Permeability Characteristics of Lower Niger Floodplain Sediments and their Implications for Drainage and Flood Mitigation

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ABSTRACT

Rising flood-related damage to infrastructure across the Lower Niger floodplains has increased the need to understand the permeability of floodplain sediments, both to explain the persistence of flooding and to assess the feasibility of dewatering these areas. These floodplains occupy about 7% of the Niger Delta and are under growing pressure from intensive development. Reliable permeability estimates are essential for flood control, groundwater flow assessment, and contaminant transport analysis, all of which are critical to sustainable land and water management in the region. This study evaluated the permeability of stratified floodplain soils using field pump tests and laboratory constant-head tests, alongside particle size distribution analysis on randomly selected samples from eight boreholes. The particle size data were also used to estimate permeability through an established empirical equation. Permeability values obtained from the field pump test ranged from 1.52×10^{-3} to 1.67×10^{-3} m/s, while constant-head test values ranged from 4.0×10^{-4} to 7.1×10^{-3} m/s. Empirically derived permeability values averaged 4.7×10^{-3} m/s. Comparison of the three methods showed strong agreement, which is attributed to the high grain uniformity of the sediments. The findings indicate that, in uniform granular floodplain soils, field, laboratory, and empirical approaches can produce comparable and acceptable permeability estimates. The measured permeability values further suggest favourable drainage conditions; where hydraulic connection exists between the surface and underlying sandy layers, natural drainage and dewatering could help reduce prolonged flooding in the Lower Niger floodplains.

Keywords: Floodplain, Flood, Niger Delta, Permeability, Drainage

INTRODUCTION

The Niger Delta is a low-lying fluvial environment criss-crossed by an extensive network of rivers, distributaries, and creeks that redistribute surface water and sediment across broad floodplains during seasonal high flows (Abam 2022). Because the delta is flat and its floodplain boundaries are poorly defined, floodwaters often extend into inter-channel areas and backswamps, where ponded water may persist when there is no effective outlet and where low-permeability subsoil restricts drainage (Abam 2022).

Flooding in the Niger Delta is increasingly damaging because hydrological pressure now coincides with rapid settlement growth, floodplain encroachment, and expansion of critical infrastructure. The impact of flood damage have been linked to food security and livelihood issues (Week and Wizor; 2020, Onugba et al 2022). Recent studies (Tosin-Orimolade 2026, Oborie 2023, Rowland 2021) show that large parts of the region are highly flood-prone, with particularly high susceptibility in the Orashi, Niger, and Forcados catchments, while roads, embankments, and poorly planned development can obstruct natural drainage and amplify inundation impacts on communities and infrastructure.

Although regional flood hazards are commonly attributed to intense rainfall, upstream dam operations, low relief, and sediment-related changes in channel conveyance, the contribution of **floodplain sediment permeability** to flood persistence remains insufficiently constrained (Eteh 2024; Abam 2022, Nones 2019). This is a critical gap because permeability governs infiltration, groundwater flow, drainage efficiency, and contaminant transport, and therefore directly affects whether floodwater can dissipate naturally or remain ponded for prolonged periods (Fenguia 2023, Miller 2014, Kalantari 2019).

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The need for such information is especially acute in the Oguta–Akri segment of the Lower Niger floodplain, where Quaternary alluvial sediments, shallow groundwater, and seasonal river-stage rise combine to expose oil and gas facilities and other installations to recurrent flooding (Udie et al 2018). Nearby hydrological records show strong seasonal water-level response to rainfall and Niger River discharge, while groundwater levels close to the surface increase the vulnerability of buried infrastructure and limit the capacity of the subsurface to accommodate additional water storage (Abam 2022, Eteh 2024).

Floodplain sediments are commonly stratified, and their hydraulic behaviour depends on the arrangement of clayey and sandy units rather than on surface appearance alone. Studies from other alluvial plains show that clay-rich layers can act as barriers to infiltration, whereas sandy or gravelly layers can provide preferential flow paths and improve drainage if they are hydraulically connected to the land surface (Fenguia 2023, Miller 2014. Yet comparable field-based evaluations of permeability in the Lower Niger floodplain are limited, despite long-standing concern that baseline hydrological data for development planning in the Niger Delta have not been adequately updated (Abam 2022).

