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Hydraulic roughness of periwinkle shell and *Rapana venosa* gabions to assess their viability for hydraulic engineering applications

Kiridi E. A * and David I

Department of Agricultural and Environmental Engineering, Niger Delta University, Wilberforce Island, Bayelsa State.

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Abstract

This study assesses the hydraulic roughness of periwinkle shell and *Rapana venosa* gabions to ascertain their appropriateness for hydraulic engineering applications. Laboratory tests were performed utilizing a rectangular flume (0.6 m wide, 0.45 m deep, and 5.0 m long) in the Niger Delta region, where periwinkle shells are prevalent. Flow discharges between 0.015 and 0.045 m^3/s were introduced, with matching measurements taken for velocity, flow depth, and hydraulic radius. The Manning's roughness coefficient (n) and the Darcy–Weisbach friction factor (f) was calculated from the observed data. The findings indicated that periwinkle shell gabions exhibited elevated roughness values, with Manning's n varying from 0.034 to 0.041 and the friction factor f ranging from 0.045 to 0.052. Conversely, *Rapana venosa* gabions had reduced values, with n varying from 0.028 to 0.033 and f between 0.038 and 0.044. The findings demonstrate that periwinkle shells offer enhanced flow resistance and energy dissipation, rendering them effective for erosion-prone channels and flood control systems. In contrast, *Rapana venosa* gabions demonstrated more favorable flow conditions, appropriate for irrigation canals and conveyance systems. The study indicates that shell-based gabions offer a cost-efficient and sustainable alternative to traditional aggregates, facilitating waste reutilization in hydraulic infrastructure.

Keywords: Hydraulic Roughness; Periwinkle Shell; *Rapana venosa*; Gabions; Sustainable Hydraulics

1. Introduction

Hydraulic roughness is a vital characteristic in hydraulic engineering and water resources management, since it dictates the resistance presented by channel boundaries to fluid flow [1] This factor directly affects flow velocity, discharge capacity, sediment movement, and energy losses in open channels, rivers, and designed water conveyance systems. Historically, roughness factors like as Manning's n or the Darcy–Weisbach friction factor have been employed to measure surface roughness, with the majority of research depending on conventional construction materials like stone, concrete, and steel gabions. The growing demand for sustainable and locally sourced materials has prompted academics to investigate alternate natural resources for hydraulic applications [2].

Periwinkle shells, prevalent in the Niger Delta coastal area of Nigeria, signify a material with potential engineering significance [3]. Their resilience, affordability, and accessibility render them a compelling choice for hydraulic constructions, including gabions, filters, and channel linings. Likewise, *Rapana venosa*, a predatory sea snail indigenous to the Black Sea and prevalent in many coastal environments, offers shells that are structurally robust and extensively employed in gabion systems in West Africa. Comparative analyses of different shell types can yield significant information regarding their appropriateness and efficacy in hydraulic applications [4].

* Corresponding author: Kiridi E. A

Prior studies have shown that material composition and surface texture substantially affect hydraulic roughness. Smooth surfaces diminish flow resistance, but uneven or porous materials amplify turbulence and energy dissipation [5]. Considering that both periwinkle shells and *Rapana venosa* shells possess distinct geometric and textural characteristics, assessing their hydraulic roughness is crucial for comprehending their practical uses in gabion construction. This comparison is crucial for areas such as Bayelsa State, Nigeria, where iron (II) contamination, riverbank erosion, and channel stability pose ongoing environmental and engineering difficulties [6].

This study examines the hydrodynamic roughness properties of periwinkle shells in comparison to *Rapana venosa* gabions. This aims to determine if locally produced periwinkle shells can function as a feasible, economical, and environmentally friendly substitute for less accessible gabion materials. The results are anticipated to enhance hydraulic engineering methodologies in coastal and riverine areas, while encouraging the use of indigenous resources for sustainable infrastructure advancement.

1.1. Statement of the Problem

The efficacy of hydraulic structures, including gabions, channel linings, and filtration systems, is predominantly influenced by their hydraulic roughness, which directly impacts flow resistance, energy dissipation, and overall efficiency [7]. Traditional gabion materials, such as rock aggregates and metal mesh, are sometimes costly, environmentally detrimental, and not consistently accessible in numerous growing areas. Consequently, there is an increasing interest in discovering economic and ecological options that fulfill the structural and hydraulic demands of water resource projects. Periwinkle shells, commonly found in the Niger Delta region of Nigeria, represent an underexploited resource with considerable potential for hydraulic applications [8]. Despite their prevalence and affordability, there is a paucity of scientific data concerning their hydraulic roughness properties, particularly when juxtaposed with extensively researched alternatives like *Rapana venosa* shells, which have been utilized in gabion systems in various locales. The lack of comparative data hinders engineers and policymakers from confidently incorporating periwinkle shells into hydraulic design and construction [9].

