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Research Article

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Examination of the Relationship between the Direction of Flow of Surface and Underground Water in Forming an Aquifer using Digitized Topography Information and Seismic Imaging

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Abstract The relationship between the direction of flow of surface and underground water has not been well established. Knowledge of this relationship is very necessary to determine how underground aquifers are formed. The aim of this work is to Examine and establish the relationship between the direction of flow of surface and underground water. The questions that require answers are, does the direction of surface water flow always correspond with underground water flow? If the direction of flow differs, at what point? What are the connection between surface water and the formation of aquifers within the subsurface? In a bid to achieve this aim and provide answers to these questions, topographic information and Seismic tomography survey were generated and carried out. Both results were processed and analyzed, and the results revealed that regions of deep (low water table) correspond with regions of high elevation, while regions with shallow (high water table) correspond with regions of low elevation. It was also noticed that the direction of flow of underground water is toward the river where the water table is shallow (closer to the surface), and flows away from the river where the water table is deep (deep below the surface). This also implies that regions with low elevation and shallow (high water table) is more likely to contribute to surface water to form rivers or lake, while region with high elevation and deep (low water table) is more likely to receive from surface water through inter connecting pores to form underground water. It was also established that the movement and flow of underground water is control by subsurface topography that exist majorly within the sand layer, while the direction of flow of surface water is being control by difference in surface elevations.

Keywords Surface Water; Underground water; Topography; Aquifer; Flow Direction

Introduction

The need to study the relationship between direction of flow of surface water and underground water is of paramount importance to the Geologist, Geophysicist and Engineers. An estimate of over 85% of water used for household in Nigeria comes from boreholes linked to underground water. The underground water receive it source from surface water through interconnecting pores. The question is, does the direction of surface water always correspond with the direction of underground water? If it defers, at what point? And why? At what point does surface water contribute to underground water, and underground water flows into surface water? In a bid to answer these questions, we have to carry out a geophysical survey which involves determining the elevations and coordinates of some selected points base on distribution and existing geology and carryout seismic survey at these points, with the midpoints of the seismic survey coinciding with the points where the elevation data were measured, so that a good comparison can answer most of our questions. Considering the previous works of other researcher we discovered that, [7]., stated that “Surface water and groundwater system are connected in most landscape”. [4]., states that “No simple relation exists between the amount of groundwater discharge in an area”.

The instruments used for the include; 12 Channel Digital Seismograph, 13 Geophones, Reels of Cables, Trigger Coil, Sledge hammer, Meter tape, 12 V sealed battery, and Global Positioning System (GPS).

Location of the study area

[1]. Otuoke and Its Environ forms the study area, which is located in the Oil rich Niger Delta of Bay elsa state, South-South Nigeria, with an average elevation of 18 m above mean sea level [1]. It is bounded by the coordinate points, 4°48'40.25"N, 6°19'38.42"E and 4°46'40.49"N, 6°18'0.10"E, (Fig. 1). The pins in figure 1 indicate the sampled points for the 30 seismic profiles lines and elevation coordinates.

