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Groundwater exploitation in Awka (Anambra – Nigeria) and environs: Prospects, and challenges while drilling and its mitigation measures

Sfruttamento delle acque sotterranee nei pressi di Awka (Anambra – Nigeria): prospettive, criticità incontrate durante le perforazioni e misure adottate

Ifeanyi Emmanuel Anyanwu[a] , **Sodiq Solagbade Oguntade[b]**

[a]Pee Drilling Company Nigeria Limited - email: *ifeanyi.e.anyanwu@gmail.com*
[b]IHE Delft Institute for Water Education - email: *sodiqoguntade@yahoo.com*

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Correspondence to:
Ifeanyi Emmanuel Anyanwu
ifeanyi.e.anyanwu@gmail.com

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Riassunto

Alcune prospezioni idrogeologiche sono state condotte nei pressi di Awka (stato di Anambra nel sud-est della Nigeria) tramite terebrazione di pozzi per analizzare le formazioni geologiche incontrate durante la perforazione, differenziare i pozzi in funzione della presenza di acquiferi confinati o non confinati, individuare le probabili zone acquifere in base ai dati stratigrafici, considerare le criticità (sia geologiche che operative) incontrate durante le indagini e identificare le misure impiegate per affrontarle. Sono stati elaborati log stratigrafici dettagliati per descrivere le unità litostratigrafiche intercettate durante la perforazione e ne sono state identificate quattro tipologie (scisti, arenarie, argille e ghiaie) comprese all'interno della Formazione Imo e della Formazione Nanka. Le informazioni ricavate dai log stratigrafici dei pozzi indicano che la falda acquifera, all'interno dell'area di studio, si pone da 11.2 m a 56.5 m dal piano campagna e che i settori acquiferi si estendono per spessori compresi tra 6.8 e 23.3 m. Un esame dettagliato della stratigrafia mostra che il 50% dei pozzi perforati mette in evidenza la presenza di falde acquifere confinate mentre la restante parte è interessata da acquiferi a carattere freatico. E' presentata anche una disamina delle criticità incontrate durante le indagini, direttamente attribuibili alle caratteristiche delle formazioni geologiche presenti nell'area di studio. Altre difficoltà tecniche sono inoltre ricondotte a guasti meccanici occorsi durante la fase di terebrazione.

Abstract

Groundwater exploitation (borehole drilling) was carried out around Awka and environs in Anambra State, Southeastern Nigeria, to understand the underlying rock units encountered while drilling, differentiate boreholes with confined aquifers from those with unconfined aquifers, delineate the probable aquiferous zones from the borehole data, evaluate the challenges encountered while drilling (both geologic and technical), and identify mitigation measures employed to address these challenges. Detailed geologic log information of the boreholes was produced to illustrate the rock units encountered while drilling. Four rock units were identified, namely: shale, sandstone, clay, and gravel. These rock units were exposed within the Imo Formation and the Nanka Formation that underlie the study area. Results from the geologic log information of the boreholes indicate that the water table within the study area ranges from 11.2 m to 56.5 m from the soil surface, and the probable aquiferous zones vary from 6.8 m to 23.3 m in thickness. A detailed look at the lithologic logs of the boreholes show that 50% of the drilled boreholes possess confined aquifers while the remaining 50% have unconfined aquifers. A careful appraisal of the challenges encountered, which are mainly geologic, is strictly attributed to the geologic formation of the study area. Other technical challenges have been derived from mechanical faults developed during drilling.

Inroduction

Potable water is the most basic need for any society to lead a healthy and productive life (Ehirim and Ebeniro 2010). Groundwater has been estimated to be about 20% of the world's freshwater resources and is widely used for various purposes (Dandwate 2012). The significance of water in facilitating the flourishing of intense agricultural activities, urbanization, and industrialization can never be over-emphasized. Groundwater exploitation is a reliable medium through which water is readily available to humanity and essential to access groundwater potential. The ever-increasing population status and the high demand for potable water are contributory factors that have led to a definite increase in groundwater exploitation globally. Approximately 100 L/day of safe drinking water has been predicted to be the minimum amount of water required per person for good healthy living (Falkenmark et al. 1989; Ehirim and Ebeniro 2010).