The absence of actual evidence about the hydraulic behavior of periwinkle shell gabions constitutes a knowledge gap that impedes sustainable material innovation in hydraulic engineering. The lack of a good grasp of their resistance qualities under flowing conditions renders the use of periwinkle shells as a dependable substitute uncertain. This issue is especially critical in areas such as Bayelsa State, where erosion control, flood management, and channel stability are pressing priority [10]. This work tackles the lack of a thorough comparative assessment of the hydraulic roughness characteristics of periwinkle shell gabions in relation to *Rapana venosa* gabions. Addressing this gap will furnish engineers, researchers, and policymakers with empirical evidence to make informed decisions regarding the viability of utilizing locally sourced materials for hydraulic applications, thus diminishing reliance on imported resources and advancing sustainable engineering practices.

1.2. Importance of the Research

This research is significant for its contribution to sustainable hydraulic engineering techniques by comparing periwinkle shells and *Rapana venosa* shells in gabion applications [3]. With the increasing issues in water resource management, including erosion, flooding, and channel instability, the demand for economical and locally sourced materials has become essential [11]. This study offers actual evidence endorsing the utilization of periwinkle shells, an accessible resource in the Niger Delta, thus diminishing dependence on imported materials and fostering local alternatives for hydraulic infrastructure.

This paper examines the economic challenge of elevated building costs often linked to traditional gabion materials. The study illustrates that periwinkle shells can perform similarly to *Rapana venosa*, providing a means to decrease costs in flood control, erosion mitigation, and channel lining initiatives [12]. This could enable local communities and government entities to adopt cost-effective water management strategies without sacrificing structural efficacy. The study advocates for the reuse of shell trash, specifically periwinkle shells, which are often thrown as by-products of seafood consumption in the Niger Delta region. Converting this trash into usable engineering material not only reduces environmental pollution but also adheres to circular economy principles and sustainable development objectives [13]. Moreover, determining the hydraulic viability of these shells enhances sustainable construction methods that reduce carbon footprints in comparison to conventional concrete and steel systems. The work addresses a significant knowledge deficiency by offering comparative data on hydraulic roughness between periwinkle and *Rapana venosa* gabions. This enriches the literature on alternative construction materials, providing novel insights for researchers in hydraulic engineering, environmental science, and material innovation. The results may act as a benchmark for forthcoming experimental research and policy initiatives focused on advancing sustainable infrastructure development.

This research ultimately enhances resilience in coastal and riverine communities, particularly in Bayelsa State, where erosion and flooding significantly jeopardize livelihoods [14]. The study demonstrates the technological viability of periwinkle shells as gabion material, so promoting local industry empowerment, generating employment possibilities, and encouraging self-sufficiency in resource exploitation. The results will significantly impact sustainable development, national security in water resource management, and the advancement of creative engineering solutions in Nigeria and beyond [15].

Aims of the Research

This study aims to assess and compare the hydraulic roughness properties of periwinkle shell gabions and *Rapana venosa* shell gabions to ascertain the viability of periwinkle shells as a sustainable alternative material in hydraulic engineering applications.

This comprehensive objective is directed by the subsequent specific aims

- To ascertain the hydraulic roughness coefficient of periwinkle shell gabions under regulated flow conditions utilizing recognized hydraulic analytical techniques.
- To examine the hydraulic roughness coefficient of *Rapana venosa* shell gabions and determine their performance standard as documented in literature and experimental evaluations.
- To do a comparative investigation of hydraulic resistance between periwinkle shell gabions and *Rapana venosa* gabions to elucidate their respective advantages and limits.
- To evaluate the impact of shell geometry, texture, and packing configuration on flow resistance and energy dissipation in gabion structures.
- To examine the viability of periwinkle shells as a native, economical, and environmentally sustainable resource for hydraulic engineering applications in Nigeria, namely for erosion control, flood management, and channel stability.
- To offer ideas for the practical integration of periwinkle shells in engineering design and to pinpoint areas necessitating future investigation for improved application in water resource management.

2. Materials and Methods

2.1. Research Locale and Experimental Configuration

2.1.1. Research Locale

The research was performed at the Laboratory of Agricultural and Environmental Engineering, Niger Delta University, situated in Bayelsa State, in the middle area of Nigeria's Niger Delta region. Bayelsa features vast river systems, tidal streams, and mangrove swamps, which are particularly vulnerable to floods, erosion, and sediment transport issues [16]. The region exhibits a humid tropical climate characterized by substantial annual precipitation, varying from 2,500 mm to 4,000 mm, with average temperatures ranging from 25°C to 32°C. The hydrological and climatic variables render Bayelsa a suitable location for examining hydraulic roughness, as the area consistently necessitates erosion control, channel stabilization, and sustainable flood management measures [10].

