



Comparative Effects of Rainwater and Borehole Water on Concrete Construction: A Case Study of the Niger Delta Region, Nigeria

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Abstract

Water quality is a critical factor influencing concrete performance, yet in the Niger Delta region of Nigeria, construction water is often selected based on availability rather than suitability. This study compares rainwater and borehole water as mixing media for concrete, assessing their physicochemical properties, effects on compressive strength, and potential durability risks under controlled laboratory conditions. Rainwater was harvested from clean roof catchments during the rainy season, while borehole water was drawn from community sources after flushing pumps to ensure fresh aquifer water. Concrete cubes (150 mm × 150 mm × 150 mm) were prepared using a 1:2:4 mix ratio and tested at 7, 14, and 28 days. Results indicate that rainwater, slightly acidic and low in dissolved minerals, enhanced early strength (7 days), whereas borehole water, mineral-rich and alkaline, achieved higher long-term strength (28 days). Both water sources fell within international permissible limits (ASTM C1602; BS EN 1008), yet their distinct chemical profiles suggest differing implications for durability, including corrosion and sulfate attack. Findings highlight the necessity of routine water testing and appropriate treatment before concrete use, with significant implications for contractors, engineers, and regulatory authorities seeking to optimize construction quality and infrastructure longevity in the Niger Delta.

Keywords: Rainwater, Borehole water, Concrete performance, Niger Delta, Durability.

Introduction

Water is a critical component in concrete production, significantly influencing hydration, strength development, and durability (Ikpa et al., 2021; Miller et al., 2018; Xue et al., 2023). In the Niger Delta region of Nigeria, water for construction is often selected based on convenience rather than quality assessment, with rainwater harvested during storms and borehole water serving as the primary groundwater source across communities (Abubakar et al., 2025; Raymond & Hamilton, 2018). Despite the importance of water quality in determining concrete performance, there is limited comparative data in the region quantifying how these sources influence key concrete properties under local environmental conditions (Ojo et al., 2025). This gap creates uncertainty for practitioners, as unsuitable water can compromise structural integrity, accelerate reinforcement corrosion, and reduce service life. Previous studies indicate that rainwater in South-South Nigeria tends to be slightly acidic, with low hardness but measurable sulphates, nitrates, and trace metals (Abulude et al., 2022; Nduka et al., 2008; Nicholas et al., 2025; Oloyede et al., 2026). Borehole water, in contrast, reflects local geology and anthropogenic influences and often contains higher concentrations of dissolved ions, such as iron, chloride, and sulphate, which can affect concrete durability (Raymond & Hamilton, 2018; Ojo et al., 2025). While international and national standards—including ASTM C1602 and BS EN 1008—specify permissible limits for chlorides, sulphates, and other impurities in mixing water (ASTM International, 2019; Babu et al., 2018), practical implementation in the Niger Delta is inconsistent. Previous studies also highlight that rainwater's low mineral content may accelerate early hydration, while borehole water's higher alkalinity may improve long-term strength but may also carry risks of chloride- or sulphate-induced degradation (Mbuh et al., 2024; Ojo, 2019). Given these findings, this study seeks to empirically compare rainwater and borehole water with respect to physicochemical properties, compressive strength development, early-setting characteristics, and potential durability concerns under controlled laboratory conditions. The purpose is to provide actionable insights for contractors, engineers, and regulatory authorities,

emphasizing the importance of routine water testing and appropriate treatment before use. The study's results are particularly relevant to stakeholders in the Niger Delta, where environmental factors such as acid rain, saline intrusion, and industrial emissions exacerbate water quality variability and its impact on concrete performance. By identifying the differential effects of water sources, this research aims to inform better material selection, reduce construction risks, and enhance infrastructure longevity in the region.

Materials and Methods

The procedures used for water sampling and handling in this study were carefully structured to ensure that the effect of water quality on concrete properties could be evaluated under controlled and reliable conditions, as recommended by Fadil et al (2022) and Mama et al. (2019). As shown in Table 1, two water sources—rainwater and borehole water—were selected, and specific protocols were followed for collection, storage, and testing. Rainwater was harvested from clean roof catchments during the rainy season and stored in airtight plastic containers, while borehole water was collected after flushing the pump for five minutes and transported in sterilized containers under cool conditions. Both samples were tested within 24 hours to minimize chemical alteration before use in concrete production. These procedures are consistent with standard experimental practices in construction materials research, where control of sample contamination and storage conditions is necessary to obtain valid results (Krauss & Paret, 2014; Mehta et al., 2024).

