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Near-Surface Lithofacies Distribution in Zenan-Field, Niger Delta: Implication for Groundwater Vulnerability Assessment

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Abstract-A sedimentologic based vulnerability assessment of groundwater resources within the Zenan Field in parts of the Niger Delta Basin has been carried out. The lithologic components from the near-subsurface were assessed through percussion drilling of 12 boreholes. Analysis of lithology revealed a cyclic stratigraphic occurrence of two lithotypes and six lithofacies. Depth to groundwater ranged from less than 3 feet to over 3 feet and flows in a northeast-southwest trend. Clayey facies component which occurs from a depth range of 5 – 28ft across the field was noticed to pose a permeability barrier to potential pollutants, except in well 7, where this component is absent. The area around well 7 serves as entry point of potential pollutant to the subsurface. Determination of groundwater flow direction which revealed a southwest flow trend, therefore indicates that locations southwest of well seven are more vulnerable to potential pollutants due to the absence of clayey facies components in the stratigraphic pile.

Keywords- *Groundwater, Vulnerability Assessment, Niger Delta, Potential Pollutants, Near-Subsurface Facies*

I. INTRODUCTION

Groundwater occurrence in the subsurface geologic media is of huge economic importance in domestic as well as for industrial purposes. Although groundwater can be easily assessed in the Niger Delta region, its quality poses a major concern in modern society. The ease at which groundwater can be assessed due to its shallow occurrence stands as an advantage in the one hand and also unfortunately puts it at a disadvantage. This is because its shallow occurrence makes it easily vulnerable to potential surface and near-surface pollutants emanating from anthropogenic activities. These potential pollutants can be in the form of organic and/or inorganic components, such as derived from petroleum products and its by-products, effluents from vehicular and industrial exhausts, degradable and non-degradable pesticides, human wastes, etc. Considering the near-surface occurrence and the high chances of being polluted, factors exists in the geologic environment that can mitigate the impact of potential pollutants and therefore reduce its vulnerability. These factors are primarily the sedimentologic characteristic of the sediments, measured by the component facies types and their consequent stratigraphic arrangement and the subsurface flow characteristics and hydrodynamics of the groundwater present in the pore spaces of the component facies.

As elementary as these two factors may seem, it is important to note that the interplay of both holds the key to assessing the vulnerability of groundwater resources in the near-subsurface and hence enables a determination of how protected our source of water in the near-subsurface is protected. In view of the foregoing, we seek to evaluate the level of protection and hence vulnerability of groundwater in the Zenan Field area, located within the operational area of one of the multinational oil concerns in Delta State, Nigeria. The field lies within the Niger Delta Basin.

II. GEOLOGY

The Niger Delta lies between longitudes 5° and 8.4°E and latitudes 3° and 6°N within the coastal area of the Gulf of Guinea (Fig.1). It covers an area of about 75,000km2 with an overall regressive fill of about 12,000m [Doust and Omatsola, 1990; Reijers, 1996].

Based on the dominant sedimentologic characteristics influenced by depositional conditions, the sedimentary pile is divided into three age-diachronous lithostratigraphic formational units, the Akata, Agbada and Benin Formations ranging in age from Eocene to Recent [Short and Stauble, 1967; Weber and Daukoru, 1975; Reijers, 2011].

The Akata Formation as the bottomset is composed of thick sequence of deep marine shales. Overlying the Akata Formation is the Agbada Formation composed of alternating sequences of sand and shale. The Benin Formation overlies the delta. It is characterized by friable sands formed in delta plain environments.

The objective sediment type in this study is the upper horizon of the Benin Formation composed of Quaternary-Recent alluvium made up of hydromorphic soils. Hydrologically, two stratigraphic units form the main aquifer system in the Niger Delta region:

- The Alluvium: The alluvial deposits occur as surface and near-surface hydrologic system of isolated sand lenses limited by lateral facies change. It overlies the three major lithostratigraphic unit of the Niger Delta Basin. This system which is close to the shore is commonly saline water bearing. These sediments occur as the overlying Recent sediments of the Benin Formation
- The Benin Formation: Sediments of the Benin Formation act as the main aquiferous system in the Niger Delta area.

Lithologically, it is composed of about 90% sand and 10% clay, silt and lignitic beds also limited by lateral facies change.

Groundwater recharge to both systems is mainly from precipitation, while discharge includes groundwater flow feedback to surface water systems and abstraction through boreholes meant for domestic and industrial purposes.

This vegetation in the area of study is of three types: Mangrove, freshwater swamp forest, dense tropical rain forest thickets. The mangrove forest is typical of areas proximal to water bodies. The freshwater swamp forests occur in areas distal from the main water courses but that are affected by season and/or annual floods, while the dense thickets are upland areas that are not liable to or affected by annual floods.