More than half of the world population rely on groundwater resources to obtain drinking water (Grönwall et al. 2010). This portrays the scenario in Awka metropolis; most of the people depend on groundwater. The primary medium through which groundwater is accessed in Nigeria is through shallow (hand-dug) wells and deep (borehole) wells (Omole 2013). The premises mentioned above account for the high prevalence of groundwater withdrawal through boreholes in the study area.

Borehole data incorporated with geologic log information have been carried out in Awka to understand the underlying lithologic units, determine the aquiferous zones of the boreholes dug through the geologic log information, delineate the types of aquifers obtainable, and evaluate the drilling challenges encountered while drilling. Intense groundwater exploitation (borehole drilling) has been carried out within the study area over the past two decades. Despite the dearth of adequate groundwater resources in Awka because of its geographical position and geological intricacies (presence of high depth of shale to sandstone lithologic units, which have an impact on the cost of drilling), there has been a heightened rate of groundwater exploitation in the recent past, leading to the availability of potable water for the populace (Ehirim and Ebeniro 2010). To exploit the groundwater, rotary drilling is predominant in Awka and its environment because of its ability to drill at a deeper depth. This type of drilling entails using a constantly rotating tool bit such as diamond core bit, tricone roller and drag bit in a circulating fluid or air to flush off cuttings.

Furthermore, a pump is needed to propel the fluid in circulation systems; a mud pump is used in mud-rotary drilling, while a compressor is used in air systems. One of the disadvantages of this type of drilling is that contamination may occur as a result of the circulating fluid, and drilling mud may jeopardize water quality by invading water-bearing formations (Naresh et al. 2009). However, it drills more quickly in coarse unconsolidated formations with large diameters (Soulsby 2021).

Over the years, notable groundwater studies have been carried out within the study area. These studies highlighted the hydrogeological properties, aquifer distribution, groundwater quality, and distribution of aquifer within the study area (Ezeigbo 1987; Ezenwa 1996; Onwuemesi and Olaniyan 1996; Nfor et al. 2007). However, a critical need remains to evaluate holistically the exploitation of groundwater and some of the challenges encountered while drilling within the study area. This will serve as a guide to the operations of borehole drilling companies within the study area. There is little to no sufficient information on the delineation of the aquifer types within the study area and the assessment of the challenges encountered while drilling. Hence, this research is aimed at highlighting the aquifer characteristics (precisely delineating the aquifer types and aquiferous zones) and identifying key challenges (with solutions) faced by borehole drilling companies while drilling within the study area. This will guide the borehole drilling companies on the possible depth they should expect to meet the aquiferous zone while drilling and provide them with possible solutions to be administered to challenges they might encounter while drilling.

Material and methods

The study area (Fig. 1a and Fig. 1b) is located within Awka and its environs and extends to Nimo. It spans between latitude 6°9'N to 6°14'N and longitude 6°59'E to 7°6'E of the Greenwich meridian and lies within the Imo Formation and Nanka Formation of the Niger Delta basin. Figure 2 shows a spatial distribution of the boreholes on satellite imagery, and a significant number of the boreholes are located towards the northeastern part of the study area. The general topographic surface of the study area is represented in Figure 3, with most parts of the study area having low to medium topographic attributes.

Boreholes were dug at Aroma, Amawbia, Nimo, Umuayom, Amaenyi, Umuokpu, and Ngozika Estate, all within Awka and its environs, as typically shown in Figure 2. Drill cuttings and the lengths of the drilling stem were recorded and well logged, giving rise to the derivation of geologic log information for the study area.