Table 1: Sources and Characteristics of Collected Water Samples

| Water Source | Collection Method | Storage Condition | Testing Timeline |
|--------------|--|---------------------------------------|------------------------|
| Rainwater | Harvested from a clean roof catchments during the rainy season | Airtight plastic containers | Tested within 24 hours |
| Borehole | Drawn from community boreholes after flushing for 5 mins | Sterilized containers, cool transport | Tested within 24 hours |

The adoption of an experimental comparative design is justified because the study aims to isolate water quality as the independent variable while measuring its influence on compressive strength, setting time, and concrete durability. Comparative experimental methods are widely recommended in concrete technology research to determine how variations in mixing water affect hydration, strength development, and long-term performance (Krauss & Paret, 2014). In addition, the choice of the Niger Delta as the study area is methodologically appropriate given its high rainfall, reliance on borehole water, and environmental stress from oil exploration and saline intrusion, all of which may alter water chemistry (Ojo et al., 2025; Raymond & Hamilton, 2018). Hydro-chemical sampling guidelines also recommend flushing boreholes, using sterilized containers, and testing samples promptly, as was done in this study, to ensure representative water-quality results (Bridgewater, 2017; Nilsson et al., 2020).

Furthermore, the preparation of concrete cubes using a 1:2:4 mix ratio with a water–cement ratio of 0.5 and testing at 7, 14, and 28 days follows internationally accepted standards for evaluating concrete strength development. Standard curing periods are necessary because concrete properties change with hydration time, and 28-day strength is commonly used as the reference for performance evaluation (ASTM International, 2022). By following these procedures, the study ensures that any observed differences in concrete performance can be attributed to water-source quality rather than to uncontrolled experimental factors, thereby strengthening the validity of the results.

Results

The physicochemical analysis of the two water sources used for concrete production revealed clear differences in their chemical composition, which have direct implications for concrete performance. As presented in Table 2, rainwater recorded a pH value of 6.2, indicating slight acidity, while borehole water showed a pH of 7.8, reflecting alkaline conditions within the permissible limits specified by BS EN 1008 and ASTM C1602 standards. Electrical conductivity and total dissolved solids were significantly higher in borehole water (320 μ S/cm and 210 mg/L) than in rainwater (45 μ S/cm and 30 mg/L), indicating a greater mineral content in groundwater. Similarly, chloride, sulphate, hardness, and iron concentrations were higher in borehole water but remained within allowable limits for concrete mixing.

Table 2: Physicochemical Properties of Rainwater and Borehole Water

| Parameter | Rainwater (Average) | Borehole Water (Average) | Permissible Limit (BS EN 1008 / ASTM C1602) |
|---|---------------------|--------------------------|---|
| pH | 6.2 | 7.8 | 6.0–8.5 |
| Electrical conductivity ($\mu\text{S}/\text{cm}$) | 45 | 320 | ≤ 2000 |
| Total Dissolved Solids (mg/L) | 30 | 210 | ≤ 2000 |
| Chloride (mg/L) | 15 | 120 | ≤ 500 |
| Sulfate (mg/L) | 10 | 80 | ≤ 600 |
| Hardness (mg/L CaCO_3) | 25 | 180 | ≤ 500 |
| Iron (mg/L) | 0.05 | 0.8 | ≤ 1.0 |

These findings are consistent with hydro-chemical studies in the Niger Delta, where rainwater acidity has been linked to atmospheric deposition and industrial emissions, while borehole water mineralization reflects geological formations and anthropogenic activities (Abubakar et al., 2025; Ojo et al., 2025). The comparative visualization shown in Figure 1 further illustrates the contrast between the two sources: rainwater has a low ionic concentration, while borehole water shows higher mineral content across most parameters. From a construction perspective, low dissolved solids in rainwater may promote early hydration, but acidic conditions can increase the risk of reinforcement corrosion, especially in coastal environments. Conversely, the higher chloride and sulphate levels in borehole water, although within permissible limits, may contribute to long-term durability concerns such as sulphate attack and steel corrosion if not properly controlled (Mehta et al., 2024; ASTM International, 2014).