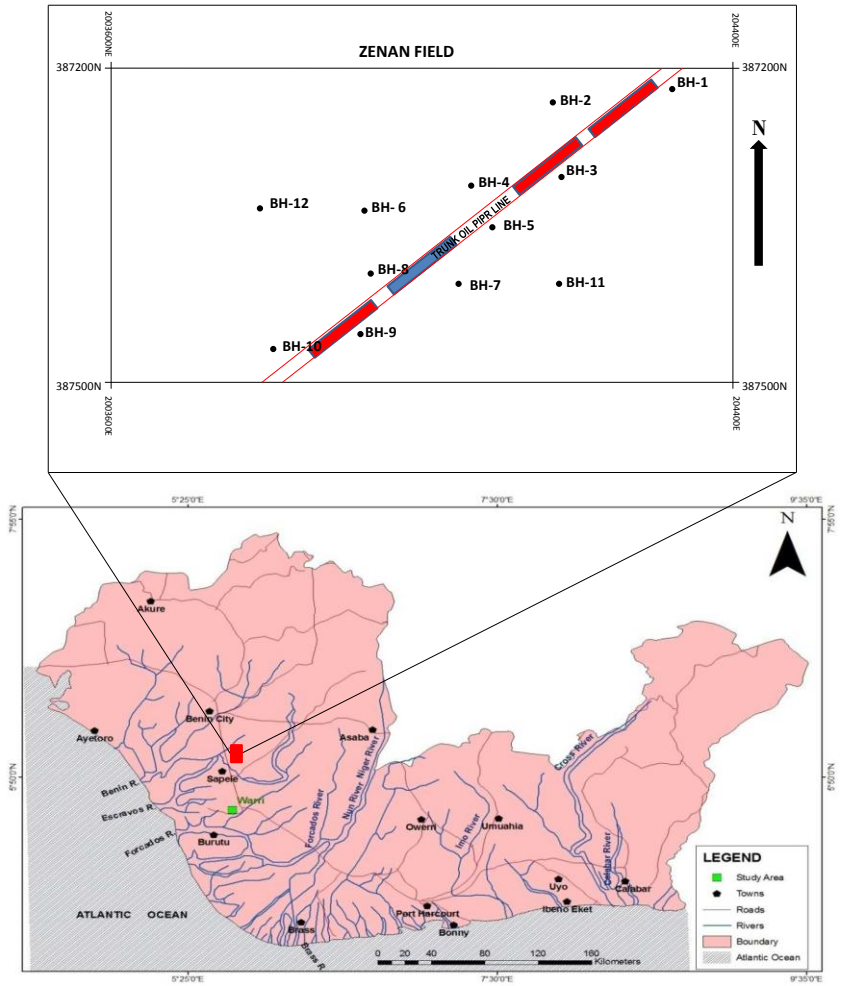

Figure 1. Geographical Map of the Niger Delta Niger Delta, Showing the study location Zenan Field) *[Modified after Olobaniyi and Owoyemi 2006]*

III. Method of Assessment

In evaluating the lithofacies components as it relates to groundwater quality in the near-subsurface, twelve shallow intrusive holes were created using the percussion drilling method. These were drilled to a maximum depth of 45ft. During drilling, samples were retrieved at 0.5m below ground level (bgl.) intervals. These were described for textural and compositional characteristics. The depth to groundwater at each borehole location was noted. The cyclic occurrence of various facies component derived from lithofacies analysis and perceived groundwater flow direction were considered a critical factor in assessment of the vulnerability of aquiferous media in the area of study.

IV. Results and Discussion

A. Hydrogeology

1) Borehole stratigraphy

A summary of borehole coordinates and locations where boreholes were drilled is presented in Table 1. Details of lithologic and sedimentologic analysis and description of well cuttings retrieved from drilled sections are presented in Tables

2-16. Groundwater levels encountered at the different borehole locations varied from less than 3 feet to over 3 feet in a northeast-southwest trend. A comparative analysis of groundwater levels across the field indicates a southwest groundwater flow trend as shown in figure 2.

TABLE I. GEO-REFERENCED COORDINATES OF THE BOREHOLE POINTS IN ZENAN FIELD

S/N	LOCATION	BH No.	Well Coordinates	Drill Method	Drill Depth (ft)
1	Zenan	1	N05° 50’ 20.5’’ E005° 55’ 40.4’’	percussion	45
2	Zenan	2	N05° 50’ 20.8’’ E005° 55’ 36.3’’	percussion	45
3	Zenan	3	N05° 50’ 35.3’’ E005° 55’ 23.1’’	percussion	45
4	Zenan	4	N05° 50’ 33.9’’ E005° 55’ 38.2’’	percussion	45
5	Zenan	5	N05° 50’ 28.6’’ E005° 55’ 26.3’’	percussion	45
6	Zenan	6	N05° 50’ 19.6’’ E005° 55’ 25.0’’	percussion	45
7	Zenan	7	N05° 50’ 26.4’’ E005° 55’ 13.1’’	percussion	45
8	Zenan	8	N05° 50’ 39.7’’ E005° 55’ 07.0’’	percussion	45
9	Zenan	9	N05° 50’ 37.4’’ E005° 55’ 00.1’’	percussion	45
10	Zenan	10	N05° 51’ 08.6’’ E005° 54’ 15.5’’	percussion	45
11	Zenan	11	05° 51’ 05.1’’ E005° 56’ 09.5’’	percussion	45
12	Zenan	12	N05° 50’ 33.6’’ E005° 55’ 20.5’’	percussion	45
13	Zenan	13	N05° 50’ 34.0’’ E005° 55’ 41.5’’	percussion	45
14	Zenan	14	N05° 52’ 36.3’’ E005° 57’ 15.1’’	percussion	45
15	Zenan	15	N05° 52’ 36.4’’ E005° 57’ 27.4’’	percussion	45