Geologic setting

The study area, which is found within the Niger Delta basin, as seen in Figure 4, consists of two lithostratigraphic units: Imo Formation and Nanka Formation. The Imo Formation underlies Awka and environs, where some locations in the study area (Aroma, Amawbia, Amaenyi, Ngozika Estate, Umuayom, and Umuokpu) are found. (Short and Stauble 1967) and (Ekwenye et al. 2014) stated that the unit is extensively distributed across southeastern Nigeria and dated Paleocene to Lower Eocene. (Reyment 1965) estimated the unit to be ca. 1000m thick and contains three sand bodies- Ebenebe Sandstone, Umuna Sandstone, and Igbaku Sandstone. (Nwajide 2013) identified that large-scale cross-beds and well-sorted sandstone primarily characterize the Ebenebe Sandstone member of the Imo Formation, which serves as the aquifer package for the most of Awka metropolis. The shales of the Imo Formation are fissile and are

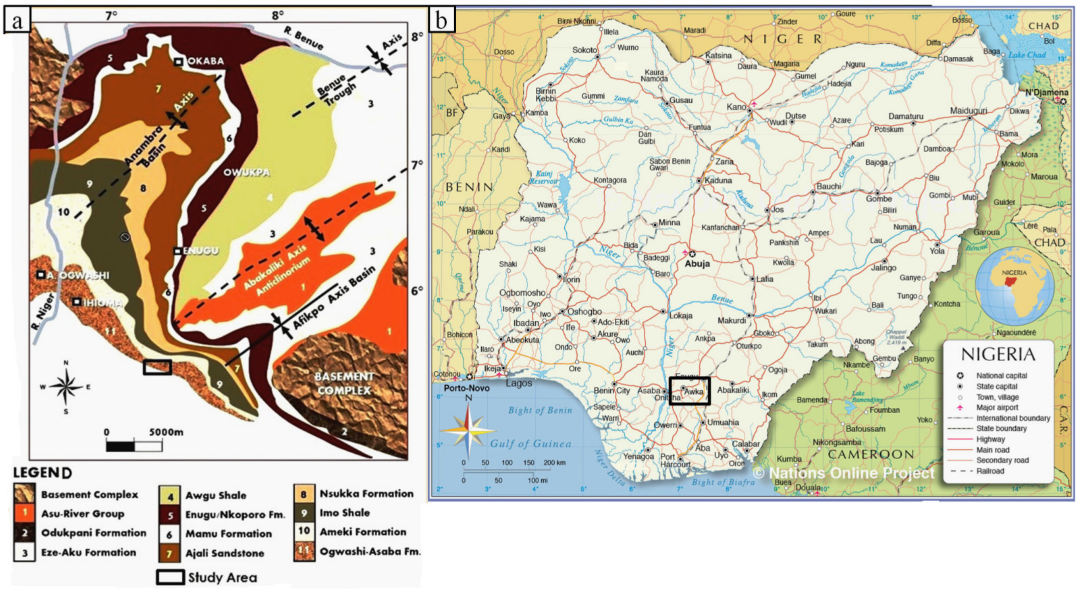

Fig. 1 - (a) Generalized geological map of southeastern Nigeria (boxed area of inset is the study area) showing the location of the Cretaceous to Tertiary sequences of the Niger Delta Basin (Akande et al. 2007) (b) Map of Nigeria (Source: https://www.nationsonline.org/maps/nigeria-political-map.jpg).

Fig. 1 - (a) Carta geologica della Nigeria sudorientale (l'area di studio è indicata nel riquadro) con l'individuazione delle sequenze dal Cretaceo al Terziario nel bacino del Delta del Niger (Akande et al. 2007) (b) Mappa di Nigeria (Fonte: https://www.nationsonline.org/maps/nigeria-political-map.jpg).

