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In-Situ Gamma-Ray Logging as Diagnostic Tool for Failed Cased Water-Supply Boreholes, Lagos State

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ABSTRACT
Frequent failure of water-supply boreholes in Lagos State, Nigeria, is often linked to poor delineation of sand-clay sequence within Coastal Plain Sands and recent alluvium. This study applies in-situ gamma-ray (GR) logging to diagnose the causes of failure in existing boreholes and to guide targeted rehabilitation. Continuous gamma-ray logs were acquired in a set of two non-productive or short-lived boreholes in Isolo, Lagos State. Log motifs were interpreted to distinguish clean, water-bearing sands (low GR) from clay-rich or silt horizons (high GR). Gamma-ray derived lithology picks were integrated with caliper logs of same boreholes. Results show that the failures are attributable to screen placement within or straddling high gamma-ray clay/silt intervals; targeting of thin sand bed bounded by clay layers that rapidly foul screens; incomplete casing through upper clay layer that allow fine particles migration and casing corrosion. The study demonstrates that in-situ gamma-ray logging is a rapid, low-cost tool for post-failure evaluation, enabling evidence-based decisions on borehole rehabilitation, optimal screen setting, and future well siting in Logos' heterogeneous coastal aquifer system. This study also confirms beyond doubt the usefulness of gamma-ray logs for accurate borehole design and the importance of borehole geophysics for subsequent continual monitoring of groundwater quality of producing boreholes.

Keywords:
Aquifer,
Borehole failure,
Gamma-ray,
Screen.

INTRODUCTION

Groundwater is a very important resource for domestic, agricultural and industrial use in Lagos State (a rapidly urbanizing region with a high population density and increasing water demand). With a growing population and increasing demand for potable water, borehole drilling has become a common practice to supplement public water supply. However, a significant number of these boreholes fail shortly after construction, leading to wasted investment and prolonged water access challenges. Understanding the underlying causes of borehole failures is therefore crucial for ensuring sustainable water resources development.

One of the key factors contributing to borehole failure is inadequate geological and hydrogeological assessment prior to drilling. Conventional approaches such as drill cuttings and lithologic logs are often insufficient to accurately delineate aquifer units, predict water quality or assess borehole performance in complex sedimentary sequences. This challenge underscores the need for effective geophysical technique capable of providing reliable subsurface information even in already cased water-supply boreholes. In this context, geophysical logging techniques, particularly in-situ gamma-ray logging, offer a valuable, non-invasive tool for evaluating subsurface conditions and identifying lithological variations that influence groundwater availability and borehole performance.

The aim of this study is to evaluate the applicability of in-situ gamma-ray logging as a diagnostic tool for characterizing lithological successions, identifying aquifer zones, and evaluating failed water boreholes across selected locations in Lagos State. By analyzing the natural gamma radiation emitted from subsurface formations, gamma-ray logs can help distinguish between clay-rich and sandy aquifer units, offering insights into the hydrogeological framework that may underlie borehole failure. The findings of this research aim to contribute to improved borehole siting practices and sustainable groundwater management strategies in the region. This study also demonstrates the importance of borehole geophysics in evaluation of cased water-supply boreholes. It also demonstrates the need and importance of borehole geophysics for borehole design and subsequent water borehole performance monitoring. The gamma-ray log is a veritable tool in formation evaluation revealing the subsurface formation lithology, its thickness, depth (location) and bed boundaries encountered during drilling.

Previous studies have highlighted the utility of gamma-ray logs in groundwater investigations. Jimoh et al. (2018) employed natural gamma-ray and resistivity logs to delineate aquifer zones and freshwater-saltwater boundaries in the Apapa coastal area of Lagos, demonstrating the method's effectiveness. Similarly, Ilugbo et al. (2019) combined electrical resistivity and gamma-ray logs to characterize aquifer units in Ikeja, Lagos Mainland and confirmed their value in identifying multiple aquifer horizons within complex alternating sand-clay sequences. Beyond Nigeria, Amartey et al. (2017) in Ghana showed that integrating gamma-ray and resistivity logs improves fracture-zone identification in crystalline terrains, further underlining the versatility of the method across different hydrogeological settings. These studies affirm that gamma-ray logging is a powerful tool for groundwater exploration, particularly in differentiating lithologies and resolving stratigraphic ambiguities.