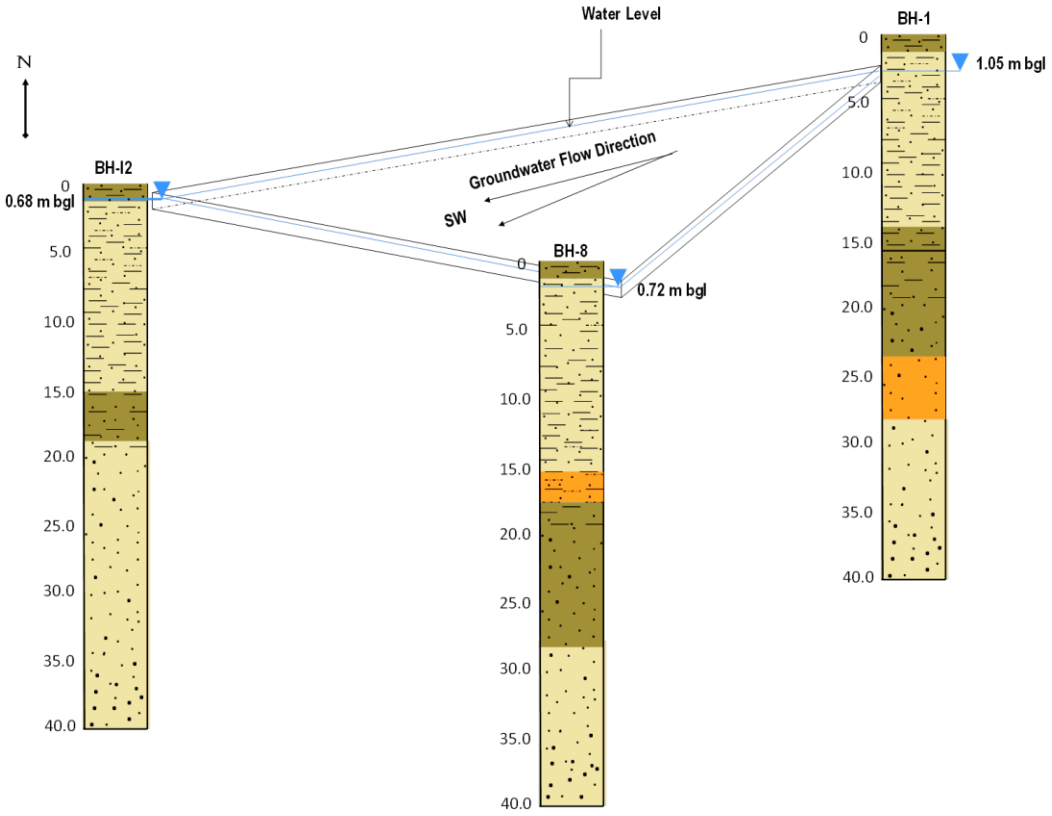

Figure 2. A model groundwater Fence diagram showing a SW groundwater flow trend in the study area. Blue lines indicate groundwater level at different well locations.

2) Lithologies

Sand and clay occur as the main litho-types in the well sections drilled. Sand occurs as the dominant lithotype in all wells drilled. Silty and sandy clays were encountered at the uppermost sections of the wells, while clean sand facies occur as basal units across the field. Six lithofacies occur in cyclic manner over the depths drilled:

- Clayey sand
- Silty clayey sand
- Very fine sand
- Fine sand
- Medium grained sand
- Coarse Sand

The clayey sand facies is composed of six subfacies with colour variation grey, mottled to reddish brown:

- Very fine – medium grained sand
- Fine – medium grained sand
- Very fine – coarse sand
- Medium – coarse sand
- Fine – coarse sand
- Very fine – pebbly sand

The medium grained sand facies is composed of eight subfacies with colour variation:

- Fine – medium sand
- Very fine – medium sand
- Medium – coarse sand
- Medium – very coarse sand
- Medium – pebbly sand

The coarse sand facies is composed of three subfacies as listed thus:

- Coarse – very coarse sand
- Coarse – pebbly sand
- Very coarse – pebbly sand

3) Clayey Sand facies

This facies is characterized by light grey, grey, medium grey, mottled, light brown and reddish brown subfacies as listed above. Grains are characteristically subrounded-subangular in shape. The subfacies include poorly sorted very fine – medium grained sand, fine – medium grained sand, very fine – coarse sand, medium - coarse sand, fine – coarse sand, very fine – pebbly sand. This facies unit represent the top sections of all the borehole sections. The clayey fine – medium grained subfacies occur as the surface sediments in almost all the wells, except in three well (8), where sandy clays constitute the surface material.