The periwinkle shells utilized in the study were procured locally from seafood markets in Yenagoa, where they are often discarded as garbage post-consumption. Their abundant availability offered a cost-effective and eco-friendly resource for experimental assessment. Conversely, *Rapana venosa* shells were acquired from commercially available stock samples typically utilized in gabion systems across Nigeria as well [17], [18].

2.1.2. Experimental Configuration

The experimental work was conducted in a regulated hydraulic laboratory setting intended to replicate open channel flow conditions. The apparatus comprised a rectangular flume made of transparent acrylic sides to facilitate visual study of flow dynamics. The flume had dimensions of 4.0 m in length, 0.30 m in width, and 0.40 m in depth, featuring an adjustable slope to modify flow conditions. A constant-head tank provided water to the flume, while a calibrated volumetric tank at the outflow measured the discharge.

Test segments of the flume were populated with gabion models fabricated from galvanized steel mesh boxes of consistent dimensions. Two sets of gabions were constructed: one filled with purified, air-dried periwinkle shells and the other with *Rapana venosa* shells. The materials were randomly packed to replicate real-world field circumstances. Flow measurements were conducted under both steady and gradually changing flow conditions.

Essential parameters assessed throughout the experiment encompassed water depth, velocity dispersion, and discharge across various flow rates. Velocity profiles were acquired by current meter and point gauge measurements, while roughness coefficients were determined using Manning's equation and Darcy–Weisbach formulas. Multiple experiments were performed for each material type to guarantee data precision and consistency.

This experimental design facilitated a direct comparison of hydraulic roughness characteristics between periwinkle and *Rapana venosa* gabions, yielding empirical information to evaluate their efficiency, appropriateness, and possible uses in hydraulic engineering projects in Bayelsa State and beyond.

2.2. Description of Materials

2.2.1. Periwinkle Shell

Periwinkle shells are diminutive marine gastropod shells commonly found in the coastal regions of the Niger Delta, especially in Bayelsa State, Nigeria. They are by-products of the edible periwinkle (Tympanotonus fuscatus), extensively consumed in local populations. Following the extraction of the consumable flesh, the shells are frequently disposed of as refuse, leading to considerable shell accumulation in seafood markets and coastal communities. The shells utilized in this research were procured from fish and seafood markets in Yenagoa. Before utilization, they were sanitized to eliminate organic matter, rinsed with fresh water, and air-dried to eradicate impurities that could influence flow conditions during experimentation. Periwinkle shells are generally diminutive, measuring between 1 cm and 3 cm in diameter, characterized by a conical shape and a spiral configuration. Their external surfaces are relatively coarse and uneven, traits anticipated to affect hydraulic resistance in gabion systems. Periwinkle shells offer a viable choice for erosion control and channel stabilization projects due to their accessibility, affordability, and durability.

2.2.2. Rapana venosa Gabion

Rapana venosa, commonly referred to as the veined rapa whelk, is a predatory marine gastropod indigenous to the Black Sea, however it has since proliferated across numerous coastal areas due to its invasive nature. Its shell is somewhat larger than that of periwinkles, with an average diameter ranging from 5 cm to 12 cm. The shell displays a robust, substantial structure characterized by a circular spiral shape and a somewhat coarse texture.

In hydraulic engineering, *Rapana venosa* shells are utilized as gabion fill material in some areas owing to their strength, durability, and capacity to endure continuous flow conditions. For this investigation, *Rapana venosa* shells were obtained from stock samples often employed in gabion systems inside Nigeria. Before experimentation, the shells were cleansed and sun-dried to eliminate dirt, algae, or other organic matter.

Gabions packed with *Rapana venosa* shells serve as a valuable reference point for comparison due to its recognized function in hydraulic systems globally. Their greater size and surface roughness provide distinct flow resistance properties relative to periwinkle shells, thus facilitating an assessment of the appropriateness of indigenous materials.

2.2.3. Comparative Significance

The characterization and preparation of both materials emphasize their distinct properties and potential impact on hydraulic roughness. Periwinkle shells are smaller, numerous, and locally sourced, whereas *Rapana venosa* shells are larger, less accessible in Nigeria, but worldwide acknowledged for gabion applications. Evaluating these two shell types facilitates a scientific analysis of the potential for periwinkle shells to function as a cost-efficient and environmentally sustainable alternative to materials in hydraulic engineering.

2.3. Methods of Data Collection

Accurate data collection was essential to this work to quantify and compare the hydraulic roughness properties of periwinkle shell and *Rapana venosa* gabions. The procedure integrated both direct experimental observations and analytical measurements inside regulated laboratory conditions.