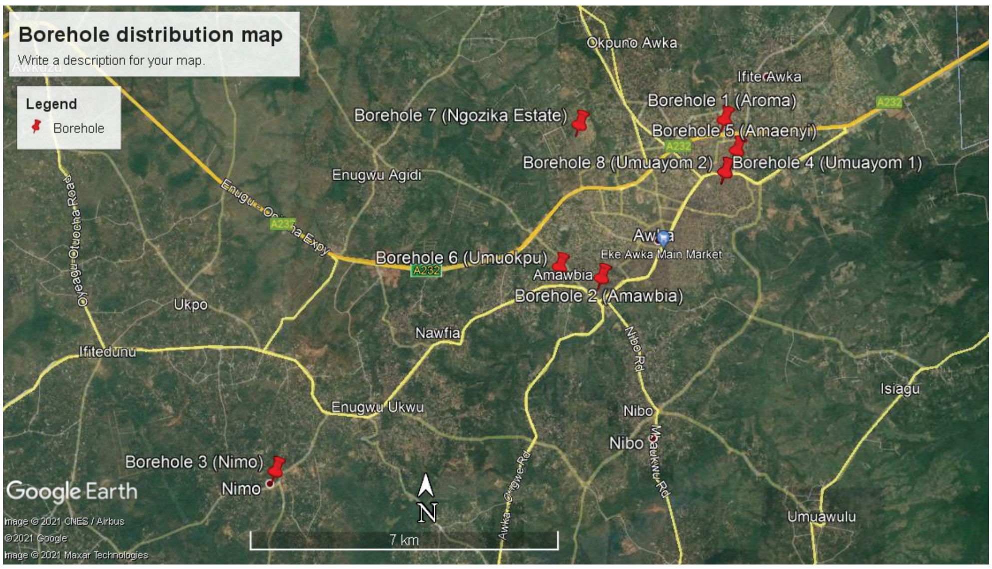

Fig. 2 - Satellite imagery map showing the distribution of the boreholes drilled in Awka and environs, Southeastern Nigeria (Source: Google Earth™).

Fig. 2 - Immagine satellitare con la distribuzione dei pozzi perforati nei pressi di Awka, Nigeria sudorientale (Fonte: Google Earth™).

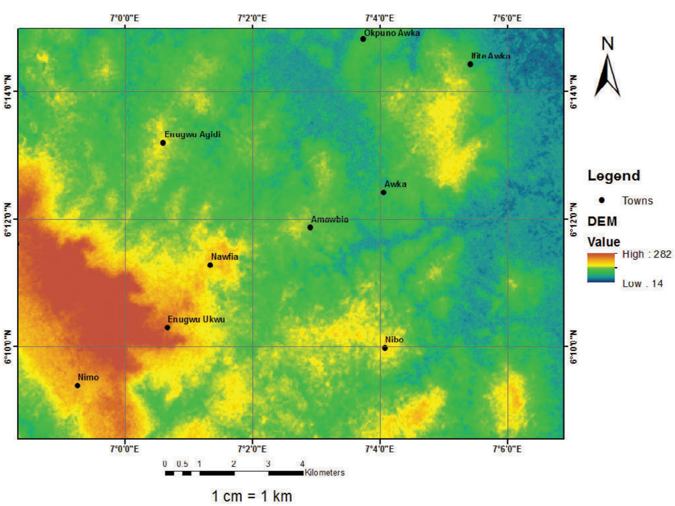

Fig. 3 - 2D Digital Elevation Map (DEM) of the study area (Note: DEM is in meters).

Fig. 3 - Mappa del modello digitale della superficie topografica (DEM) dell'area di studio (valore espresso in metri).

occasionally interbedded with sandstone intercalations, giving rise to prominent aquifer-aquitard systems (Ezeigbo 1987).

Nimo is essentially underlain by the Nanka Formation (Fig. 5), which is one of the lateral equivalents of the Ameki Group. The Ameki Group consists of the Nsugbe Formation, Nanka Formation, and Ameki Formation (Nwajide 1980), all lateral equivalents. The Nanka Formation, which is regarded as the loose sand facies of the Ameki Group, comprises overwhelmingly loose, flaser-bedded, fine to medium-grained sand, with few mudrock breaks (Nwajide 2013). (Ekwenye 2014) suggested tidal channel to the tidal flat environment for the formation, while (Nwajide 2013) suggested shallow marine to fluvial environments.