This subfacies is also characterized by plant remains, which occur as accessories within this subfacies component and has a gradational contact with the underlying facies. The low clay content implies high average permeability.

4) Silty Clayey Sand facies

The facies is composed of five colours variations (grey, medium grey, mottled light brown and light grey). It is composed of very fine – medium grained sand and occurs from surface to less than 20 m interbeded with clayey medium grained sand subfacies in all wells. It has gradational contact with the underlying facies. High porosity and low permeability is implied based on the lithofacies characteristics, thus acts as a permeability barrier.

5) Sand Clay facies

This facies which occur as surfaces sediments in boreholes 8 displays a characteristic grey and medium grey colouration and is composed of rounded – angular, very fine – medium sand components. Sand content is about 10%. This facies, due to its high clay content acts as permeability barriers to surface fluids.

6) Coarse Sand facies:

This facies is composed of six subfacies characterized by grey and light grey medium – pebbly poorly sorted sand. This facies is present as the basal unit across the area of study and acts as the main and first aquifer. The absence of clay in this facies implies high permeability.

7) Environment of Deposition

A visual an analysis of the textural parameters (grain size distribution, grain shape, sorting, and clay content and mineralogical composition) infers deposition in a fluvial environment reminiscent of a delta plain setting. Static water levels decrease progressively in a north-south direction, indicating that groundwater flow regime is towards the Atlantic Ocean in consonance with the general topographic trend of the Niger Delta area. Thus groundwater recharge is from the high topographic areas in the north [Freeze and Cherry, 1979].

8) Vulnerability Assessment

Considering the cyclic occurrence of lithofacies component from top the well base, the occurrence of clayey facies component is considered an important factor in the protection of groundwater against potential pollutant in the soil and sediment media. The mottled clayey facies in the area of study occurs from a depth range of 5 – 28ft in all the wells, except in well 7, were this facies component if observed to be absent. The absence of a protective facies component in well 7 at shallow depths invariably implies that in the event of oil spillage around the location, the groundwater body stands a high chance of being impacted from surface flow into the subsurface. Well 7 location thus serves as an entry point of potential pollutants into the subsurface in the area of operation in the Zenan Field should there be operational spillage. Groundwater bodies southwest of well 7, are thus, vulnerable to such pollutants if the lateral flow is not impeded by the occurrence of clayey facies that can mitigate the impact of potential pollutant in the subsurface.

TABLE II. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-1, ZENAN FIELD

BH-1						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Clayey sand	Medium Grey	vf - mSd	Moist	Nil	Plant remains
5	Silty clayey sand	Grey	vf – mSd	Moist	Slightly	Plant remains
10	Clayey sand	Grey	vf – mSd	Wet	Slightly	Nil
15	Clayey sand	Mottled	vf – mSd	Wet	Low	Nil
20	Clayey sand	Mottled	f – mSd	Wet	Low	Nil
25	Clayey sand	Medium Grey	m – cSd	Wet	High	Nil
30	Clayey sand	Brownish	f – mSd	Wet	High	Nil
35	Sand	Light grey	m - cSd	Wet	Nil	Nil
40	Sand	Light grey	m - cSd	Wet	Nil	Nil
45	Sand	Light grey	m - cSd	Wet	Nil	Nil

TABLE III. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-2, ZENAN FIELD

BH-2						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Clayey sand	Grey	vf - mSd	Moist	Nil	Plant remains
5	Clayey sand	Grey	vf – mSd	moist	Slightly	Plant remains
10	Clayey sand	Mottled	vf – mSd	Wet	Low	Nil
15	Clayey sand	Grey	vf – mSd	Wet	Low	Nil
20	Clayey sand	Grey	vf – mSd	Wet	Low	Nil
25	Clayey sand	Grey	vf – mSd	Wet	Low	Nil
30	Clayey sand	Medium Grey	f – mSd	Wet	High	Nil
35	Clayey sand	Light grey	vf - cSd	Wet	High	Nil
40	Clayey Sand	Light grey	m - cSd	Wet	High	Nil
45	Sand	Light grey	m - cSd	Wet	Nil	Nil

TABLE IV. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-3, ZENAN FIELD

BH-3						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Silty Clayey Sand	Grey	vf - mSd	Moist	Nil	Plant remains
5	Clayey sand	Grey	vf – mSd	moist	Slightly	Plant remains
10	Clayey sand	Grey	vf – mSd	Wet	Slightly	Nil
15	Silty clayey sand	Medium Grey	vf – mSd	Wet	Slightly	Nil
20	Clayey sand	Medium Grey	f – mSd	Wet	Low	Nil
25	Clayey sand	Mottled	vf – mSd	Wet	Low	Nil
30	Clayey sand	Grey	vf – mSd	Wet	Low	Nil
35	Sand	Light grey	m - cSd	Wet	Nil	Nil
40	Sand	Light grey	m - cSd	Wet	Nil	Nil
45	Sand	Light grey	m - cSd	Wet	Nil	Nil