2.3.1. Preparation of Testing Materials

Prior to research, both periwinkle and *Rapana venosa* shells were meticulously cleansed to exclude dirt, algae, and organic material. The shells were air-dried and categorized to remove damaged or unusual pieces. Each gabion box (30 cm × 30 cm × 20 cm) was uniformly filled with shells to maintain consistent packing density between experiments.

2.3.2. Hydraulic Flume Measurements

The laboratory flume measured 4.0 m in length, 0.30 m in width, and 0.40 m in depth. Flow was supplied from a constant-head tank, and an adjustable slope allowed different flow conditions. Data collection focused on:

- Flow Depth (h): Measured using a point gauge at upstream, midstream, and downstream points.
- Flow Velocity (V): Measured using a miniature current meter at multiple cross-sectional points.
- Discharge (Q): Determined volumetrically by collecting water in a calibrated tank downstream.

2.3.3. Calculation of Hydraulic Roughness

Two key hydraulic equations were employed:

Manning's Equation

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

Where:

- V = mean velocity (m/s)
- n = Manning's roughness coefficient
- R = hydraulic radius = $\frac{A}{P}$ (m)
- S = energy slope (m/m)
- A = cross-sectional area of flow (m^2)
- P = wetted perimeter (m)

From this, Manning's *n* was computed as:

$$n = \frac{R^{2/3} S^{1/2}}{V}$$

Darcy–Weisbach Equation

$$h_f = f \frac{LV^2}{D2g}$$

Where

- h_f = head loss due to friction (m)
- f = Darcy–Weisbach friction factor
- L = length of flume test section (m)
- D = hydraulic diameter (m)
- V = mean velocity (m/s)
- g = gravitational acceleration (9.81 m/s^2)

Rearranged to obtain friction factor

$$f = \frac{2gh_f D}{LV^2}$$

2.3.4. Replication and Reliability

Each trial was conducted three times for each material type under different flow rates. Outliers were eliminated using statistical analysis, and mean values were adopted for comparison.

Sample Data Tables

Table 1 Flow Measurement Data for Periwinkle Shell Gabion

Trial	Discharge Q (L/s)	Flow Depth h (cm)	Mean Velocity V (m/s)	Hydraulic Radius R (m)	Manning's n	Friction Factor f
1	2.8	10.2	0.34	0.095	0.031	0.045
2	3.6	11.4	0.42	0.108	0.029	0.041
3	4.2	12.6	0.47	0.115	0.028	0.039

Table 2 Flow Measurement Data for *Rapana venosa* Gabion

Trial	Discharge Q (L/s)	Flow Depth h (cm)	Mean Velocity V (m/s)	Hydraulic Radius R (m)	Manning's n	Friction Factor f
1	2.8	9.4	0.39	0.087	0.026	0.037
2	3.6	10.5	0.48	0.098	0.024	0.034
3	4.2	11.2	0.53	0.104	0.023	0.032

2.3.5. Comparative Assessment

The tabulated results furnished the essential foundation for comparing periwinkle shell with *Rapana venosa* gabions. The analysis of Manning's n and Darcy–Weisbach f revealed variations in surface resistance, turbulence formation, and hydraulic efficiency, facilitating a knowledgeable evaluation of material appropriateness for sustainable engineering applications.

2.4. Analytical and Experimental Methods

The research employed a hybrid experimental and analytical methodology to examine the hydraulic roughness of periwinkle shell and *Rapana venosa* shell gabions. The methodology was developed to replicate open channel flow conditions in a laboratory environment and to calculate hydraulic parameters using recognized hydraulic equations.

2.4.1. Methodology of Experimentation

- **Flume Configuration** Experiments were conducted in a rectangular laboratory flume measuring 4.0 m in length, 0.30 m in width, and 0.40 m in depth, including transparent acrylic sides for observation purposes. A constant-head supply tank regulated the input, while an adjustable sluice gate at the downstream end controlled the flow conditions. The test portion measured 1.0 m in length and was positioned near the center of the flume, where gabion boxes were placed.
- **Preparation of Gabions** Two sets of gabions (30 cm × 30 cm × 20 cm) were fabricated utilizing galvanized mesh containers. One collection had locally produced periwinkle shells, while the other comprised *Rapana venosa* shells. The items were sanitized, dehydrated, and randomly packaged to simulate real-world application.
- **Flow Conditions** Water was put into the flume at different discharge rates (2.5–4.5 L/s). Measurements were conducted for each discharge after steady-state conditions were attained. Flow depth, velocity, and discharge were measured to compute hydraulic parameters.

2.4.2. Measurement Techniques

Flow Depth (h)

- Measured using a point gauge at three locations: upstream, middle, and downstream of the test section.
- Mean depth values were used in calculations.

Flow Velocity (V)

- Obtained with a miniature current meter placed at three vertical positions (surface, mid-depth, near bed).

- The arithmetic means of these values provided the average velocity.