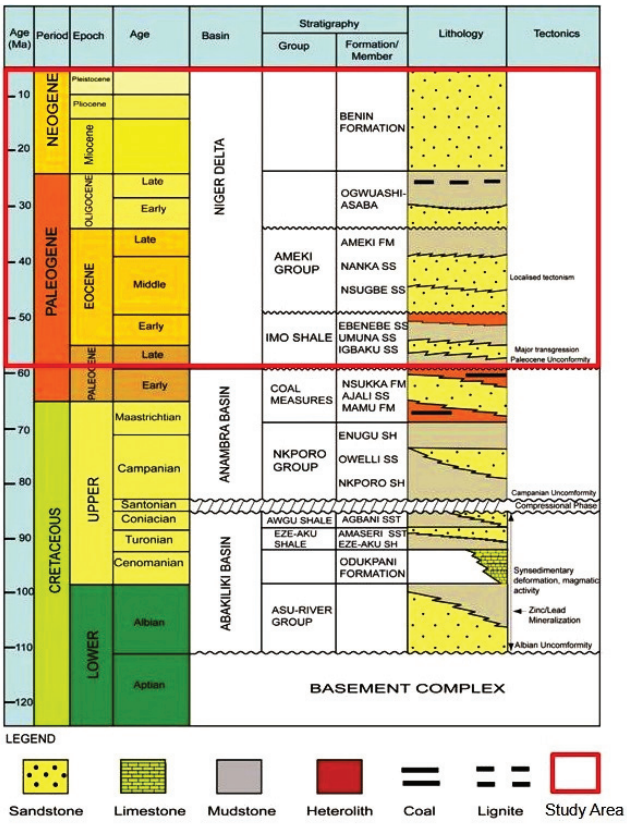

Fig. 4 - Stratigraphic succession in the Anambra Basin and Niger Delta basins (Short and Stauble 1967; Nwajide 2013; Ekwenye et al. 2014).

Fig. 4 - Successione stratigrafica del bacino dell'Anambra e del bacino del Delta del Niger (da Short and Stauble 1967; Nwajide 2013; Ekwenye et al. 2014).

Hydrogeology of the study area

The extent and distribution of groundwater within the study area are primarily controlled by lithology and other secondary factors, including topography and nearness to the source of recharge (Nfor et al. 2007). The geology of the aquifer at Awka and Nise, both in Awka South LGA of Anambra State, is the Ebenebe Sandstone lower member of the Imo Formation. However, (Nfor et al. 2007) asserted that the Imo Formation constitutes a poor aquifer due to its sedimentological characteristics. Within this area, sustainable

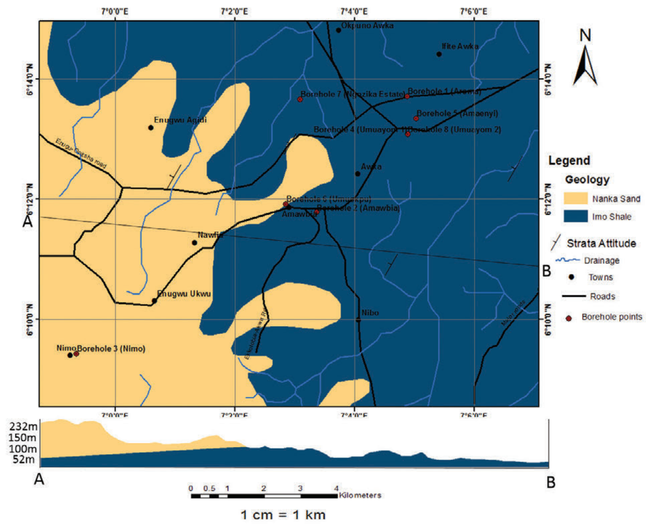

Fig. 5 - Geologic map and geologic cross-section (A-B) across the study area.

Fig. 5 - Carta geologica e sezione geologica (A-B) dell'area di studio.

water production is only carried out by drilling beyond the over 150 m thick pile of shale in the Imo Formation into the underlying aquiferous Ajali Sandstone (Nfor et al. 2007), especially at Ifite, Amansea, Ezeozu, and some other places. The major problem with drilling more than about 30 m at Ifite-Awka after encountering the water table (underlying aquiferous Ajali Sandstone), is the high probability (about 98%) of having iron content in the water, which on exposure to fresh air, leads to changes in the colour of the water to reddish-brown, hence unfit for human consumption. This portrays the overriding influence of lithology on groundwater distribution in the study, as (Nfor et al. 2007) proposed.