TABLE V. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-4, ZENAN FIELD

BH-4						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Silty Clayey Sand	Medium Grey	vf - mSd	Moist	Nil	Plant remains
5	Silty Clayey Sand	Grey	vf – mSd	moist	Slightly	Plant remains
10	Clayey sand	Mottled	vf – mSd	Wet	Slightly	Nil
15	Clayey sand	Light grey	vf – mSd	Wet	Slightly	Nil
20	Clayey sand	Light grey	vf – mSd	Wet	Slightly	Nil
25	Clayey sand	Light grey	vf – mSd	Wet	Low	Nil
30	Clayey sand	Light grey	vf – mSd	Wet	Low	Nil
35	Sand	Light grey	m - cSd	Wet	Nil	Nil
40	Sand	Light grey	m - cSd	Wet	Nil	Nil
45	Sand	Light grey	c - vcSd	Wet	Nil	Nil

TABLE VI. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-5, ZENAN FIELD

BH-5						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Clayey sand	Medium Grey	vf - mSd	moist	Nil	Plant remains
5	Silty clayey sand	Grey	vf – mSd	moist	Nil	Nil
10	Clayey sand	Grey	f – mSd	moist	Slightly	Nil
15	Silty clayey sand	Grey	vf – mSd	moist	Slightly	Nil
20	Clayey sand	Mottled	vf – mSd	moist	Slightly	Nil
25	Clayey Sand	Mottled	m – cSd	moist	Low	Nil
30	Sand	Medium Grey	vf – mSd		Low	Nil
35	Sand	Grey	vf – mSd	Wet	Slightly	Nil
40	Sand	Light grey	m - cSd	Wet	Nil	Nil
45	Sand	Light grey	m - cSd	Wet	Nil	Nil

TABLE VII. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-6, ZENAN FIELD

BH-6						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Clayey sand	Grey	vf - mSd	Moist	Nil	Plant remains
5	Clayey sand	Grey	vf – mSd	Wet	Slightly	Plant remains
10	Clayey sand	Grey	vf – mSd	Wet	Slightly	Nil
15	Silty clayey sand	Mottled	vf – mSd	Wet	Nil	Nil
20	Clayey sand	Medium Grey	vf – mSd	Wet	Slightly	Nil
25	Clayey sand	Medium Grey	vf – mSd	Wet	Low	Nil
30	Clayey sand	Light grey	vf – mSd	Wet	Low	Nil
35	Clayey sand	Light grey	f – mSd	Wet	Slightly	Nil
40	Clayey Sand	Light grey	m - vcSd	Wet	Slightly	Nil
45	Sand	Light grey	vcSd - pSd	Wet	Nil	Nil

TABLE VIII. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-7, ZENAN FIELD

BH-7						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Clayey Sand	Medium Grey	vf - mSd	Moist	Nil	Plant remains
5	Silty Clayey sand	Grey	vf – mSd	Wet	Slightly	Plant remains
10	Clayey sand	Grey	vf – mSd	Wet	Slightly	Nil
15	Silty clayey sand	Medium Grey	vf – mSd	Wet	Nil	Nil
20	Clayey sand	Medium Grey	vf – mSd	Wet	Slightly	Nil
25	Clayey sand	Medium Grey	f – mSd	Wet	Low	Nil
30	Clayey sand	Medium Grey	f – mSd	Wet	Slightly	Nil
35	Sand	Light grey	m - cSd	Wet	Nil	Nil
40	Sand	Light grey	cSd - vcSd	Wet	Nil	Nil
45	Sand	Light grey	cSd - vcSd	Wet	Nil	Nil

TABLE IX. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-8, ZENAN FIELD

BH-8						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Sandy Clay	Medium Grey	vf - mSd	Moist	Low	Plant remains
5	Clayey sand	Grey	vf – mSd	Wet	Slightly	Plant remains
10	Clayey sand	Grey	f – mSd	Wet	Slightly	Nil
15	Silty clayey sand	Mottled	vf – mSd	Wet	Nil	Nil
20	Clayey sand	Medium Grey	vf – mSd	Wet	Slightly	Nil
25	Clayey sand	Medium Grey	vf – mSd	Wet	Low	Nil
30	Clayey sand	Light grey	f – mSd	Wet	Low	Nil
35	Clayey Sand	Light grey	f - cSd	Wet	Slightly	Nil
40	Sand	Light grey	m -cSd	Wet	Nil	Nil
45	Sand	Light grey	m - cSd	Wet	Nil	Nil