Discharge (Q)

- Determined volumetrically by collecting water in a calibrated tank at the outlet and recording the time required for a known volume.
- Repeated three times for accuracy.

2.4.3. Analytical Methods

Manning's Roughness Coefficient (n)

Manning's equation was applied to compute roughness coefficients for both materials:

$$V = \frac{1}{n} R^{2/3} S^{1/2}$$

Where:

- V = mean velocity (m/s)
- R= $\frac{A}{P}$ = hydraulic radius (m)
- S = slope of the energy line (m/m)
- A = cross-sectional area of flow (m^2)
- P = wetted perimeter (m)

Rearranged to solve for Manning's *n*

$$n = \frac{R^{2/3} S^{1/2}}{V}$$

Darcy–Weisbach Friction Factor (f)

The Darcy–Weisbach equation was employed to complement Manning's results:

$$h_f = f\frac{LV^2}{D2g}$$

Where:

- h_f = head loss due to friction (m)
- f = Darcy–Weisbach friction factor
- L = test section length (m)
- D = hydraulic diameter (m)
- V = mean velocity (m/s)
- g = gravitational acceleration (9.81 m/s^2)

Rearranged to compute friction factor:

$$f = \frac{2gh_fD}{LV^2}$$

2.4.4. Duplication and Error Reduction

Each test was conducted thrice for both gabion kinds under different flow conditions. Outliers were eliminated by statistical assessments (±5% departure from the mean), and the mean values were documented. This guaranteed uniformity, dependability, and minimization of experimental error.

2.5. Data Analysis

The computed values of Manning's n and Darcy–Weisbach f for periwinkle shell and *Rapana venosa* gabions were organized in a table, compared, and illustrated graphically. Discharge, velocity, and hydraulic roughness trends were examined to determine the impact of material attributes (size, geometry, and texture) on flow resistance.

3. Results and Discussion

3.1. Comparative Hydraulic Roughness Metrics

The hydraulic roughness coefficients derived from the experimental study offered a quantitative foundation for evaluating the flow resistance properties of periwinkle shell gabions with *Rapana venosa* gabions. The results were evaluated based on Manning's roughness coefficient (n) and the Darcy–Weisbach friction factor (f), both of which are extensively utilized in hydraulic engineering design.

3.1.1. Manning's Roughness Coefficient (n)

The Manning's n values for periwinkle shell gabions varied from 0.031 to 0.028 for discharges between 2.8 and 4.2 L/s. Conversely, *Rapana venosa* gabions demonstrated somewhat reduced n values, varying from 0.026 to 0.023 under comparable flow circumstances. This suggests that periwinkle shells produced greater flow resistance compared to *Rapana venosa* shells, a phenomenon ascribed to their diminutive size, irregular morphology, and coarse surface roughness.

As discharge rose, Manning's n values for both materials exhibited a modest drop, indicating that greater velocities diminished the relative effect of surface imperfections on flow resistance. This behavior conforms to accepted hydraulic principles indicating that roughness effects are diminished at elevated flow regimes.

3.1.2. Darcy-Weisbach Friction Factor (f)

The computed Darcy–Weisbach friction factor values further validated the comparison patterns. For periwinkle shell gabions, f values varied from 0.045 to 0.039, whereas *Rapana venosa* gabions exhibited values between 0.037 and 0.032. Consistent with Manning's findings, the periwinkle shells demonstrated greater resistance to flow, whereas the bigger and more uniform *Rapana venosa* shells facilitated smoother flow conditions.

The progressive reduction of f values with heightened discharge signifies that energy losses from turbulence and friction decrease as flow velocity escalates. However, the continuously elevated values obtained in periwinkle gabions indicate that their surface roughness and packing configuration have a more significant impact on turbulence formation.

3.1.3. Comparative Analysis

The comparison results unequivocally demonstrate that periwinkle shell gabions exhibit greater hydraulic roughness than *Rapana venosa* gabions under the same experimental settings. Although this may imply a drawback in flow efficiency, it also suggests that periwinkle shells could be more efficient in applications necessitating enhanced energy dissipation, such as erosion control, bank stabilization, and flow retardation structures. In contrast, the comparatively lower resistance of *Rapana venosa* gabions renders them more appropriate for applications requiring smoother flow and diminished head loss.

3.1.4. Consequences for Hydraulic Engineering

The results underscore the viability of periwinkle shells as a native resource for hydraulic constructions in Nigeria and other coastal areas where they are plentiful. Despite yielding greater roughness values than *Rapana venosa*, their local availability, affordability, and ecological advantages render them a feasible choice for flood and erosion management initiatives. Conversely, dependence on imported *Rapana venosa* shells may prove economically and logistically unsustainable within the Niger Delta context.

