organization. A permeable and porous sediment textural characteristic is responsible for the ingress of hydrocarbon and iron contaminants into the groundwater. There are numerous sources of non-point sources of hydrocarbon contaminants in this region. These include oil leaks from corroded pipes and deliberate spills arising from crude oil transport and bunkering.

Spatial data and GIS studies support that the vulnerable textural characteristic of the associated segregated sediments provides links for the transport of these contaminants into the groundwater in Aluu. In this study, we provide information on the danger of misunderstanding the critical state of groundwater in the oil exploration sections of the delta. In this study, groundwater aquifer sediments are viewed as carriers of these contaminants into groundwater courses. The spatial data maps and GIS interpretation provide further insight into the distribution of these contaminants on a location basis, the range of contaminants dissolved in groundwater, and bound fractions in fine and medium sand. However, the point source of these contaminants in the groundwater remains elusive. Worthy of note in these findings is that organo-contaminants and Fe have migrated into groundwater rendering it unsafe as it presents the reason for potable water health risk in Aluu.

Hence, extraction of water near hydrocarbon sources and spills requires critical assessment and management. An immediate fix of damaged oil facilities and a prompt clean-up process are required as remediation strategies for the recovery of contaminated groundwater in this region. Finally, the data distinctively climax the need to clarify the occurrence, fate and impact of Fe and organo-contaminants in Aluu groundwater. This contamination is linked to the frequent high fever gastrointestinal disorders in Aluu residents who consumed the well water.

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Conflict of interest

The authors declare no competing financial interest.

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