Accordingly, this study investigates the permeability of stratified floodplain sediments in the Oguta–Akri area (Fig.1) in order to clarify the role of subsurface hydraulic properties in the persistence of flooding and to assess the feasibility of dewatering as a flood-mitigation option. By combining field pump tests, laboratory constant-head tests, and particle-size-based empirical estimation, the study also evaluates whether different methods produce comparable permeability values for these relatively uniform granular alluvial sediments. This approach addresses a clear gap in Niger Delta flood research by linking sediment properties to drainage behaviour and infrastructure resilience in an actively developing floodplain.

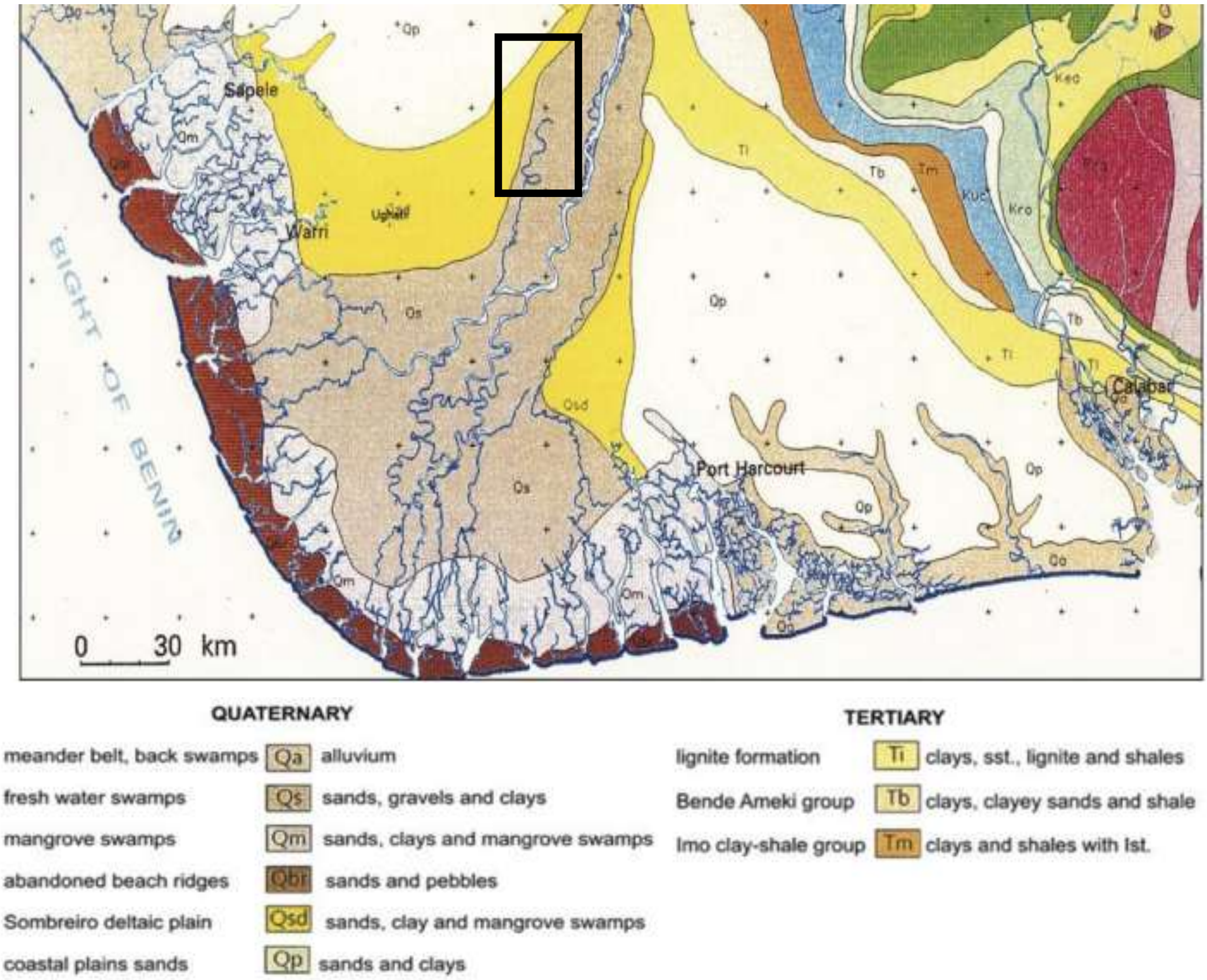

Fig. (1) Study area and its Geology (after Reijers, 2011)

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METHODS OF STUDY

A total of eight geotechnical boreholes were drilled at each of the two study locations, **Oguta** and **Akri**, which are approximately 7.5 km apart. Because the lithologic profiles at the two sites were broadly similar, one representative litholog was selected for each location for interpretation and presentation.