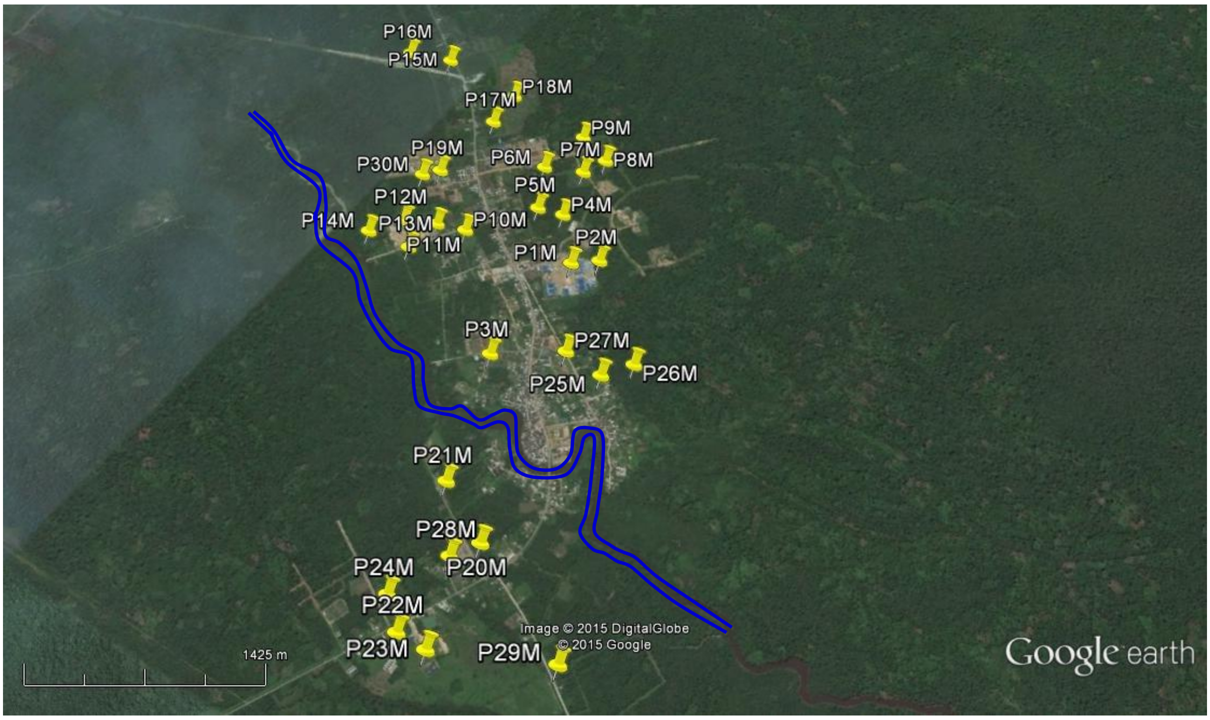

Figure 1: Imagery map of the study area depicting the 30 sample elevation point and seismic profile lines, The blues outline depict the river across the study area. Adapted from Google Earth 2015

Geology of the study Area

The study area is Otuoke and its environs in Bayelsa state, within the fresh water and meander belt geomorphic unit of the Niger Delta, [3]. The Formation of the present Niger Delta started during Early Paleocene as a result of the built up of fine grained sediments eroded and transported to the area by the River Niger and its tributaries. The regional geology of the Niger Delta consists of three lithostratigraphic units; Akata, Agbada and Benin Formations, overlain by various types of Quaternary Deposits [6], [8]., [2]. These Quaternary Sediments, according to [5]. are largely alluvial and hydro morphic soils and lacustrine sediments of Pleistocene age.

Methodology

The seismic imaging data acquisition started by planting 12 geophones at interval of 10 m, to form a total spread of 110 m. An offset distance of 50 m was used for data acquisition on both sides. Shots were deployed at an interval of 10 m, starting from 50 m before the first geophone, at each geophone point and 50 m beyond the last geophone. At each shot point, a stack of 5 shots was used to acquire the data. The sledge hammer was hammered on base plate to concentrate the energy underground. When the shots were completed at each shot points, the shot and the trigger geophone were moved to a new location 10 m from the previous, and the process of shooting was repeated all over again. The generated seismograms (Fig. 2) were recorded for onward processing.

The data acquisition for topographic information was carried out with a Global Positioning system (GPS) survey and a Google Earth map. After the seismic data acquisition, the GPS instrument was taken to the centre of the profile where data on elevation, easting and northing coordinate of that point was acquired. This was achieved by positioning the GPS instrument to search for available satellites, and when great accuracy was established, the coordinates and elevation (height above mean sea level) where noted down.

