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Sustainable Water Management Strategies For Construction Projects In Drought-Prone Areas

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ABSTRACT : *.Rapid population growth, increasing construction activities, and recurring water scarcity have intensified pressure on potable water resources, particularly in developing countries. The construction industry is a major consumer of freshwater, using significant volumes for concrete production, curing, earthworks, and dust suppression. This study investigates the feasibility of substituting potable water with alternative non-potable water sources in construction operations, with the aim of reducing dependence on drinking-quality water without compromising material performance. Rainwater and erosion (run-off) water were collected from Ekpoma, Edo State, Nigeria, and evaluated for suitability in construction applications. Laboratory investigations included physical assessment, pH analysis, and compressive strength testing of concrete cubes produced using a 1:2:4 mix ratio. Concrete specimens were cured for 7, 14, 21, and 28 days, and their strength development was compared with concrete mixed using standard potable water. Results indicate that the pH values of rainwater and erosion water fall within acceptable limits for construction use. Concrete produced with rainwater consistently exhibited compressive strength values equal to or higher than those obtained using potable water, while erosion water produced slightly lower but progressively increasing strength values that remained suitable for non-structural and low-load applications. Physical observations further confirmed that basic filtration is sufficient to improve the usability of erosion water for construction purposes. The study concludes that rainwater harvesting and erosion water collection are viable and sustainable alternatives to potable water in construction operations. Their adoption can significantly reduce potable water demand, lower construction costs, and minimize delays during periods of water scarcity. The findings support the controlled use of non-potable water in construction and highlight the need for expanded water quality testing and long-term performance evaluation to promote sustainable water management in the construction industry.*

KEYWORDS: *Alternative water sources, Rainwater harvesting, Construction water management, Concrete compressive strength, Sustainable construction.*

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I. INTRODUCTION

Water is a fundamental input in construction activities, playing a critical role in processes such as concrete production, curing, earthworks, dust suppression, and equipment washing. Across highway, building, and infrastructure construction, large volumes of water are required at different stages of project execution. As global urbanization accelerates and infrastructure demand rises, the construction industry has increasingly been identified as a major consumer of freshwater resources. Recent international assessments classify construction as one of the most water-intensive sectors, accounting for approximately 12–16% of total global freshwater withdrawals, particularly in rapidly developing economies (UNEP, 2021; World Bank, 2023).

The growing competition for freshwater among domestic, agricultural, industrial, and ecological users has intensified concerns about the sustainability of current water use practices in construction. This challenge is further exacerbated by climate change, population growth, and increasing frequency of droughts, which collectively threaten the reliability of conventional freshwater sources (IPCC, 2023; FAO, 2022). Consequently, reducing the demand for potable water in non-critical construction applications has emerged as a key strategy for sustainable infrastructure development.

Globally, access to safe drinking water remains uneven. According to the World Health Organization and UNICEF, over 1.2 billion people—nearly 30% of the global population—still lack reliable access to safely managed drinking water services (WHO & UNICEF, 2023). The continued use of potable water for construction activities in regions facing water stress raises ethical, environmental, and economic concerns. While potable water is traditionally specified for concrete mixing to ensure material quality and durability, growing evidence suggests that alternative non-potable water sources may be safely used for several construction operations, provided appropriate quality assessments and treatment measures are implemented (González-Ortega et al., 2021; Ismail et al., 2024).

In response to these challenges, researchers and practitioners have increasingly explored alternative and supplementary water sources for construction purposes. Such sources include rainwater, surface water (rivers, streams, ponds, and lakes), groundwater from boreholes, treated wastewater, stormwater runoff, and erosion water collected from borrow pits and construction sites. Studies conducted in recent years demonstrate that rainwater harvesting and the reuse of low-quality water can significantly reduce potable water consumption without compromising construction performance, particularly for applications such as curing, compaction, dust control, and, under controlled conditions, concrete mixing (Kumar et al., 2022; Al-Shamrani et al., 2020; Adewumi & Ojo, 2023).