At Nimo, the core source of water for the area is the Nanka Formation. The Nanka Formation dips gently away from the water divide that runs from the north to the south of Anambra State, where the study area is located (Reyment 1965). However, (Nfor et al. 2007) identified that the groundwater flows southwesterly and easterly away from the water divide. Nanka Formation is considered to be highly prolific in water production, having four aquifer horizons, and recognized as: shallow, upper, lower, and deep aquifers; and the most exploited are the upper and lower aquifers, the most prolific of them being the deep aquifer with an average of 5 L/s (Nfor et al. 2007).

Total drilled depths of the boreholes dug at eight (8) locations within Awka and environs were recorded, as well as the length of each drilling stem used in drilling. Drill cuttings, taken from the flow line close to the drill hole, were recovered during drilling, washed, and sampled at intervals depending on the drilling stem length. A thorough sample description was made to characteristically identify the recovered samples' rock types and grain sizes. Detailed geologic log information (generated using data obtained from the different borehole locations) were built using modified SedLog 2.1.4TM. These geologic log information were used to identify probable aquiferous zones encountered at each borehole, characterize the aquifer type and identify depths

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at which drilling challenges were encountered. Geologic or technical challenges were characteristically evaluated, and feasible solutions employed during the drilling were identified.

The geologic log information of boreholes dug at the different locations within the study area is typically shown in Figure 6 below.

Results and discussion

From the geologic log information of the boreholes drilled in the study area (Fig. 6), it is noteworthy that 50% of the boreholes drilled within the study area cross confined aquifers and the remaining 50% have unconfined aquifers. The geologic logs of the boreholes indicate that the water table within the study area ranges from 11.2 m to 56.5 m from the soil surface, and the probable aquiferous zones vary from 6.8 m to 23.3 m in thickness. Also, the total drilled depth in the study area ranges from 18 m to 79.8 m, although this could be more for some other parts of Awka, such as Ifite and Amansea. Table 1 above shows the summary of the results, and the coordinates of the boreholes, respectively.

A detailed study of the geology and hydrogeology of the study area has shown that some parts of the study area are known to host shallow aquifers, such as Ngozika Estate, Aroma, Umuokpu, and Amaenyi. However, the geology of the study area has complexities that differ from location to location. Therefore, it is imperative to carry out detailed geophysical surveys to determine the actual depth to the water table, as some places such as Ngozika Estate tend to