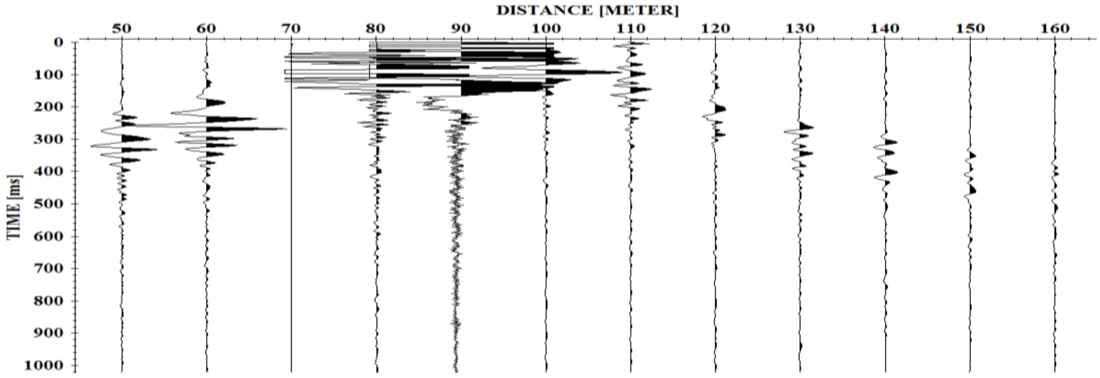

Figure 2: Generated Seismogram (Raw Seismic Data)

Data Processing

Data processing for the seismic imaging started with importing of the raw seismic data into dedicated geophysical software used for the processing. Geometrical correction to edit out the wrong geometry was implemented. The band-pass filter was applied to remove signals of very high frequency and very low frequency. The gain filter was applied to remove the effect of attenuation and geometrical spreading. The first arrival travel times were picked (Fig. 3), and assigned into layers. The assigned travel times were subjected to wavefront inversion, to generate an initial model, this initial model was iteratively used to develop a tomography model. The depth to the water tables were extracted from each model by taking advantage of the velocity of the water table (1400 m/s) and the subsurface geometry.

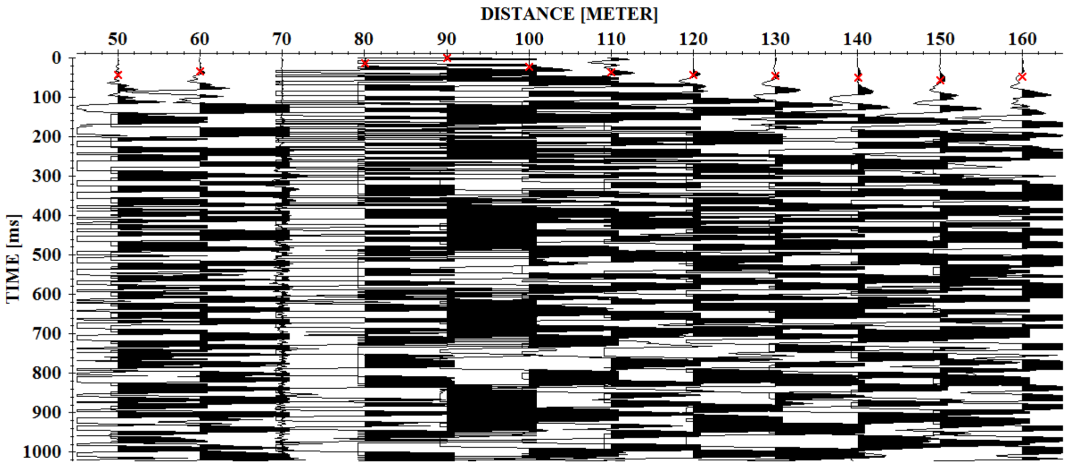

Figure 3: Processed seismic data with travel time picks

The topographic information was generated by converting the minutes and seconds in the coordinate data into degree, and adding it to the degree coordinate. The generated values where arrange in three columns, the Easting(X), The Northing(Y) and Elevation (Z). This was used to generate a contour map for the depth to water table and for elevation in the survey area.

Results

Representative six seismic tomography models are show in figure 4 to 11. The models represent the distribution of seismic velocity within the subsurface. The model depicts depth to water table, thickness of the overburden, and depth to consolidated sand layer, base on their seismic wave velocities and their subsurface geometry.