Permeability was evaluated using three complementary approaches: **field pumping tests**, **constant-head laboratory tests**, and **empirical estimation from particle-size data**. The field permeability test was conducted in situ using pairs of boreholes spaced 30 m apart, with one borehole serving as the pumping well and the other as the observation well. Each borehole had an outer diameter of 5 inches. A 1.0 HP submersible pump was installed in the pumping well and operated continuously for 480 minutes at an average discharge of about 2.7 m^3/h. Water-level depression in both the pumping and observation wells was monitored at time intervals using a dip meter until near-equilibrium conditions were attained. Hydraulic conductivity was then computed from the borehole geometry, drawdown response, depth to the impermeable boundary, and pumping rate. Because the tested sandy units were highly permeable, the pumped-borehole variant was adopted as it is better suited to formations in which water levels recover too rapidly for reliable measurement under conventional methods. Saturated hydraulic conductivity was evaluated using **Zanger's analytical solution** for boreholes penetrating less than 20% of a deep, homogeneous, unconfined aquifer.

Laboratory permeability testing was carried out (Head 1987) on samples recovered from the boreholes within the **0–10 m** and **10–20 m** depth intervals. Owing to the predominantly granular nature of the subsurface materials, the **constant-head permeability test** was selected. In this method, water is allowed to flow through the soil specimen under a constant hydraulic head, while the discharged volume over a measured time is used to compute hydraulic conductivity based on Darcy's law.

Permeability was also estimated empirically from grain-size characteristics using **Hazen's relationship**, which relates hydraulic conductivity to the effective grain size, $\mathbf{D_{10}}$. To obtain D_{10}, particle-size distribution analyses were performed (ASTM D422-63) by dry sieving on four randomly selected samples from each borehole at depths ranging from 3 m to 20 m. This approach provided an independent basis for comparing permeability derived from field and laboratory measurements.

RESULTS AND DISCUSSION

The lithostratigraphic profiles at Oguta and Akri (Fig. 2) indicate a consistent subsurface sequence across the 7.5 km study corridor. The floodplain is characterized by a **top silty clay layer** of about 2.5 m thickness underlain by sandy deposits of varying grain sizes and relative densities. This continuity suggests lateral persistence of the main sedimentary units across the investigated floodplain.