TABLE X. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-9, ZENAN FIELD

BH-9						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Silty Clayey Sand	Medium Grey	vf - mSd	Moist	Nil	Plant remains
5	Silty Clayey Sand	Grey	vf – mSd	Wet	Slightly	Plant remains
10	Clayey sand	Grey	f – mSd	Wet	Slightly	Nil
15	Clayey sand	Medium Grey	vf – mSd	Wet	Nil	Nil
20	Clayey sand	Medium Grey	vf – mSd	Wet	Slightly	Nil
25	Clayey sand	Medium Grey	vf – mSd	Wet	Slightly	Nil
30	Clayey sand	Brown	f – mSd	Wet	Slightly	Nil
35	Clayey sand	Light grey	m – mSd	Wet	Slightly	Nil
40	Sand	Light grey	m - vcSd	Wet	Nil	Nil
45	Sand	Light grey	vcSd - pSd	Wet	Nil	Nil

TABLE XI. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-10, ZENAN FIELD

BH-10						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Clayey sand	Mediumt Grey	vf - mSd	Moist	Nil	Plant remains
5	Silty clayey sand	Light brown	vf – mSd	Wet	Slightly	Plant remains
10	Clayey sand	Light brown	vf – mSd	Wet	Low	Nil
15	Clayey sand	Light grey	vf – mSd	Wet	Nil	Nil
20	Sand	Light grey	vf – mSd	Wet	Low	Nil
25	Sand	Light grey	F – mSd	Wet	High	Nil
30	Sand	Light grey	F – mSd	Wet	High	Nil
35	Sand	Light grey	F – mSd	Wet	Low	Nil
40	Sand	Light grey	vcSd - pSd	Wet	Nil	Nil
45	Sand	Light grey	vcSd - pSd	Wet	Nil	Nil

TABLE XII. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-11, ZENAN FIELD

BH-11						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Clayey sand	Medium Grey	vf - mSd	Moist	Nil	Plant remains
5	Clayey sand	mottled	vf – mSd	Wet	Slightly	Plant remains
10	Clayey sand	mottled	vf – mSd	Wet	Slightly	Nil
15	Clayey sand	Light grey	vf – mSd	Wet	Nil	Nil
20	Clayey sand	Light grey	vf – mSd	Wet	Slightly	Nil
25	Clayey sand	Light grey	vf – mSd	Wet	Low	Nil
30	Clayey sand	Light grey	vf – mSd	Wet	High	Nil
35	Clayey sand	Light grey	vf – mSd	Wet	High	Nil
40	Sand	Light grey	vcSd - pSd	Wet	Nil	Nil
45	Sand	Light grey	vcSd - pSd	Wet	Nil	Nil

TABLE XIII. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-12, ZENAN FIELD

BH-12						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Clayey Sand	Grey	vf – mSd	Moist	Nil	Plant remains
5	Silty Clayey sand	Light grey	vf – mSd	moist	Slightly	Plant remains
10	Clayey sand	mottled	vf – mSd	Wet	Low	Nil
15	Silty clayey sand	mottled	vf – mSd	Wet	Nil	Nil
20	Clayey sand	Medium grey	vf – mSd	Wet	Low	Nil
25	Clayey sand	Medium grey	vf – mSd	Wet	High	Nil
30	Clayey sand	Medium grey	vf – mSd	Wet	High	Nil
35	Clayey sand	Light grey	vf – cSd	Wet	High	Nil
40	Clayey Sand	Light grey	vf - pSd	Wet	Low	Nil
45	Sand	Light grey	vcSd - pSd	Wet	Nil	Nil

TABLE XIV. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-13, ZENAN FIELD

BH-13						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Clayey Sand	Medium Grey	vf - mSd	Moist	Nil	Plant remains
5	Silty Clayey sand	Light Grey	vf - mSd	Wet	Low	Plant remains
10	Clayey sand	Light Grey	vf - mSd	Wet	Low	Nil
15	Silty clayey sand	Light Grey	vf - mSd	Wet	Slightly	Nil
20	Clayey sand	Light Grey	vf - mSd	Wet	Low	Nil
25	Clayey sand	Medium grey	vf - mSd	Wet	Low	Nil
30	Clayey sand	Brown	m - vcSd	Wet	Slightly	Nil
35	Clayey sand	Light grey	m - cSd	Wet	Slightly	Nil
40	Sand	Light grey	vcSd - pSd	Wet	Nil	Nil
45	Sand	Light grey	vcSd - pSd	Wet	Nil	Nil

TABLE XV. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-14, ZENAN FIELD

BH-14						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Sandy Clay	Medium Grey	vf - mSd	Moist	Low	Plant remains
5	Silty Clayey sand	Light Grey	vf - mSd	Wet	Slightly	Plant remains
10	Clayey sand	Light Grey	vf - mSd	Wet	Low	Nil
15	Silty clayey sand	Medium grey	vf - mSd	Wet	Nil	Nil
20	Sand	Light Grey	vf - mSd	Wet	Low	Nil
25	Sand	Light grey	vf - mSd	Wet	High	Nil
30	Sand	Light grey	vf - mSd	Wet	High	Nil
35	Sand	Light grey	m - cSd	Wet	Nil	Nil
40	Sand	Light grey	m - cSd	Wet	Nil	Nil
45	Sand	Light grey	cSd - pSd	Wet	Nil	Nil