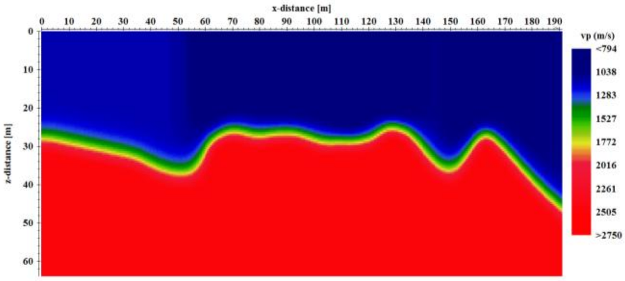

Figure 4: 2D Velocity Model for Profile 1

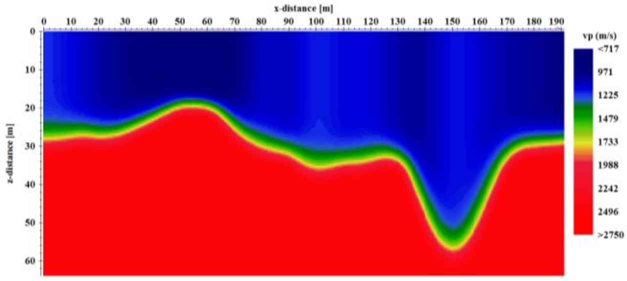

Figure 5: 2D Velocity Model for Profile 2

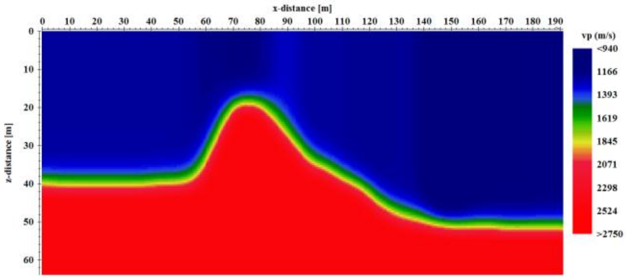

Figure 6: 2D Velocity Model for Profile 3

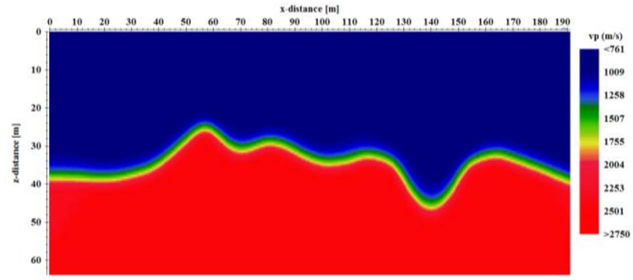

Figure 7: 2D Velocity Model for Profile 4

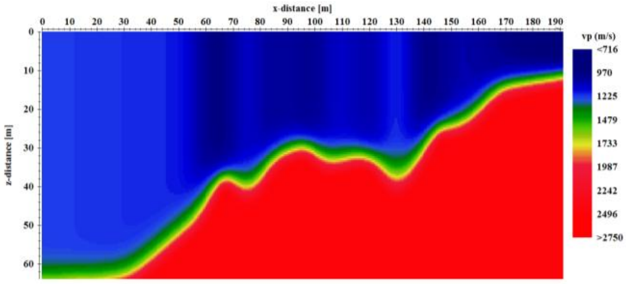

Figure 8: 2D Velocity Model for Profile 5

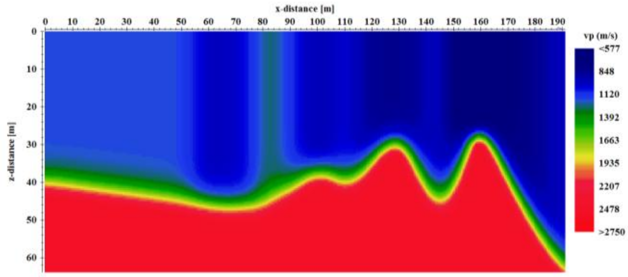

Figure 9: 2D Velocity Model for Profile 6

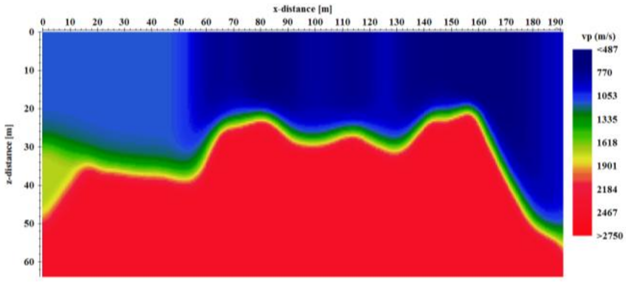

Figure 10: 2D Velocity Model for Profile 7

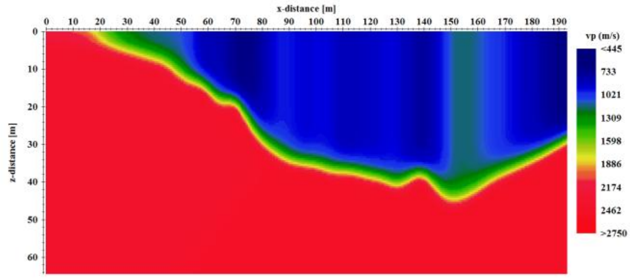

Figure 11: 2D Velocity Model for Profile 8

Table 1 represent the depths to the water table and their corresponding location coordinates, while Table 2 represents the elevation of the various points above mean sea level and their corresponding coordinates.

Table 1: Profiles Coordinates and Depth to Water Table

Profiles	Easting (Degree)	Northing (Degree)	Depth to water table (m)
Profile 1	6.320352778	4.792030556	-31
Profile 2	6.321527778	4.790666667	-37

Profile 3	6.312361111	4.792252778	-38
Profile 4	6.322922222	4.794586111	-37
Profile 5	6.322408333	4.796227778	-36
Profile 6	6.325177778	4.797783333	-41
Profile 7	6.326366667	4.795466667	-29
Profile 8	6.327944444	4.794791667	-29
Profile 9	6.328597222	4.797091667	-27
Profile 10	6.318319444	4.799002778	-39
Profile 11	6.317619444	4.800794444	-37
Profile 12	6.316580556	4.802702778	-33
Profile 13	6.315202778	4.801147222	-41
Profile 14	6.314622222	4.804000000	-35
Profile 15	6.328466667	4.808480556	-48
Profile 16	6.327338889	4.811180556	-31
Profile 17	6.326080556	4.802805556	-51
Profile 18	6.328627778	4.802969444	-28
Profile 19	6.320941667	4.803238889	-29
Profile 20	6.302800000	4.785433333	-49
Profile 21	6.304505556	4.789302778	-35