Despite these advances, most applications of gamma-ray logging in Lagos have been limited to open-hole logging with little emphasis on its use for post-construction evaluation of fully cased water-supply wells. This represents a critical knowledge gap, as the majority of operational boreholes in Lagos are cased and thus difficult to assess using conventional geophysical tools.

The contributions of this study lies in demonstrating that gamma-ray logging can be effectively utilized in situ within cased water-supply boreholes, thereby extending the applicability of borehole geophysics in hydrogeological evaluations. This approach provides a cost-effective, non-destructive method for identifying productive aquifer intervals, improving borehole design, and mitigating risks of saline intrusions in coastal zones. Furthermore, the findings are expected to support groundwater management and regulatory practices in Lagos State by providing a framework for integrating gamma-ray log data into water-resource assessment.

Area of study and its Geology

The area of the research is Isolo in Oshodo-Isolo Local Government Area of Lagos State, Nigeria. The geographic coordinates of Isolo is Latitude 6.52916ºN and Longitude 3.32172ºE. Isolo is underlain by recent sedimentary formations, primarily consisting of clays, silts, and sands. These deposits are typical of coastal plains and are often associated with low shear strength and high compressibility. According to Oladimeji et al. (2025), in addition to these saturated shallow coastal plain sands and alluvium, two main stratiform aquifer groups have been identified and mapped. These are the Abeokuta formation and the lower part of Ewekoro formation. Another is the Ilaro formation which is predominantly both marine and continental deposits and the sands are usually coarse, angular, poorly sorted and contains considerable clay fractions.

MATERIALS AND METHODS

Natural gamma logging was performed with a wire-line sonde equipped with thallium-doped Sodium-Iodide (Nal(Tl) scintillation detector optimized for counts-per-second (CPS). When a gamma ray strikes the crystal, a small flash of light produced is amplified by a photomultiplier and the resulting current is amplified further by conventional amplifiers. Since the flash of light and the number of primary electrons are proportional to the energy of the gamma ray, the final current from the scintillation counter is also proportional to the energy of the incident gamma ray.

The primary source of natural gamma radiation in the earth's crust are radioactive isotopes of potassium-40 (^{40}K), Uranium (^{238}U) and thorium (^{232}Th). High gamma-ray counts typically indicate presence of clay or shale formations which are often impermeable and may hinder groundwater flow while low counts suggest the presence of cleaner more permeable sandy or gravelly materials favorable for water production (Kearey et al. 2002). According to Amadi et al. (2012), shale, clay and granite have the highest amount of gamma radiation count per second in scintillation counters (60 to 105) while amphibolite show the lowest gamma radiation counts per second (16 – 46) in scintillation counters. Once the gamma rays are emitted from an isotope in the formation, they progressively reduce in energy as the result of collisions with other atoms in the rock by means of Compton scattering. By providing a continuous vertical profile of radioactivity along the borehole depth, in-situ gamma-ray logs helps in identifying lithological transitions, locating aquifer boundaries and detecting zones of potential hydraulic conductivity contrast, thereby enhancing the success rate of borehole development (Mohammed et al. 2023).

The field acquisition procedure begins with ensuring that all electrical connections are correct and firmly secured. Then, the sonde is lowered into the borehole with all logs recorded from surface to target depth (TD) at 3-6 m/min with 0.10-0.15m depth sampling; slower speeds (≤ 3 m/min) were used over screened/perforated zones to maximize count statistics. Depth was referenced to the top of casing (TOC) and corrected using a casing-collar locator. Since the wells were non-producing and abandoned over time, no turbulence and scintillation spike artifacts were observed. Raw CPS were filtered with a 3- to 5- sample moving median to suppress possible spikes around collars.