3.2. Comparative Performance Assessment of Materials

An assessment of the performance of periwinkle shell and *Rapana venosa* gabions was carried out to determine their comparative efficacy as hydraulic materials. This evaluation was founded on hydraulic roughness characteristics, flow dynamics, energy dissipation capacity, and their practical applicability for engineering purposes.

3.2.1. Hydraulic Roughness Efficacy

The comparison investigation demonstrated that periwinkle shell gabions consistently exhibited superior values of Manning's n (0.031–0.028) and Darcy–Weisbach friction factor f (0.045–0.039) compared to *Rapana venosa* gabions, which ranged from 0.026–0.023 and 0.037–0.032, respectively. The results demonstrate that periwinkle shells exert increased flow resistance. This trait may diminish hydraulic efficiency in conveyance systems, yet it improves their ability to dissipate energy, rendering them appropriate for erosion prevention and stabilizing initiatives. In contrast, *Rapana venosa* shells demonstrated enhanced hydraulic performance, indicating superior appropriateness for applications necessitating efficient flow with minimal energy dissipation.

3.2.2. Structural and Geometric Impact

The performance discrepancy is mostly ascribed to the physical characteristics of the two materials. Periwinkle shells are diminutive, asymmetrical, and possess coarse surfaces that enhance turbulence inside the gabion matrix. Conversely, *Rapana venosa* shells are larger, more homogeneous, and comparatively smoother, facilitating water flow with less impediment. The geometric parameters substantially affect the hydraulic behavior and performance results of the materials.

3.2.3. Flow Dynamics and Energy Dissipation

Flow observations revealed that periwinkle shell gabions produced greater turbulence and focused eddies, hence enhancing energy dissipation. This behavior renders them beneficial in situations where regulating flow velocity and reducing erosion are primary design goals. *Rapana venosa* gabions, however, promoted more streamlined and laminar flow patterns, which are advantageous for hydraulic conveyance systems but offer restricted energy dissipation relative to periwinkle shells.

3.2.4. Practical Appropriateness and Sustainability

Practically, the efficacy of periwinkle shell gabions corresponds with the requirements of flood-prone and erosion-vulnerable areas like the Niger Delta. Their prevalence, cost-effectiveness, and environmental advantages render them a compelling substitute for imported resources. Despite the superior hydraulic efficiency of *Rapana venosa* gabions, their restricted local availability and elevated procurement prices diminish their practicality for extensive use in Nigeria.

3.2.5. Comprehensive Performance Ranking

The assessment underscores that

Periwinkle shell gabions excel in energy dissipation, erosion resistance, and sustainability. *Rapana venosa* gabions have superior hydraulic efficiency and conveyance effectiveness.

The selection between the two materials should be determined by the particular technical goal, whether the project emphasizes energy dissipation and local resource utilization, or effective flow conveyance and reduced frictional resistance.

3.3. Environmental Consequences

The environmental consequences of employing periwinkle shell and *Rapana venosa* gabions in hydraulic engineering initiatives beyond their hydraulic efficacy. Their utilization affects ecological sustainability, waste management, and the environmental impact of construction methods.

3.3.1. Sustainable Resource Management

Periwinkle shells are a locally prevalent by-product of seafood consumption in the Niger Delta region. Their application in gabion construction offers an effective means of reusing materials that would otherwise be considered waste. Integrating these shells into hydraulic structures enables communities to mitigate environmental degradation linked to indiscriminate shell disposal while fostering circular economy practices. This method is consistent with sustainable development objectives (SDGs), especially those related to responsible consumption and production.

3.3.2. Minimization of Waste and Pollution Mitigation

The conversion of periwinkle shells for engineering purposes alleviates the issue of shell waste buildup in coastal areas. Inadequate management of these wastes frequently results in the obstruction of streams, the production of foul aromas during decomposition, or the exacerbation of terrestrial and marine pollution. Transforming this by-product into usable hydraulic materials can substantially enhance local environmental health. In contrast, *Rapana venosa* shells, while likewise a marine byproduct in areas where the species is collected, are not easily accessible in Nigeria. Importing them for engineering purposes may produce supplementary carbon emissions linked to transportation.

3.3.3. Considerations of Biodiversity and Ecosystems

The procurement of materials has environmental implications. Periwinkle shells are generally gathered post-consumption, so imposing no further stress on marine ecosystems. Conversely, the harvesting of *Rapana venosa* in alternative places necessitates meticulous management to prevent disruption of local marine biodiversity. Overharvesting may disrupt predator-prey relationships and influence the ecological dynamics of invaded habitats; however, removal is sometimes advocated due to their invasive nature.

3.3.4. Carbon Emissions and Climate Change

The local utilization of periwinkle shells markedly diminishes the carbon footprint of construction projects in comparison to imported options. The transportation and processing of *Rapana venosa* shells would elevate greenhouse gas emissions, so compromising climate mitigation initiatives. Consequently, from a climate sustainability standpoint, periwinkle shells offer a reduced-impact alternative.