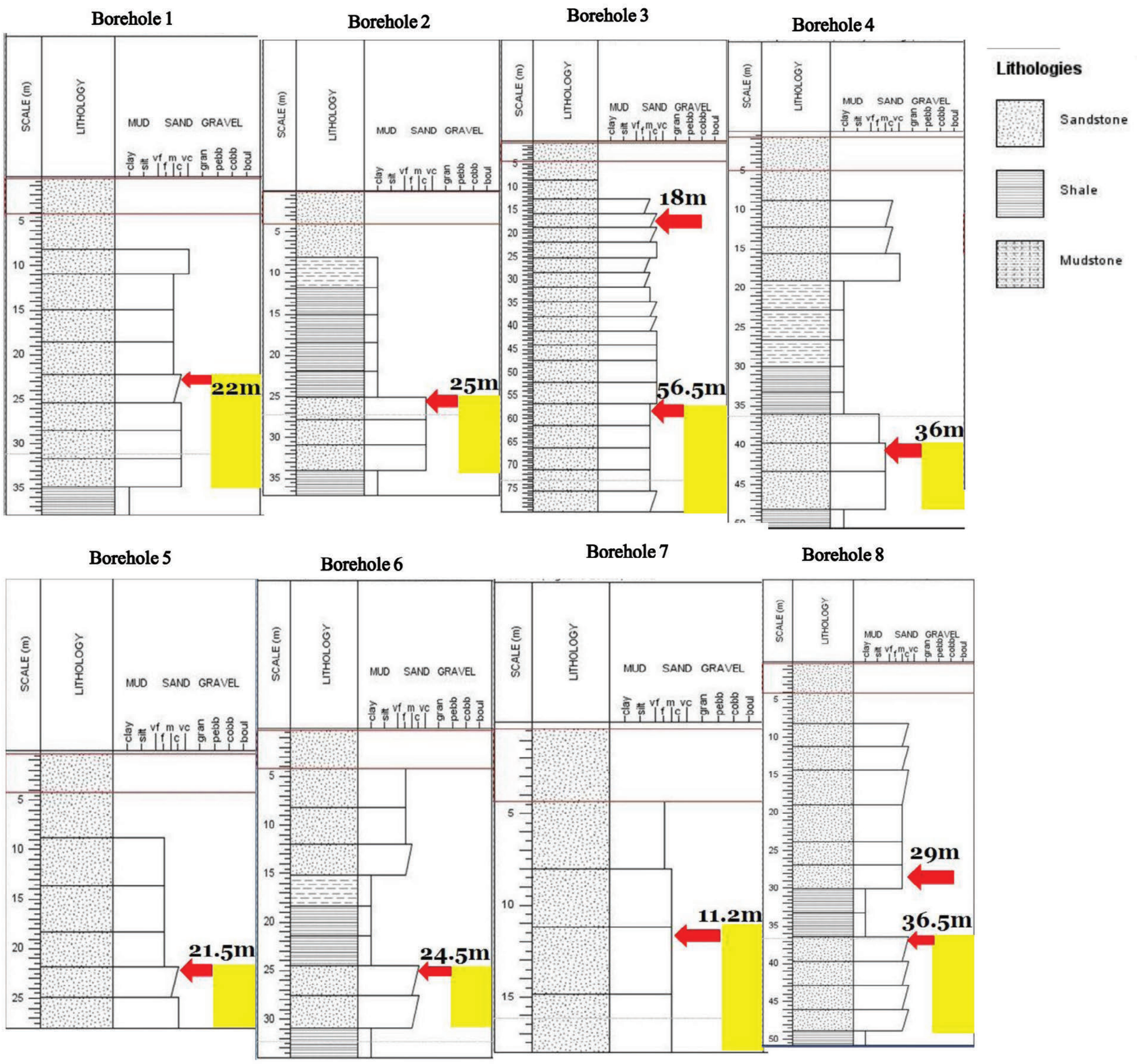

Fig. 6 - Detailed geologic log information of boreholes 1- 8 drilled within the study area.

Fig. 6 - Log litostratigrafici di dettaglio dei pozzi 1- 8 perforati all'interno dell'area di studio.

Tab. 1 - A detailed summary of the borehole locations, total drilled depths, probable aquiferous zones, and aquifer type encountered within the study area.

Tab. 1 - Riepilogo dettagliato delle posizioni dei pozzi, delle profondità totali di perforazione, dei settori di possibile intresse idrogeologico e della tipologia dell'acquifero intercettato

Borehole Numbers	Borehole Locations	Latitude	Longitude	Total Drilled Depths (m)	Probable aquiferous zone thickness (m)	Type of Aquifer
Borehole 1	Aroma	6° 13' 42.96"	7° 4' 53.04"	37.9	13	Unconfined
Borehole 2	Amawbia	6° 11' 47"	7° 3' 22"	36.8	9	Confined
Borehole 3	Nimo	6° 9' 25"	6° 59' 21"	79.8	23.3	Unconfined
Borehole 4	Umuayom 1	6° 13' 4.8"	7° 4' 53.4"	52.3	12	Confined
Borehole 5	Amaenyi	6° 13' 20.64"	7° 5' 2.04"	27.8	6.3	Unconfined
Borehole 6	Umuokpu	6° 11' 55"	7° 2' 51"	33.7	6.5	Confined
Borehole 7	Ngozika Estate	6° 13' 39.6"	7° 3' 5.7"	18	6.8	Unconfined
Borehole 8	Umuayom 2	6° 13' 4.8"	7° 4' 53.4"	51.7	12.5	Confined

have both shallow and deep aquifers. Hence, the geophysical survey will help the hydrogeologists and drillers plan how to execute the drilling operation efficiently. From the results shown above, the prevalence of shallow aquifers within the study area will translate to a more reduced cost of drilling as opposed to areas with deep aquifers, which connotes high cost of drilling. This serves as a good guide for the drilling companies in their operations within the study area.