Profile 22	6.296250000	4.786050000	-39
Profile 23	6.296469444	4.784175000	-42
Profile 24	6.297547222	4.787797222	-31
Profile 25	6.315147222	4.785963889	-33
Profile 26	6.316716667	4.784741667	-37
Profile 27	6.315202778	4.788627778	-38
Profile 28	6.301216667	4.786366667	-38
Profile 29	6.300027778	4.777913889	-38
Profile 30	6.320000000	4.803988889	-43

Table 2: Profiles Coordinates and Points Elevations

Profiles	Easting (Degree)	Northing (Degree)	Elevation (m)
Profile 1	6.320352778	4.792030556	15
Profile 2	6.321527778	4.790666667	16
Profile 3	6.312361111	4.792252778	15
Profile 4	6.322922222	4.794586111	14
Profile 5	6.322408333	4.796227778	16
Profile 6	6.325177778	4.797783333	18
Profile 7	6.326366667	4.795466667	18
Profile 8	6.327944444	4.794791667	16
Profile 9	6.328597222	4.797091667	20
Profile 10	6.318319444	4.799002778	14
Profile 11	6.317619444	4.800794444	15
Profile 12	6.316580556	4.802702778	16
Profile 13	6.315202778	4.801147222	16

Profile 14	6.314622222	4.804000000	16
Profile 15	6.328466667	4.808480556	17
Profile 16	6.327338889	4.811180556	19
Profile 17	6.326080556	4.802805556	16
Profile 18	6.328627778	4.802969444	16
Profile 19	6.320941667	4.803238889	16
Profile 20	6.302800000	4.785433333	15
Profile 21	6.304505556	4.789302778	12
Profile 22	6.296250000	4.786050000	16
Profile 23	6.296469444	4.784175000	17
Profile 24	6.297547222	4.787797222	17
Profile 25	6.315147222	4.785963889	9
Profile 26	6.316716667	4.784741667	16
Profile 27	6.315202778	4.788627778	11
Profile 28	6.301216667	4.786366667	15
Profile 29	6.300027778	4.777913889	16
Profile 30	6.320000000	4.803988889	15

The values of the location coordinates points and depth to water table from table 1, and values of the location coordinates points and elevations points from table 2 were contoured into contour maps for ease of interpretation.