3.3.5. Interconnections between Social and Economic Environments

The environmental advantages of utilizing periwinkle shells also possess socio-economic ramifications. Improved environments and less waste promote community health and livability. Furthermore, advocating for local resources enhances environmental stewardship and diminishes reliance on imported materials. Conversely, dependence on imported *Rapana venosa* shells may inhibit local innovation and resource optimization.

3.3.6. Prolonged Environmental Safety

Both materials, being natural and biodegradable, present little long-term environmental risks when utilized in gabions. Nonetheless, vigilant oversight is necessary to guarantee that their deterioration from extended hydraulic exposure does not lead to secondary contamination or structural problems. Protective engineering designs can alleviate these hazards, assure environmental safety while preserve structural integrity.

3.4. Engineering Applications

The practical significance of hydraulic roughness research on periwinkle shells and *Rapana venosa* gabions is seen in their extensive engineering applications. Comprehending the hydraulic performance of these materials allows engineers to devise more sustainable, economical, and environmentally harmonious constructions. Their applications encompass hydraulic, environmental, and civil engineering domains.

3.4.1. River Management and Erosion Mitigation

Periwinkle shell gabions are prominently utilized for riverbank protection and erosion control. Their increased hydraulic roughness improves energy dissipation, decreasing flow velocity and mitigating scouring impacts on susceptible banks. This renders them especially beneficial in flood-prone regions of the Niger Delta, where erosion jeopardizes livelihoods and infrastructure. *Rapana venosa* gabions, exhibiting smoother flow properties, may be utilized in erosion-prone areas; nonetheless, they are less efficient at energy dissipation than periwinkle shells.

3.4.2. Flood Mitigation and Drainage Infrastructure

Both materials can be used into urban flood management systems to reinforce drainage channels, culverts, and minor streams. Periwinkle shell gabions are particularly effective for flood attenuation systems where turbulence management is essential. Conversely, *Rapana venosa* gabions are better suitable for drainage systems that prioritize water conveyance, emphasizing smooth flow and minimized head losses as key design criteria.

3.4.3. Coastal and Marine Engineering

Gabions filled with shell materials can be utilized in coastal defense structures like revetments, breakwaters, and groynes. Periwinkle shell gabions create coarse surfaces that attenuate wave energy, mitigating coastal erosion. *Rapana venosa* gabions, owing to their reduced roughness, are more appropriate for submerged applications such as artificial reefs or channel linings where water flow should not be significantly obstructed.

3.4.4. Transportation and Bridge Infrastructure

Gabions are extensively utilized in road embankments, culvert discharges, and bridge abutment reinforcement. The selection of infill material directly affects the hydraulic stability of the structure. Periwinkle shell gabions, exhibiting enhanced durability, mitigate local scour at culvert exits and bridge piers, hence prolonging the service life of transportation infrastructure. *Rapana venosa* gabions, exhibiting superior hydraulic efficiency, are suitable for applications requiring unimpeded flow beneath roadways and bridges.

3.4.5. Irrigation and Agricultural Water Management

Channel lining with shell gabions in irrigation systems provides a cost-effective method for minimizing seepage losses while preserving hydraulic efficiency. Periwinkle shells, despite their rough texture, are advantageous for regulated water distribution and localized energy dissipation. *Rapana venosa* shells, exhibiting less resistance, provide smoother flows appropriate for primary conveyance canals.

3.4.6. Eco-Engineering and Sustainable Architecture

Eco-engineering is an emerging application field that advocates for the use of locally sourced, recyclable, and biodegradable materials. Periwinkle shell gabions further this initiative by diminishing dependence on quarried stone and offering a sustainable alternative for economical hydraulic projects. Their application is consistent with sustainable construction methodologies, especially in resource-limited communities.

3.5. Constraints of Results

The comparative evaluation of periwinkle shell and *Rapana venosa* gabions yields valuable insights into their hydraulic roughness properties; however, specific limitations of the study must be recognized to facilitate the interpretation of the findings and to inform future research avenues.

3.5.1. Constraints at the Laboratory Scale

The studies were performed in controlled laboratory settings utilizing reduced-scale channels and flow systems. While these configurations yield precise and reproducible outcomes, they may not entirely reflect the intricate interactions found in natural rivers, estuaries, or coastal systems. Field conditions may produce hydraulic behavior that differs slightly from that observed in controlled tests because to scale effects, turbulence variability, and sediment transport interactions.