RESULTS AND DISCUSSION

The figures 1, 2 and 3 below show the result of gamma-ray logging of the cased water boreholes.

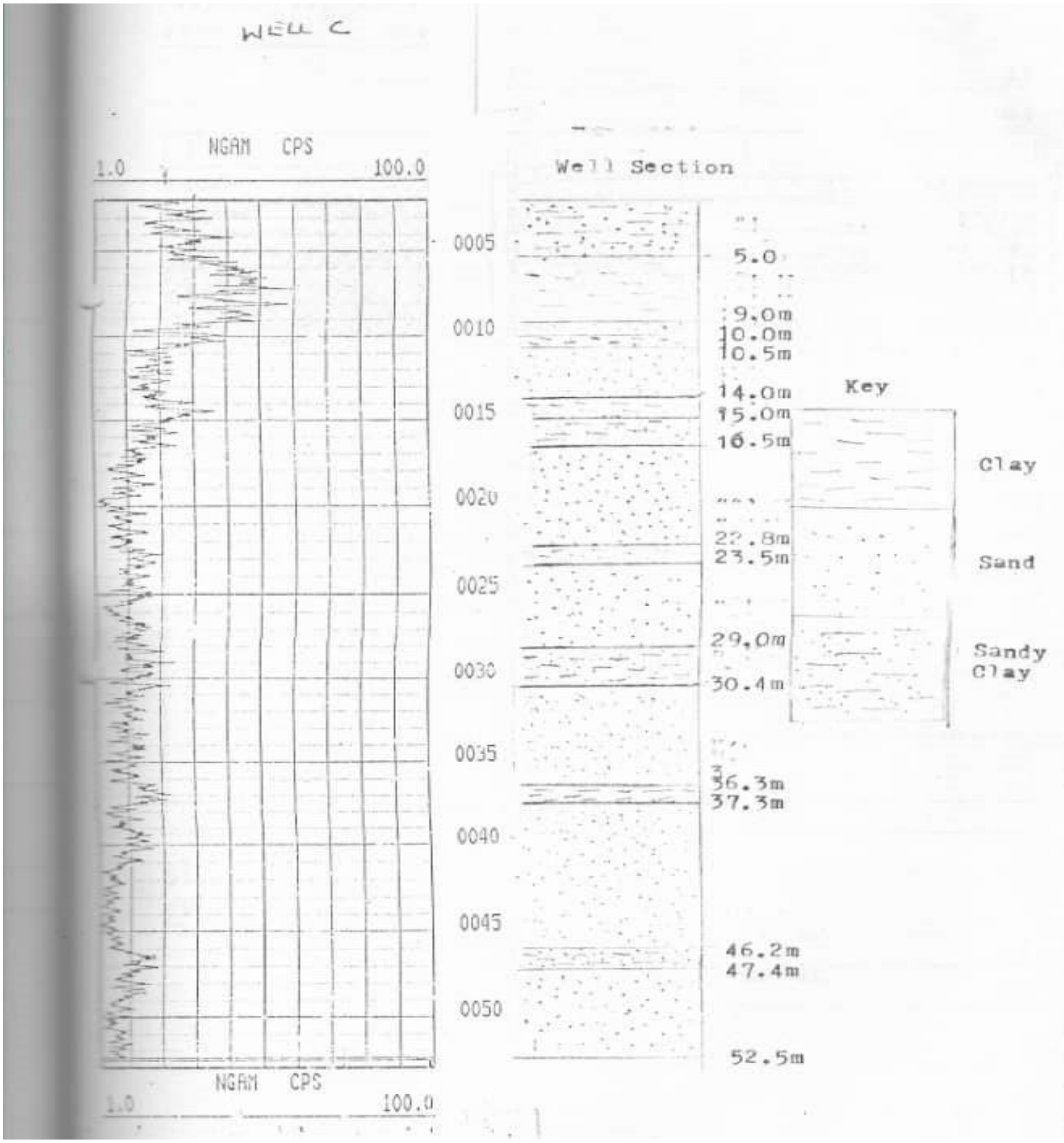

Figure 1: Showing well C natural gamma-ray log

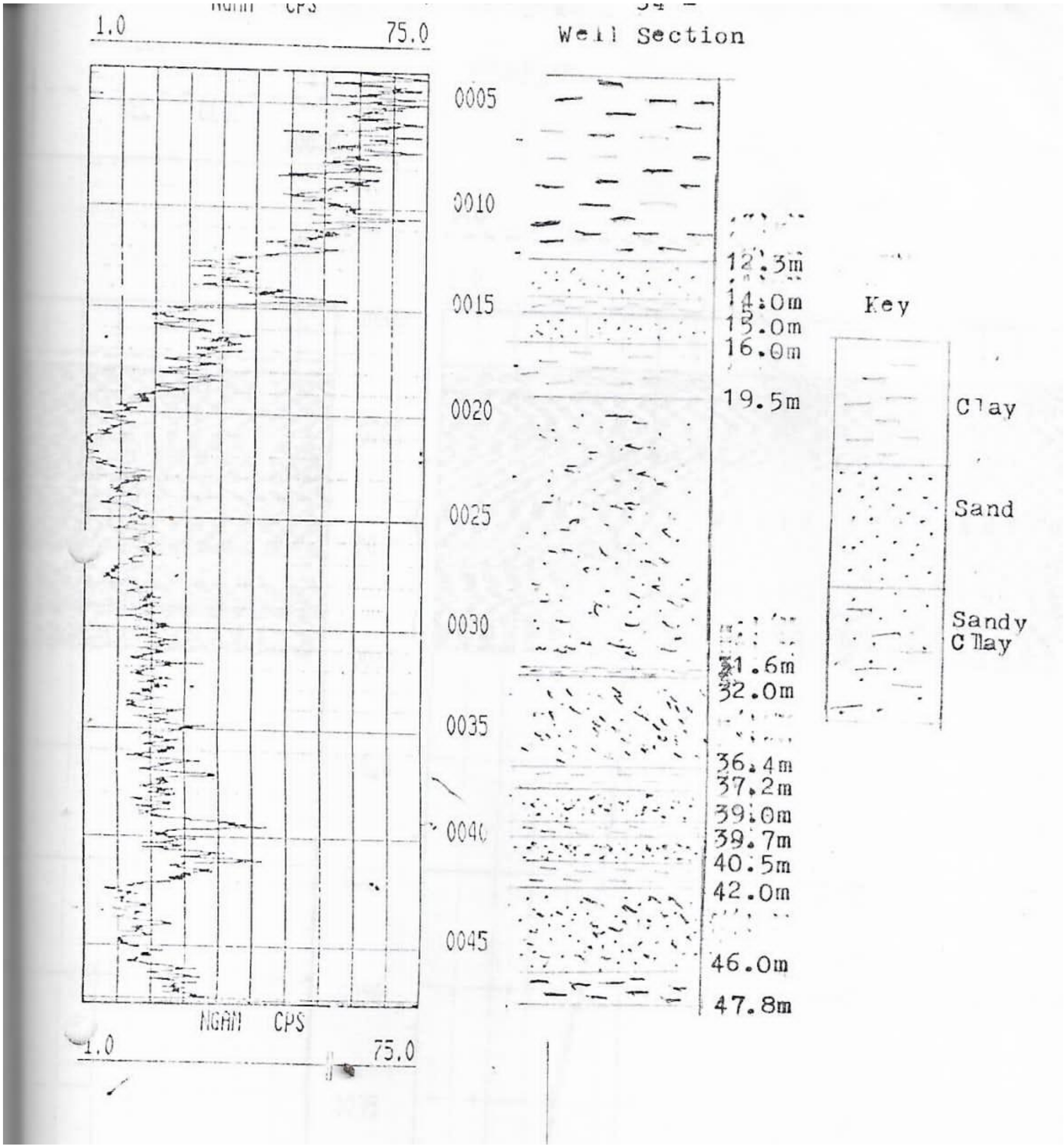

Figure 2: showing well D natural gamma-ray log

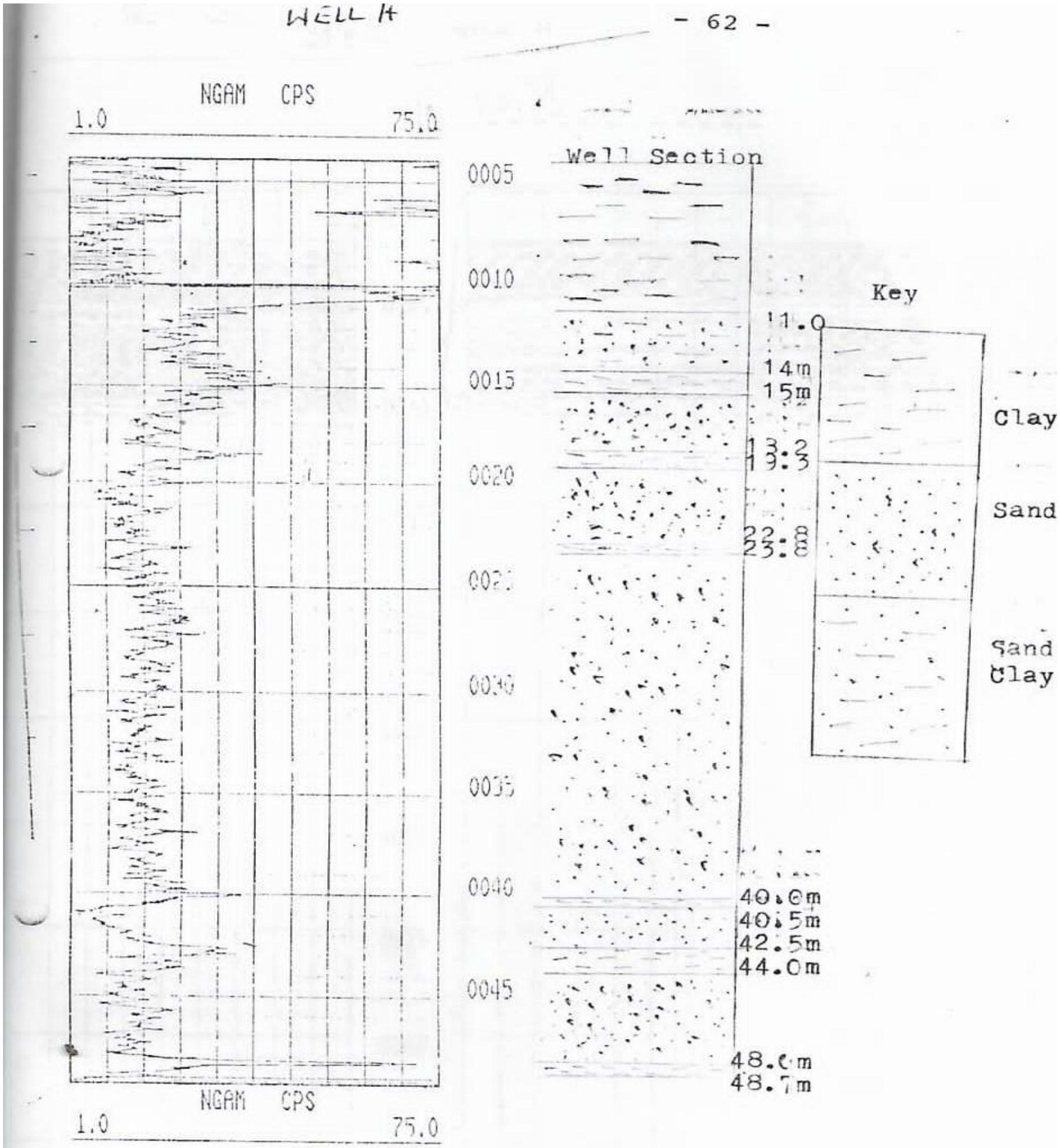

Figure 3: showing well H natural gamma-ray log

Discussion

Natural-gamma (GR) motifs were interpreted qualitatively to delineate clay-rich (high GR) versus sand-dominated (low GR) packages, then correlated across wells to identify aquifer tops/bases and intra-aquifer clay breaks typical of Dahomey Basin (Jimoh et al. 2018; Akinlalu & Afolabi, 2018). The application of in-situ gamma-ray logging in the evaluation of failed water boreholes in Lagos State yielded critical insight into the subsurface lithological conditions contributing to borehole failures. The gamma-ray log exposed the accurate lithological bed thickness, location and fine bed boundaries of the formations encountered during drilling as seen in figure 1 of well C, figure 2 of well D and figure 3 of well H above. The findings underscore the importance of integrating geophysical logging methods, particularly gamma-ray logs, in borehole siting, drilling and post-failure analysis.