Figure 12, depicts the contour maps of depth to the water table, and their corresponding profiles elevation within the study area. Figure 12a represents the contour map of depth to water table, with a range of values of 26 m to 51 m and an average value of 39 m. The negative sign on the scale bar should be ignored, and the absolute value used for interpretation. Figure 12a shows regions of deep (low water table), that runs from the North East to South West, if we use the centre of the survey area where profile 3 is located as the reference point. The deepest (lowest water tables) in the survey area are located in the extremes of North East and South West. Figure 12b shows the contour map of the profile elevation above mean sea level, which ranges from 9 m to 20 m, with an average value of 15 m. Figure 12b shows central region of low elevation that is flanked by regions of high elevation, with the exception of the Southern region that extend the continuation of the low elevation beyond the survey area. Comparison of figure 12a and figure 12b shows that with exception of profile 7,8, 12, 14 and 24, regions of deep (low water table) in figure 12a corresponds with regions of high elevation in figure 12b, similarly, regions of shallow (high water table) in figure 12a correspond with regions of low elevation in figure 12b. With this result it can easily be inferred that landscape with high elevation, is most likely to have deep (low water table), and while Landscape with low elevation is most likely to accommodate shallow (high water table). Figure 12c and figure 12d show the contoured vector map for both depth to water table and elevation topography above mean sea level. These two vector map was generated to ascertain the direction of water flow both underground and at the surface, taking advantage of difference in elevation and pressure. A close comparison of figure 12c and figure 12d vector maps, shows that the surface water would flow from regions of high elevation to regions of low elevation, While underground water majorly flow from shallow (high water table) to deep (low water table). Also, an assessment of figure 12c and figure 12d, shows that the direction of flow of underground water is controlled by subsurface topography that exist most time within the sand layer, while the direction of water flow at the surface is controlled by elevation. An evaluation of the vector arrows which indicate the direction flow of both the underground water and surface water, gave a clear indication that their direction of flow most times and at most points are not the same. The direction of underground water could be altered by impervious rock material that will restrict the flow at the subsurface.

Considering the vector map of figure 12c, it was noticed that the direction of flow of underground water is toward the river where the water table is shallow (closer to the surface), and flows away from the river where the water table is deep (deep below the surface). It means knowing the depth to the water table and location of a river is a very good yardstick for predicting the direction of water flow.

The elevation contour map in figure 12d shows that the direction of flow on the surface is always towards the river or in the same direction with the river, except for situations where there is a major valley or depression adjacent to the river, where the direction of flow will be toward the valley or major depression. This surface water could either sink underground and link up with underground water through permeable surface layer, or form a pond on impervious surface, or flows toward the river.