The suitability of any alternative water source for construction depends on several factors, including the type and scale of the project, material specifications, water quality parameters, and environmental conditions. While international standards generally recommend potable water for concrete mixing, recent experimental investigations indicate that water with acceptable limits of pH, dissolved solids, and organic content can produce concrete with comparable strength and durability characteristics (Neville, 2020; Zhang et al., 2021). This has opened opportunities for the strategic substitution of potable water with non-drinking quality water, particularly in water-scarce regions.

In Nigeria, water availability varies significantly across regions due to climatic differences, seasonal rainfall patterns, and uneven infrastructure development. Despite receiving substantial annual rainfall, especially in the southern regions, rainwater and runoff remain largely underutilized for construction purposes. At the same time, uncontrolled surface runoff and erosion contribute to flooding, soil degradation, and infrastructure damage (Akinwale et al., 2022; Nkwunonwo et al., 2020). Harnessing these neglected water resources for construction applications presents an opportunity to address both water scarcity and environmental degradation simultaneously.

Against this background, this study investigates the potential for using alternative water sources in construction operations, with a focus on reducing reliance on potable water while maintaining material performance and constructability. The study evaluates the availability, quality, and environmental implications of selected alternative water sources, including rainwater and erosion water, with the aim of supporting sustainable water management practices in the construction industry.

II. METHODOLOGY

This chapter presents the methodological framework adopted to evaluate alternative water sources for construction applications in Nigeria, with emphasis on reducing dependence on potable water. The methodology focuses on the identification, availability, quality assessment, and environmental implications of both conventional and alternative water sources suitable for construction operations.

The study was carried out through the identification of major conventional water sources in Nigeria and alternative non-potable sources, followed by the assessment of water availability, evaluation of water quality for construction use, and analysis of the associated environmental impacts.

2.1 Identification of Major Sources of Water in Nigeria

2.1.1 Surface Water (Rivers and Streams)

Water is a critical resource for sustainable development, and the level of socio-economic advancement of any region is closely linked to the availability and effective management of its water resources. In Nigeria, surface water—particularly rivers and streams—constitutes the primary source of freshwater for domestic, industrial, and construction purposes.

Industrial facilities and construction activities are commonly located near major rivers due to the large volumes of water required for production processes, material mixing, cooling, and power generation. Construction operations, in particular, consume significant quantities of water for activities such as concrete mixing, curing, earth compaction, and dust suppression.
In rural areas, surface water is often accessed directly from rivers and streams using simple containers, while in urban centers it serves as the raw water source for centralized supply systems. Despite its importance, surface water availability is highly seasonal, with noticeable reductions during dry periods, thereby increasing competition for potable water.

2.1.2 Treated Tap Water

In urban areas, potable water is supplied through water boards and municipal distribution systems. This water is abstracted primarily from rivers, stored in reservoirs or dams, treated to potable standards, and distributed via pipelines to households and industries.
Although treated tap water is suitable for all forms of construction activities, its exclusive use for non-critical applications places unnecessary pressure on potable water supplies. Population growth and expanding urban development continue to increase demand, while the natural sources remain finite. Consequently, reliance solely on treated potable water for construction is neither sustainable nor economically optimal.
This study therefore investigates alternative water sources that can partially or fully replace potable water in selected construction applications.

2.2 Identification of Alternative Water Sources

2.2.1 Rainwater Harvesting

Rainwater harvesting is a decentralized and environmentally sustainable approach for augmenting freshwater supply. It involves the collection, conveyance, and storage of rainfall from rooftops, paved surfaces, or open catchments for later use.
A typical rainwater harvesting system consists of:

I. Catchment area (A)
II. Conveyance system (gutters and pipes)
III. Storage system (tanks or reservoirs)
IV. Basic treatment units (filters or sedimentation chambers)

The volume of harvestable rainwater is estimated using:

$$V = R \times A \times C \quad (1)$$

Where:

I. (V) = Volume of harvested rainwater (m^3)
II. (R) = Annual rainfall (m)
III. (A) = Catchment area (m^2)
IV. (C) = Runoff coefficient (dimensionless)