One of the central observations from the gamma-ray logs is the prevalence of high gamma-ray counts in sections of the borehole associated with clay-rich formations. These high radioactivity zones are indicative of shale and clay layers, which are generally impermeable and act as aquitards. In these failed boreholes, judgment on aquifers location was poorly made leading to installation of screens on depth range covering sandy formation interbedded with clayey sand and this resulted to poor yields and rapid clogging due to fine particles infiltration. This finding aligns with studies by Offodile (2002) and Ogunsanya & Ogunsanya (2021). Dinneya et al. (2021) in their studies on "Reservoir Characteristics of Pole Field in Niger Delta Basin, Using Well Logging" also confirmed the usefulness of gamma-ray log and other logs in distinguishing reservoir units.

The spatial variability in lithology observed through the gamma-ray data highlights the heterogeneity of the subsurface. This underscores the need for site-specific subsurface characterization rather than reliance on regional geological assumptions. These statements agree with studies on "use of geophysical logs in hydrogeological studies and borehole designs" by Jimoh, R.A et al. (2018). The borehole failures examined in this study stem from insufficient pre-drilling investigation or a lack of detailed lithological logs, leading to inappropriate well design or poor aquifer targeting.

In addition to lithological misinterpretation, the study reveals that poor borehole construction practices may have exacerbated the failure rates. For instance, in wells C and D, the logs indicate the boreholes were screened across both aquifer and aquitard, allowing fine particles and contaminants to enter the well. Leading to clogging and water quality deterioration. The screens were placed at the depths 46.0m to 52.0m in well C and depths of 40.0m to 46.0m which corresponds to clayey-sand and sand sequence. The presence of clay within this region hampered the water borehole performance. This observation is confirmed in studies by Konikow, L.F. et al. (2001) on "effects of clay dispersion on aquifer storage and recovery". This reinforces the critical role that gamma-ray logs play not only in aquifer identification but also in informing optimal screen placement and casing depth.

Overall, the results from this study demonstrate that gamma-ray logging is a valuable, cost-effective diagnostic tool for evaluating borehole performance and preventing future failures. By identifying subsurface formations and distinguishing between aquifer and non-aquifer units, gamma-ray logs offer a reliable means of guiding drilling decisions, borehole design, completion, borehole performance monitoring and improving borehole longevity.

CONCLUSION

The evaluation of failed water boreholes using in-situ gamma-ray logging in Lagos State has provided crucial insights into the subsurface conditions responsible for poor borehole performance. This study clearly demonstrated that a significant proportion of borehole failures are linked to improper aquifer targeting, drilling into clay-rich formations, and inadequate borehole design- all of which can be effectively identified and mitigated using gamma-ray log data. Gamma-ray logs proved instrumental in distinguishing between sand (potential aquifer zones) and clay (aquitard) layers, thus enabling a clearer understanding of the lithological sequences encountered during drilling. In the failed boreholes, high gamma-ray responses corresponds to thick impermeable clay zones, which offer limited or no groundwater yield. The misinterpretation of these formations, coupled with poor construction practices such as improper screen placement, contributed significantly to borehole failure. This study, therefore, confirms beyond doubt the usefulness of gamma-ray logs for accurate borehole design and the importance of borehole geophysics for subsequent continual monitoring of groundwater quality of producing boreholes.

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