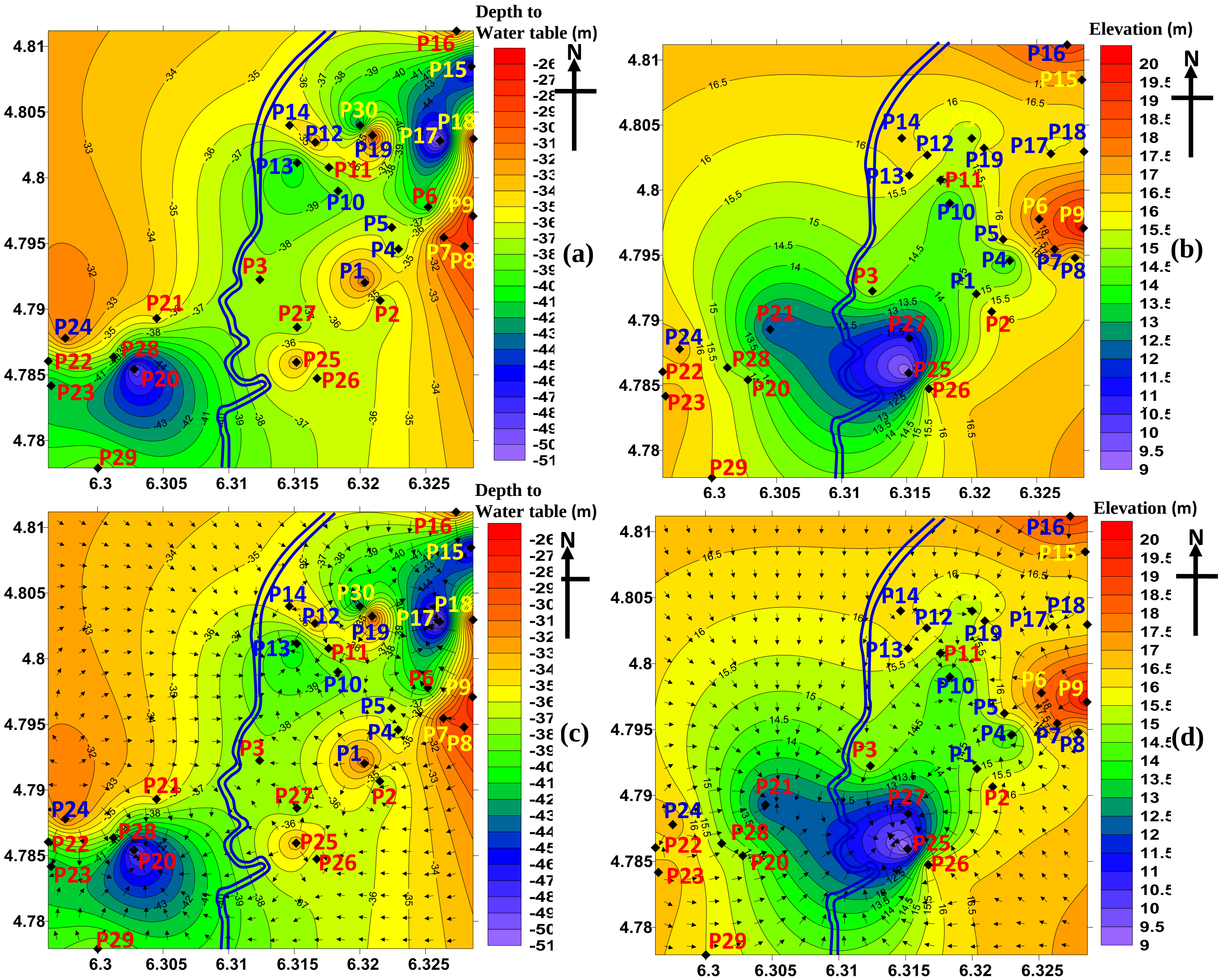

Figure 12: Contour map Models for profiles depth to water table and elevation (a) depth to water table (m) (b) elevation (m) (c) Depth to water table contour map with vector arrows (d) elevation contour map with vector arrows

Conclusion

A comparison of the contour map of the water table and that of the elevation has shown that with the exception of few location, regions of deep (low water table) correspond with regions of high elevation, similarly regions of shallow (high water table) corresponds with regions of low elevation. It can therefore be concluded from this

outcome that regions with high elevation topography at the surface is more likely to be associated with deep (low water table), and regions with low elevation topography are prone to have shallow (high water table).
It was also noticed that the direction of flow of underground water is control by subsurface topography that exist within the sand layer, while the surface water flow is controlled by difference in elevation.
It was observed that the direction of flow of underground water is toward the river where the water table is shallow (closer to the surface), and flows away from the river where the water table is deep (deep below the surface). It means knowing the depth to the water table and location of a river is a very good standard for predicting the direction of water flow. This also implies that regions with low elevation and shallow (high water table) is more likely to contribute to surface water to form rivers or lake, while region with high elevation and deep (low water table) is more likely to receive from surface water through inter connecting pores to form underground water.

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