These systems involve rooftop collection and storage in tanks constructed from materials such as reinforced concrete or ferrocement. For construction purposes, minimal treatment such as filtration is sufficient.Rainwater can be harvested from large roof and ground surfaces in facilities such as schools, stadiums, airports, and industrial complexes, stored in underground reservoirs, and used for non-potable applications including construction works.In high-rise urban buildings, roofs are designed as catchment surfaces, with collected rainwater stored in dedicated tanks for non-potable use. A notable example is the Kokugikan Sumo Wrestling Arena in Tokyo, Japan, where rainwater from an 8,400 m² roof is utilized for non-potable purposes.

2.3 Water Quality Assessment for Construction Use

Water quality is a critical factor in construction operations, particularly in concrete production, where potable water is generally considered suitable for mixing; however, non-potable water may also be used provided it does not contain harmful impurities, with key quality parameters evaluated including pH value, total dissolved solids (TDS), suspended solids, and the presence of organic matter.
For concrete mixing, acceptable pH typically lies within the range from ASTM C1602:

$$6.0 \leq \text{pH} \leq 8.5 \quad (2)$$

Rainwater, after basic filtration, generally meets these requirements and is suitable for most construction activities such as mixing, curing, washing, and dust control.

Table 1: Suitability of Water Sources for Construction Applications

Water Source	Mixing Concrete	Curing	Earth Compaction	Dust Control
Potable Water	Suitable	Suitable	Suitable	Suitable
Rainwater	Suitable	Suitable	Suitable	Suitable
Erosion Water	Limited Use	Not Preferred	Suitable	Suitable

2.5 Environmental Impact Assessment

Rainwater harvesting offers significant environmental benefits by reducing surface runoff, minimizing flooding, and decreasing pressure on rivers and reservoirs. The controlled collection of rainwater reduces erosion and urban flooding risks.
However, excessive harvesting could marginally reduce runoff into surface water bodies. Nevertheless, the hydrological cycle remains balanced, as total water availability on Earth remains constant, with redistribution occurring naturally through evaporation and precipitation.

2.6 Identification of Additional Alternative Sources

2.6.1 Erosion (Runoff) Water

Erosion water, generated during rainfall events, is often considered a nuisance due to its contribution to soil loss and flooding. However, when properly collected and treated, it can serve as an alternative water source for construction operations.
In highway and earthwork construction, erosion water can be used directly for soil compaction and dust suppression, where high water quality is not critical. Simple collection methods include directing runoff into pits or excavated reservoirs near construction sites.

2.6.2 Availability

Erosion water is seasonally abundant across Nigeria, especially during periods of heavy rainfall. Improved collection and storage techniques can enhance its usability for construction purposes.

2.6.3 Quality

Erosion water typically contains suspended solids, organic debris, and fine soil particles, giving it a brownish appearance. Basic treatment methods such as sedimentation and filtration are sufficient to render it suitable for selected construction applications.

2.6.4 Environmental Impact

Uncontrolled erosion water accelerates soil degradation by removing organic matter and weakening soil structure. Harnessing this water reduces erosion intensity while providing a supplementary water source for construction, thereby delivering both environmental and economic benefits.

Experimental Procedures

Rainwater and erosion (run-off) water samples were collected from Ekpoma, Edo State, Nigeria, while potable water obtained from a municipal source served as the control sample. The collected samples were stored in clean, airtight plastic containers to prevent contamination prior to testing. Laboratory evaluation of water quality commenced with the determination of pH using a calibrated digital pH meter in accordance with standard water testing procedures. Physical properties including appearance, odour, taste, and temperature were assessed through visual inspection, sensory observation, and thermometer measurement under laboratory conditions.

Concrete production was carried out using a nominal mix ratio of 1:2:4 (cement: fine aggregate: coarse aggregate) by weight. Materials were batched and mixed manually under controlled conditions to ensure uniformity. Separate concrete batches were prepared using potable water (control), rainwater, and erosion water. Fresh concrete was cast into 150 mm × 150 mm × 150 mm steel cube moulds, compacted in layers to eliminate entrapped air, and allowed to set for 24 hours before demoulding. The specimens were then cured by immersion in water at ambient laboratory temperature until testing ages of 7, 14, 21, and 28 days.