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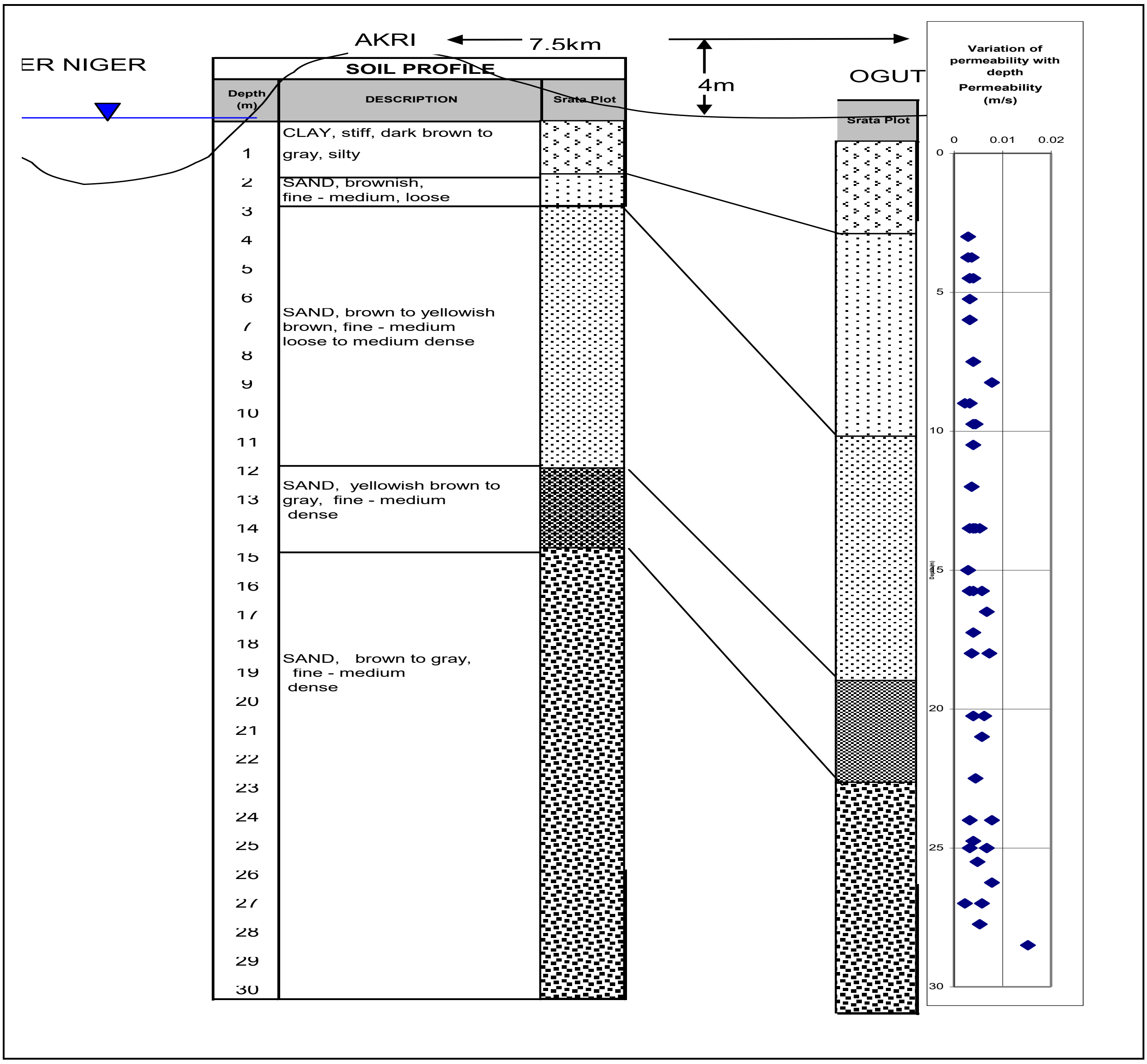

Fig. 2 lithostratigraphy of the floodplain at Oguta and Akri

Field pumping-test results from Oguta and Akri indicate hydraulic conductivity values in the range of **1.52 × 10⁻³ to 1.67 × 10⁻³ m/s**, confirming that the sandy sublayers are moderately to highly permeable. The drawdown data show an initial rapid fall in water level followed by stabilization toward equilibrium, which is typical of permeable formations subjected to constant-rate pumping. Because pumping tests integrate the response of a relatively large volume of subsurface material, these values are considered representative of average floodplain-scale permeability rather than isolated point conditions.

The **constant-head test** results produced hydraulic conductivity values ranging from **4.0 × 10⁻⁴ to 7.0 × 10⁻³ m/s**. Although this range is wider than that obtained from the pumping tests, it remains of the same order of magnitude and reflects local variability in texture and packing within the granular layers. The wider spread is expected because laboratory tests are more sensitive to small-scale changes in sample structure, grading, and fines content.

Empirical estimates derived from particle-size parameters were also comparable to both field and laboratory results. This agreement suggests that grain-size characteristics provide a useful basis for estimating permeability within the studied sandy floodplain deposits. Comparison of permeability with sediment indices further shows that the **uniformity coefficient** exhibited a depth pattern closely matching the permeability trend, indicating that it exerted a strong influence on hydraulic behavior.

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Particle-size analysis also showed that **D_{10}**, **D_{50}**, and **SPT-N values** generally increased with depth, (Fig.3) indicating progressive densification of the sandy sediments downward. Despite some increase in embedded fine materials at depth, permeability generally increased downward as well (Fig.4). This implies that the influence of improved grain packing and coarser texture outweighed the restricting effect of the finer fraction within the predominantly sandy sublayers.