Challenges Encountered During Drilling and their Solutions

Groundwater exploitation through drilling has always been a noble process geared towards ensuring the availability of clean water to the masses for various agricultural, industrial, and domestic functions. However, the drilling of boreholes within Awka metropolis has not been successful without challenges. This can be attributed to the area's geology, primarily composed of shaly and clayey formations with a good proportion of sand; therefore, one would expect most of the challenges to be attributed to the geologic composition of the study area. Other challenges result from man-induced technical and mechanical errors or malfunctioning of the drilling rig and other types of drilling equipment. These challenges slow down the rate of the drilling operations; they also consume the capital involved and could result in the high cost of borehole drilling in Awka and its environs. Some of these challenges and their solutions are:

a. Blockage of the nozzle of the diamond bit.

This situation was encountered while drilling Borehole 8. It occurred at 29 m drilling depth, as shown in Fig. 6, and entirely due to the geologic nature of the area, which the Imo Formation underlies. During drilling, sandy drill cuttings that had caved in were noticed to have blocked the nozzle of the diamond bit used in drilling, leading to the drilling mud's reduced flow to the surface and causing the drilling stem to hoist water as there is no gateway for water discharge.

Solution. Having noticed this anomaly, the drilling operation was paused. The drilling stems, together with the drilling bit, were pulled out from the drill hole. Manually, the drilling bit was thoroughly washed, and sandy drill cuttings stuck in the nozzle were carefully removed to facilitate easy flow of the drilling mud.

b. Stocking of drilling stems in the drill hole.

This occurred at Nimo, underlain by the Nanka Formation. It happened at 18 m drilled depth, as shown in Borehole 3 (Fig. 6), and is also attributed to the study area's geology. This is due to the sandy drill cuttings that caved-in into the drill hole, resulting in the smooth pulling up of the drilling stem during the drilling operation.

Solution. Four risers of 3.96 m, each fitted with galvanized sockets, were used to remedy the situation. The delivery hose from the mud pump was connected to the risers, and then water from the suction pit was circulated into the drill hole. The risers were inserted into the drill hole with marine rope and forced to the base to free the stocked drilling stems.

c. Cave-in of the drill cuttings.

This condition occurs when the rock cuttings drilled collapse and fill back the drill hole. The situation occurred while drilling Borehole 4 (Fig. 6), underlain by the Imo Formation. While drilling, the filling back of the drill hole by the drill cuttings resident within the walls of the drill hole occurred.

Solution. Thorough flushing was carried out with the addition of polymers, extender, and bentonite (drilling chemicals used in borehole drilling) to facilitate the flushing out of the drill cuttings from the drill hole. This process led to the sealing of the drill hole wall to avoid further cave-in of the drill cuttings, the cooling of the drill bit and the flushing of the drill cuttings that have filled back into the drill hole.

Risk management in borehole drilling

Risk management is essential in borehole drilling due to the number of human and non-human resources involved. The cave-in of boreholes during drilling can be managed in many ways; a good understanding of the area's geology will assist the drillers in taking some preventive measures at specific depth during drilling, especially at unconsolidated subsurface geology. In Nigeria, a lack of a detailed hydrogeological map is one of the major challenges of borehole drilling (Akujieze

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et al. 2003). This can be solved through a detailed geophysical survey, a severe problem in Nigeria; the high demand for groundwater has resulted in many unqualified geophysicists (Eduvie 2006). Furthermore, the clogging of the drilling bit can be prevented by adding the required drilling mud to prevent frictional movement of the bit.

Conclusions

Detailed borehole drilled depths of the different boreholes drilled within Awka and environs and generated geologic log information of the boreholes have provided useful data for establishing the type of aquifers encountered, the probable thickness of the aquiferous zones, and the range of the water table within the study area. The study area is characterized by mainly sandstone, shale, and clay, found within the underlying Imo Formation and Nanka Formation of the Niger Delta basin. An evaluation of some of the challenges encountered while drilling and the mitigation measures employed will guide the different borehole drilling companies within Awka and beyond should they encounter such challenges while drilling.

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Competing interest

The authors declare no competing interest.

Author contributions

Anyanwu IE and Oguntade SS conceptualised the study; Anyanwu IE collected the data and wrote the first manuscript. Oguntade SS guided the interpretation of the results, did literature searches, and revised the manuscript. All the authors read and approved the final manuscript.

Additional information

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