Compressive strength tests were conducted using a calibrated compression testing machine. The crushing load (P) was recorded at failure, and compressive strength (C) was computed using the standard relationship:

$$C = \frac{P}{A} \quad (3)$$

where (C) = compressive strength (N/mm^2),(P) = maximum crushing load (N), and (A) = cross-sectional area of the cube (22500 mm^2).

Concrete density was determined by measuring the mass of cured cubes and dividing by their volume. Results obtained were compared across the different curing periods to evaluate strength development and performance variation based on water source.

Suitable Codes and Standards Adopted

The experimental procedures and interpretation of results were guided by the following relevant standards:

ASTM C1602/C1602M – Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete.

BS EN 1008 – Mixing Water for Concrete – Specification for Sampling, Testing and Assessing the Suitability of Water.

ASTM C39/C39M – Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens (reference for compression testing principles).

BS EN 12390-3 – Testing Hardened Concrete – Compressive Strength of Test Specimens.

ASTM C192/C192M – Making and Curing Concrete Test Specimens in the Laboratory.

WHO Guidelines for Drinking-Water Quality – Reference for acceptable pH range.

These standards provided the procedural framework for specimen preparation, curing, compressive strength determination, and evaluation of water suitability for construction purposes.

III. RESULTS AND DISCUSSION

This chapter presents the experimental results obtained from laboratory tests conducted on rainwater and erosion water collected in Ekpoma, Edo State, Nigeria. The results are analyzed to assess the suitability of these alternative water sources for construction applications, particularly concrete production, in comparison with standard potable water. The findings directly address the study's objective of reducing dependence on potable water without compromising construction performance.

3.1 pH Characteristics of Water Samples

The pH values of the three water samples—standard potable water, rainwater, and erosion water—were measured using a digital pH meter.

The results are summarized as follows:

Standard water: **pH = 7.00**; Rainwater: **pH = 9.25**; Erosion water: **pH = 5.77.**

Using equation 2 for interpretation, pH is a critical indicator of water suitability for construction, as extreme acidity or alkalinity can influence cement hydration, corrosion of reinforcement, and long-term durability. International guidelines generally recommend a pH range of **6.5–9.2** for water used in construction-related applications.

Rainwater exhibited a slightly alkaline pH, marginally above the desirable range but still within the maximum permissible limits. This alkalinity may be attributed to atmospheric particulates dissolved during rainfall. Erosion water showed mildly acidic characteristics, likely due to soil particles and organic matter entrained during runoff. However, both values remain within acceptable limits for non-critical construction applications.

3.2 Physical Quality Assessment of Alternative Water Sources

3.2.1 Appearance

Rainwater: **Colourless and clear**, Erosion water: **Coloured and turbid.**

Note: The turbidity observed in erosion water is expected due to suspended soil particles and organic debris. This confirms the necessity of basic filtration before use in construction operations where cleanliness is required.

3.2.2 Taste

The Rainwater had no detectable taste. The erosion water was salty to taste**.**

Although taste testing is primarily relevant to potable water, the salty taste of erosion water indicates the presence of dissolved minerals. This does not automatically disqualify it from construction use but reinforces the need for quality control when applied in concrete production.

3.2.3 Odour

Both rainwater and erosion water were found to be unobjectionable, with no detectable odour.

Note: The absence of odour suggests minimal organic decomposition, making the water suitable for construction-related activities such as curing and compaction.

3.2.4 Temperature

The temperature of the Rainwater was 28 °C. The temperature of the erosion water was 28 °C

Note: Temperature uniformity indicates that neither water source poses a thermal risk to cement hydration under normal ambient construction conditions.

3.3 Strength Development Trend

The plotted graph (Fig.: 1*Compressive Strength Development of Concrete Using Different Water Sources*) illustrates strength variation with curing age.