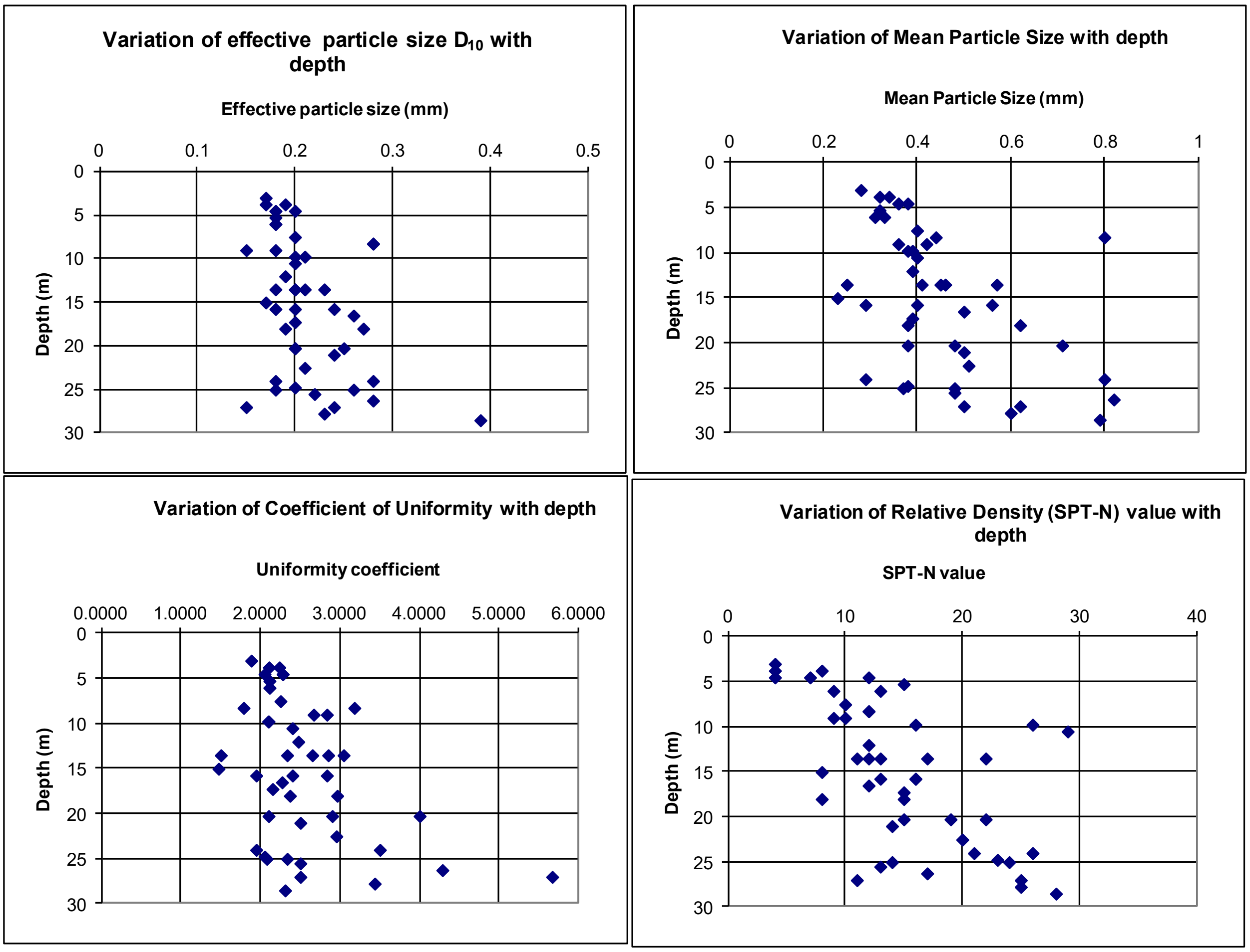

Fig. (3) Particle size attributes and relative density of floodplain sediments

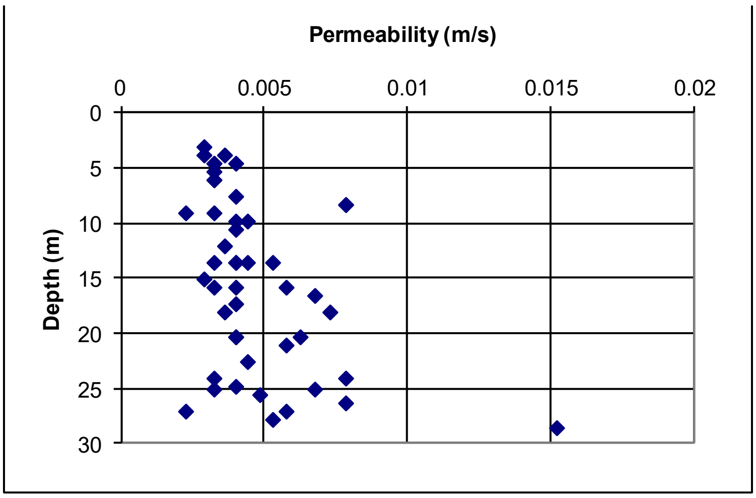

Fig. (4) Variation of permeability with depth.