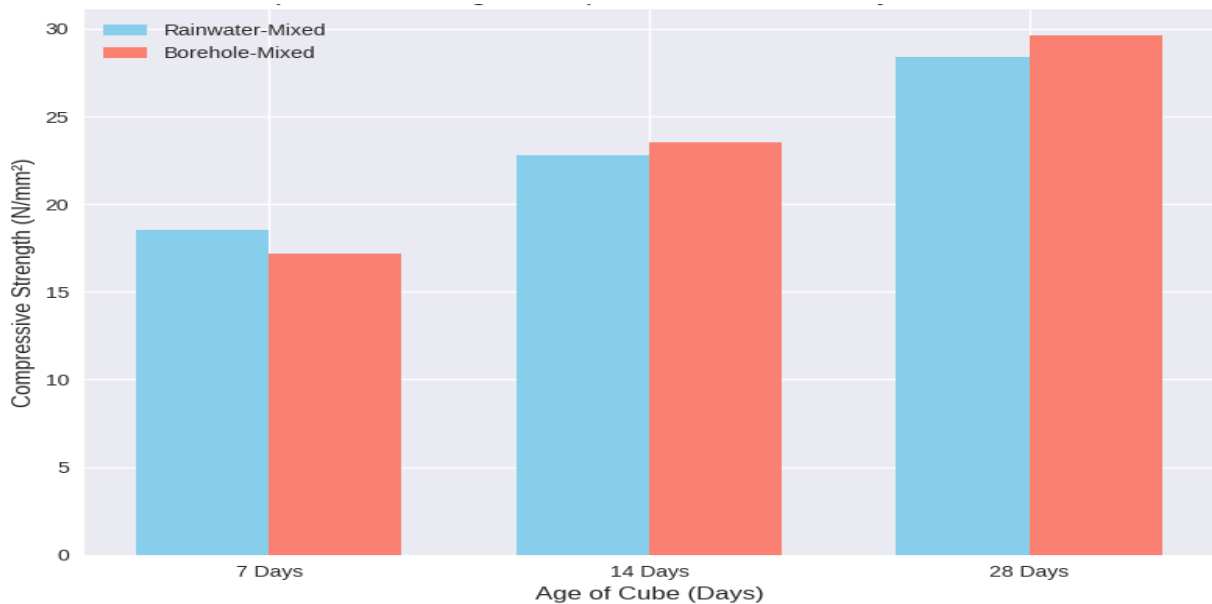


Figure 1: Compressive strength comparison of concrete by water source

The compressive strength results of concrete cubes prepared with the two water sources also showed noticeable differences at different curing ages. As indicated in Table 3, rainwater-mixed concrete achieved slightly higher early strength at 7 days (18.5 N/mm²) compared to borehole-mixed concrete (17.2 N/mm²), suggesting that the lower mineral content of rainwater may facilitate faster initial hydration reactions. However, at 14 days, borehole water concrete (23.5 N/mm²) slightly exceeded rainwater concrete (22.8 N/mm²), although the difference was not statistically significant. At 28 days, borehole-mixed concrete achieved the highest strength value (29.6 N/mm²),

surpassing rainwater-mixed concrete (28.4 N/mm²), and the ANOVA results confirmed that this difference was statistically significant. These findings agree with established concrete technology principles, which state that water with moderate mineral content can enhance long-term strength development by influencing cement hydration products and pore structure (Krauss & Paret, 2014; Mehta et al., 2024). Similar results were reported by Mbuh et al. (2024), who observed variability in concrete strength when rainwater was used, depending on its chemical composition, while Ojo (2019) noted that mineral-rich water may improve long-term durability under controlled conditions.

Table 3: Average Compressive Strength of Concrete Cubes (N/mm²)

| Age of Cube | Rainwater-Mixed Concrete | Borehole-Mixed Concrete |
|-------------|--------------------------|-------------------------|
| 7 Days | 18.5 | 17.2 |
| 14 Days | 22.8 | 23.5 |
| 28 Days | 28.4 | 29.6 |

The statistical analysis further confirmed that water quality significantly influences concrete performance. Differences in compressive strength at 7 days and 28 days were statistically significant, indicating that the source of mixing water affects both early and long-term strength development. These results emphasize the need for routine water quality testing before use in construction. In the Niger Delta environment, durability concerns are particularly important due to high humidity, saline intrusion, and industrial pollution. Rainwater acidity may accelerate reinforcement corrosion, while higher chloride and sulphate levels in borehole water may contribute to efflorescence, cracking, or sulphate attack over time (Nduka et al., 2008; Raymond & Hamilton, 2018). Therefore, although both rainwater and borehole water can be used for concrete production, their suitability depends on proper monitoring and treatment. Rainwater may require neutralization to reduce acidity, whereas borehole water should be tested for chloride and sulphate content, especially in coastal communities. These findings demonstrate that careful evaluation of water quality, as summarized in Table 2, the strength results in Table 3, and the comparative illustration in Figure 1 are essential for ensuring durable and reliable concrete structures in the Niger Delta region.