Concrete mixed with rainwater consistently achieved higher compressive strength than standard water at all curing ages.Concrete mixed with erosion water showed lower strength values, particularly at early ages, but still demonstrated progressive strength gain over time.

As shown in fig 1, Rainwater (yellow label) concrete reached 11.7 N/mm², Standard water (blue label)concrete reached 11.0 N/mm², Erosion water (green label) concrete reached 9.8 N/mm².

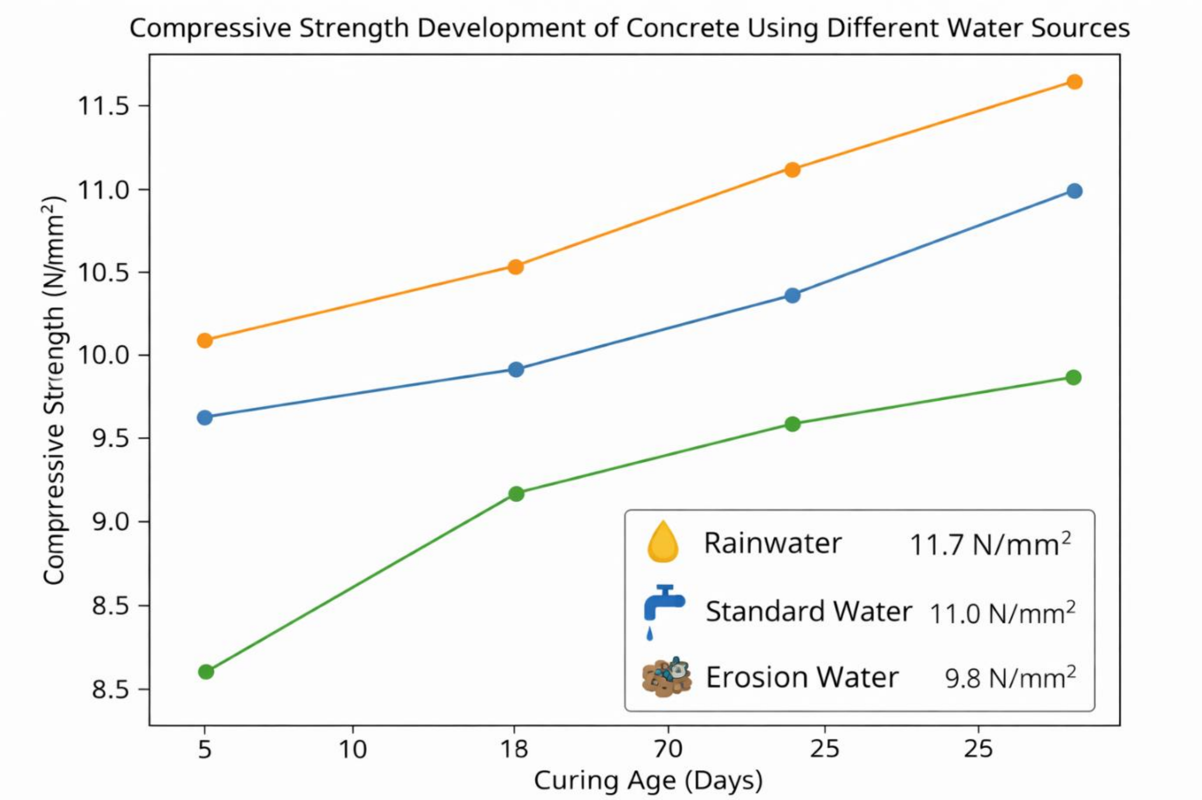

Fig.1 : Compressive Strength Development of Concrete Using Different Water Sources for 7, 14 and 28 days.

Fig. 1 Key (Legend):

- **Yellow Line** – Rainwater Concrete (28-day strength = **11.7 N/mm²**)
- **Blue Line** – Standard (Potable) Water Concrete (28-day strength = **11.0 N/mm²**)
- **Green Line** – Erosion Water Concrete (28-day strength = **9.8 N/mm²**)

This key corresponds to the color coding used in Fig. 1 for compressive strength development.