Taken together, the results show that the lower Niger floodplain sediments possess appreciable subsurface drainage potential. The persistence of seasonal flooding in the area is therefore not explained by low permeability of the deeper sandy units, but more likely by the combined effects of **low surface elevation** and the presence of a **thin, relatively impermeable silty clay cap** that limits vertical infiltration and through-flow

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of surface water. This interpretation is consistent with the observed tendency for prolonged surface ponding despite the presence of permeable materials beneath.

This study has also revealed several other possible applications of soil permeability in floodplain flood management as summarized in Table (3)

Table 3: Potential applications of soil permeability in floodplain flood management

No.	Application	How permeability is used	Flood-management benefit
1	**Flood infiltration assessment**	Determine the rate at which floodwater can infiltrate into floodplain soils.	Identifies areas capable of rapidly absorbing floodwater and areas prone to prolonged inundation.
2	**Flood-risk zoning**	Combine permeability data with elevation, drainage, rainfall, and groundwater information.	Enables classification of floodplains into high-, moderate-, and low-infiltration zones.
3	**Design of drainage systems**	Use hydraulic conductivity/permeability to estimate infiltration and drainage rates.	Helps size drains, culverts, soakaways, and subsurface drainage systems.
4	**Floodwater detention and retention**	Identify relatively low-permeability soils suitable for temporary water storage.	Supports the design of detention basins, wetlands, and flood-storage areas.
5	**Managed aquifer recharge**	Identify highly permeable sandy/alluvial zones where excess floodwater can infiltrate.	Converts part of the floodwater into groundwater storage and can improve groundwater availability.
6	**Levee and embankment design**	Assess permeability and seepage through flood-control embankments.	Helps prevent piping, internal erosion, and embankment failure.
7	**Floodplain restoration**	Identify natural permeable and impermeable zones and their relationship with wetlands and abandoned channels.	Supports restoration of natural flood-storage and infiltration functions.
8	**Agricultural flood management**	Determine infiltration capacity and drainage characteristics of agricultural soils.	Guides crop selection, field drainage, and soil-management practices.
9	**Urban development control**	Map permeability before constructing houses, roads, and other infrastructure.	Helps avoid development in areas where poor infiltration can produce prolonged flooding.
10	**Nature-based**	Use permeability information to locate infiltration zones, riparian buffers,	Enhances natural storage, infiltration, and attenuation of

	flood mitigation	wetlands, and floodplain forests.	flood peaks.
11	**Prediction of flood duration**	Combine permeability with soil thickness, groundwater level, and flood depth.	Helps estimate how long floodwater may persist after rainfall or river-level recession.
12	**Contaminant management during floods**	Assess permeability and groundwater connectivity.	Helps predict whether contaminated floodwater may rapidly migrate into shallow aquifers.

For the Niger Delta, soil permeability can be particularly useful because floodplains commonly contain alternating soft clay, silty clay, organic soils and medium- to fine-grained sands. These materials have markedly different hydraulic conductivities. Low-permeability clay/organic layers result in slow infiltration and consequently prolonged surface flooding and high flood persistence whereas permeable sand/alluvial deposits result rapid infiltration leading to reduced surface-water residence time and consequently greater potential for groundwater recharge.

CONCLUSION

The study shows that the floodplain sediments at **Oguta** and **Akri** are underlain by sandy units with **relatively high permeability**, with field-derived hydraulic conductivity values on the order of **10^{-3} m/s**. These values indicate that the subsurface materials are reasonably well drained and possess significant capacity to transmit water.

The prolonged partial submergence commonly observed in the lower Niger floodplain is therefore more plausibly attributed to the **low relief of the terrain** and the presence of a **near-surface silty clay layer** that restricts downward percolation, rather than to poor permeability of the underlying sediments. In practical terms, this suggests that where hydraulic connection can be established between ponded surface water and the permeable sandy sublayers, the potential exists for improved natural drainage and localized dewatering.

The study also shows that permeability values obtained from **pumping tests**, **constant-head tests**, and **particle-size-based empirical estimation** are broadly comparable. This consistency indicates that, for the fairly uniform granular soils encountered in the study area, any of the three methods can provide acceptable estimates of hydraulic conductivity when properly applied.

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