TABLE XVI. LITHOFACIES AND DEPTH OF OCCURRENCE IN WELL SECTION OF BH-15, ZENAN FIELD

BH-15						
Depth (Ft)	Lithology	Colour	Grain size	Moisture content	Plasticity	Accessories
0 – 2	Sandy Clay	Grey	vf - mSd	Moist	Low	Plant remains
5	Clayey sand	Light brown	vf - mSd	Wet	Slightly	Plant remains
10	Clayey sand	Reddish brown	vf - mSd	Wet	Slightly	Nil
15	Clayey sand	Light grey	vf - mSd	Wet	Medium	Nil
20	Sand	Light grey	f - mSd	Wet	High	Nil
25	Sand	Light grey	f - mSd	Wet	High	Nil
30	Sand	Light grey	vf - mSd	Wet	High	Nil
35	Sand	Light grey	m - cSd	Wet	Nil	Nil
40	Sand	Light grey	mSd - pSd	Wet	Nil	Nil
45	Sand	Light grey	mSd - pSd	Wet	Nil	Nil

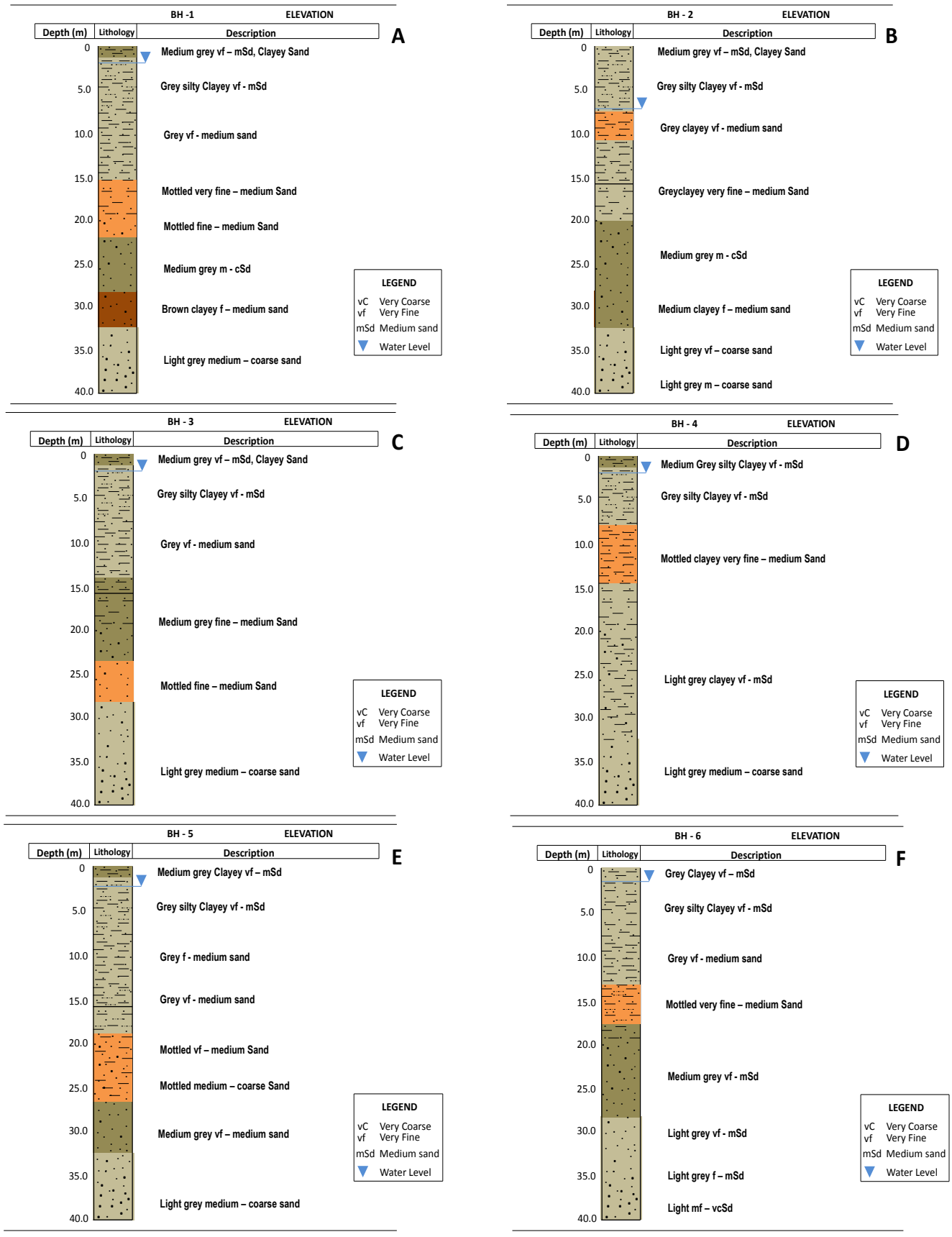

Figure 3. F: Lithologs of well section of wells 1 – 6 drilled to depths of 45ft in the Zenan Field