Discussion of Findings

The results of this study highlight significant variations in the physicochemical properties of rainwater and borehole water used for concrete production in the Niger Delta region, and their consequential effects on concrete performance. Rainwater was slightly acidic (pH 6.2) with low dissolved solids, chloride, sulphate, and hardness, whereas borehole water was alkaline (pH 7.8) and relatively mineral-rich (Table 2). These differences affected concrete behaviour: rainwater-mixed concrete exhibited slightly higher early strength at 7 days (18.5 N/mm²) than borehole water (17.2 N/mm²), likely due to accelerated initial hydration reactions facilitated by the lower mineral content. However, borehole water-mixed concrete surpassed rainwater-mixed concrete at 28 days (29.6 N/mm² vs. 28.4 N/mm²), indicating better long-term strength development (Table 3, Figure 1). The statistical analysis confirmed that the differences at early and late ages were significant, emphasizing that water source materially influences both early and long-term concrete performance (ANOVA, $p < 0.05$).

These findings are consistent with previous studies that report rainwater's low mineral content promotes early hydration but may risk reinforcement corrosion if acidity is unaddressed, whereas mineral-rich water supports long-term strength and durability (Krauss & Paret, 2014; Mehta et al., 2024; Mbuh et al., 2024; Sanchez-Rendon, 2025). The elevated chloride and sulphate levels in borehole water, though within permissible limits, highlight the need for site-specific water testing to prevent potential sulphate attack, efflorescence, or corrosion, particularly in coastal and industrially influenced areas like the Niger Delta (Abubakar et al., 2025; Dawoud & Al Hassan, 2025; Kaura & Mohammed, 2025; Raymond & Hamilton 2018).

The study's outcomes have practical implications for multiple stakeholders. Civil engineers and construction managers can optimize concrete mix designs by selecting water sources appropriate to the intended service life, while policymakers and environmental regulators can establish guidelines for routine water-quality monitoring. Additionally, educational institutions can incorporate these findings into engineering curricula to emphasize the interplay between water chemistry and concrete performance. Despite these insights, the study has limitations.

Only two water sources were analysed, and environmental variations such as seasonal changes were not considered. Future research should investigate additional water sources, incorporate long-term durability tests under varying environmental conditions, and explore treatment methods to mitigate the acidity of rainwater or the high ionic content of borehole water, thereby enhancing concrete sustainability and resilience.

Conclusions

The study demonstrates that the choice of water source significantly affects the performance and durability of concrete in the Niger Delta region. Rainwater, characterized by low mineral content and slight acidity, promotes slightly higher early compressive strength in concrete, facilitating faster hydration reactions. However, its acidic nature necessitates neutralization to prevent potential reinforcement corrosion over time. Borehole water, on the other hand, is alkaline and richer in dissolved minerals, chloride, and sulphate. While this contributes to superior long-term strength development, the elevated ionic content, particularly in coastal and industrially impacted areas, may pose durability risks such as sulphate attack, efflorescence, or steel corrosion if not properly monitored. Despite both water sources meeting international standards (BS EN 1008; ASTM C1602), environmental conditions in the Niger Delta—including acid rain, saline intrusion, and industrial emissions—underscore the need for careful water-quality assessment before use in concrete production.

In conclusion, effective concrete performance in the Niger Delta requires strategic management of water quality. It is recommended that regulatory agencies mandate water-quality certification for construction projects to ensure compliance with safety and durability standards. Contractors should implement routine testing of water sources before mixing concrete, and incorporate simple, cost-effective field assessments, such as pH strips and conductivity meters. By integrating these measures, stakeholders can optimize concrete strength, enhance durability, and mitigate risks associated with environmental and chemical variability, ultimately supporting safer, longer-lasting infrastructure in the region.

Recommendations

Based on the findings of this study, the following recommendations are proposed to enhance concrete performance and durability in the Niger Delta:

- i. **Mandatory Water Testing** – Regulatory bodies should require certification of water quality for all construction projects before use in concrete mixing.
- ii. **Pre-Mixing Quality Checks** – Contractors should routinely test water sources for pH, chloride, sulphate, and total dissolved solids to ensure suitability.
- iii. **Neutralization of Rainwater** – Rainwater should be treated to reduce acidity to prevent reinforcement corrosion in concrete structures.
- iv. **Monitoring Borehole Water** – Borehole water should be periodically checked for chloride and sulphate levels, especially in coastal or industrially impacted areas.
- v. **Use of Simple Field Tools** – Low-cost tools such as pH strips and portable conductivity meters should be used on-site for quick water quality assessments.

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