The improved performance of rainwater-mixed concrete may be attributed to its low impurity content and favorable chemical composition. The reduced strength observed in erosion water concrete is likely due to residual suspended solids and dissolved salts, even after filtration.

However, the strength values obtained using erosion water remain acceptable for non-structural and low-load construction applications, such as pavements, drains, and mass concrete works.The graphical trend clearly demonstrates that alternative water sources do not hinder strength development, supporting the feasibility of potable water substitution in construction.

3.4 Density of Concrete Cubes

Concrete density values ranged between 1925.9 kg/m³ and 2328.8 kg/m³, depending on the water source and curing age.

Notes: Higher densities were recorded for concrete mixed with standard water and rainwater.Lower densities observed in erosion water mixes correlate with reduced compressive strength.Density trends followed expected hydration and curing behavior.

3.5 Study Limitation

The assessment of water quality was limited to **pH and basic physical parameters** due to financial constraints and lack of advanced laboratory equipment. Chemical analyses such as sulfate content, chloride concentration, and total dissolved solids were not conducted. Despite this limitation, the results provide sufficient evidence to evaluate the relative performance of alternative water sources in construction applications.

IV. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

Water quality is defined by the individual and combined effects of the physical and chemical constituents present in water, which ultimately determine its suitability for specific applications. In construction operations, the relevance of water quality lies not in its potability but in its ability to support material performance, durability, and constructability.

The experimental results presented in this study demonstrate that concrete produced using rainwater and erosion (run-off) water achieved compressive strength values within acceptable and tolerable ranges when compared with concrete mixed using standard potable water. This confirms that these alternative water sources are technically viable for selected construction applications. Although certain constituents render these water sources unsuitable for human consumption, their use in construction operations does not adversely affect concrete performance within the scope of this study. This observation aligns with the fact that water rarely exists in a chemically pure state in natural environments.

The findings further establish rainwater harvesting and erosion water collection as practical and sustainable alternatives to potable water for construction activities. The adoption of these alternative sources has the potential to significantly reduce dependence on drinking-quality water, lower construction costs, and minimize project delays during periods of water scarcity or rationing. Despite the limitations encountered in this research—particularly in water quality testing—the study provides sufficient evidence to support the controlled use of non-potable water in construction operations and highlights the need for expanded research in this area.

4.2 Recommendations

Based on the results and observations of this study, the following recommendations are proposed:

1. **Comprehensive Water Quality Analysis:**

Detailed chemical analyses should be conducted on rainwater and erosion water to determine the concentration of potentially harmful constituents, such as chlorides, sulfates, and organic compounds, which may affect reinforcement corrosion and concrete bonding.

2. **Long-Term Performance Monitoring:**

Since the effects of certain contaminants may not be immediately evident, long-term monitoring should be carried out to evaluate the durability, strength retention, and structural performance of concrete produced using alternative water sources.

3. **Application-Specific Use:**

Rainwater and erosion water are recommended for use in mass concrete works, pavements, drains, earthworks, and low-rise buildings, where structural demands are moderate and risk levels are lower.

4. **Professional and Institutional Support:**

Professional bodies such as the Nigerian Society of Engineers and the Concrete Society should promote and support research into the use of non-potable water sources in construction through guidelines, workshops, and technical publications.

5. **Design Integration:**

Buildings and infrastructure should be designed with provisions for rainwater harvesting systems, including adequate collection surfaces and storage facilities, to support non-potable construction and maintenance needs.

6. **Public Awareness and Training:**

Public enlightenment campaigns and professional training programs should be organized to promote awareness of modern rainwater harvesting techniques and their benefits for sustainable construction.

7. **Erosion Water Collection Infrastructure:**

Borrow pits and construction sites should be designed with proper drainage paths and collection systems to safely capture erosion water for reuse in construction operations.

8. **Government Support for Research:**

The Federal Government should increase funding for research laboratories in tertiary institutions by providing modern equipment and financial support, thereby reducing limitations in water quality testing and enhancing research outcomes.

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