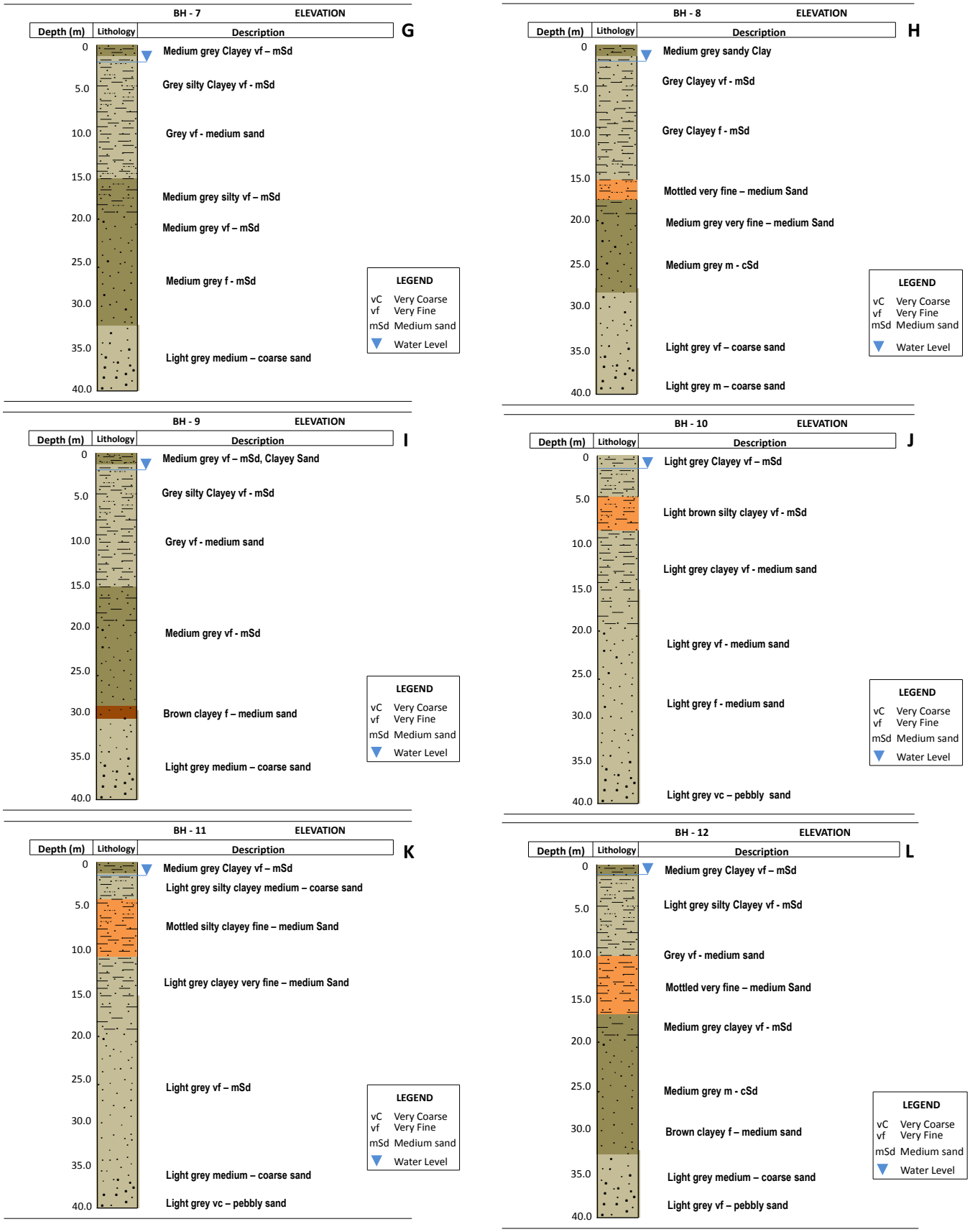

Figure 4. cont`d G - L: Lithologs of well section of wells 7 – 12 drilled to depths of 45ft in the Zenan

V. CONCLUSION

The facies components and the stratigraphic arrangements of the facies present in any given geologic environment plays a pivotal role in the determining the vulnerability of groundwater resources, especially when considering near-surface groundwater components. The flow direction of groundwater interplays with the arrangements of facies in the subsurface to determine the rate at which potential pollutants migrates in the subsurface and hence the exposure. The lithologic analysis of the near-surface sediments in the study area has shown that majority of the area is well protected against potential pollutants emanating from oil exploration and production activities within and around the objective area. However, sedimentary sequence around well 7 of the study area displays a different sedimentary signature as the clay lithofacies present in other parts of the study area is absent. This situation creates a vulnerability pathway for potential pollutants into the subsurface.

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