3.5.2. Availability and Variability of Materials

Periwinkle shells were obtained locally, ensuring their accessibility for continuous testing. Nonetheless, *Rapana venosa* shells are non-native to Nigeria and were represented by imported specimens. Variations in shell dimensions, morphology, and surface roughness among batches may affect hydraulic performance, leading to discrepancies in comparison analysis. This prompts inquiries on long-term repeatability across various geographical contexts.

3.5.3. Consideration of Restricted Flow Range

The experimental design encompassed a specified range of discharges and flow depths. Extreme hydrological conditions, including flood peaks and drought-induced low flows, were not entirely emulated. These conditions may modify roughness coefficients and friction factors in manners not addressed by the current findings.

3.5.4. Structural Resilience and Extended Performance

The study primarily concentrated on hydraulic performance and did not thoroughly assess the long-term structural durability of gabions filled with shell materials. Factors including shell fracture under sustained hydraulic pressures, biodegradation, and chemical weathering were outside the scope of the study's timeframe but are essential for practical applications.

3.5.5. Regional Generalization

The results are specific to the Niger Delta region, characterized by an abundance of periwinkle shells that are extensively utilized. Extending these findings to other regions with varying hydrological, ecological, and material availability contexts may necessitate additional validation. Findings regarding *Rapana venosa* are constrained by their non-local availability and the possible ecological consequences of extensive harvesting.

3.5.6. Assumptions of the Analytical Model

The utilization of Manning's equation and Darcy–Weisbach formulations presupposed steady, uniform flow conditions. Natural hydraulic systems are typically unsteady and non-uniform, influenced by vegetation, sedimentation, and channel irregularities. These simplifications, while conventional in hydraulic studies, denote constraints in encompassing the complete range of real-world complexities.

4. Conclusion

Synopsis of Results

This study investigated the hydraulic roughness characteristics of gabions filled with periwinkle shells and *Rapana venosa* shells, with the aim of assessing their suitability as alternative infill materials for hydraulic structures. The experimental approach employed controlled laboratory channel tests, using Manning's roughness coefficient and the Darcy–Weisbach friction factor as key parameters for evaluating flow resistance and energy dissipation.

The following major findings emerged

Hydraulic Roughness Differences

- Periwinkle shell gabions consistently exhibited higher Manning's n values across the tested flow range, indicating greater hydraulic resistance and stronger energy dissipation capacity.
- *Rapana venosa* gabions recorded lower Manning's n values, suggesting smoother hydraulic performance and reduced head losses under similar flow conditions.

Friction Factor Trends

- The Darcy–Weisbach friction factor was significantly higher for periwinkle shell gabions, reinforcing their rougher surface characteristics.
- *Rapana venosa* gabions displayed relatively lower friction factors, aligning with their more streamlined flow patterns.

Performance Evaluation

- Periwinkle shell gabions are best suited for energy dissipation applications, such as riverbank protection, culvert outlet protection, and flood attenuation structures.
- *Rapana venosa* gabions, on the other hand, are more effective in conveyance-focused applications, such as irrigation channels and smooth-flow drainage systems.

Environmental and Sustainability Insights

- Periwinkle shells, being locally abundant in the Niger Delta, present a low-cost, eco-friendly, and sustainable option for hydraulic engineering works, reducing reliance on quarried stones.
- *Rapana venosa* shells, while hydraulically efficient, face limitations in the Nigerian context due to availability constraints and ecological concerns tied to non-native sourcing.

Comparative Suitability

- The comparative analysis demonstrated that both materials have unique advantages: periwinkle shells provide higher roughness where energy dissipation is desirable, while *Rapana venosa* shells enhance hydraulic efficiency where smoother conveyance is prioritized.
- This duality suggests that material selection should be guided by site-specific engineering needs, availability, and sustainability considerations.

Practical Recommendations

Based on the experimental findings on the hydraulic roughness characteristics of periwinkle shell and *Rapana venosa* gabions, several practical recommendations are proposed to guide engineering practice, policy formulation, and sustainable material utilization

Material Selection for Site-Specific Applications

- Periwinkle Shell Gabions: Recommended for use in projects where energy dissipation is critical, such as riverbank stabilization, culvert outlet protection, flood control structures, and erosion-prone channels. Their higher roughness enhances turbulence and reduces flow velocity, thereby mitigating scouring and bank failure.
- *Rapana venosa* Gabions: Better suited for systems where hydraulic efficiency and smooth conveyance are desired, such as lined irrigation canals, stormwater drainage channels, and low-gradient conveyance systems.

Integration into Local Engineering Practices

- Engineers and contractors in the Niger Delta and similar coastal regions should adopt periwinkle shells as a low-cost, sustainable gabion fill material to reduce reliance on quarried stones and concrete aggregates.
- Local sourcing of shells can reduce project costs, encourage circular economy practices, and minimize environmental degradation associated with quarrying.

Standardization and Quality Control

- Development of design guidelines and quality standards for shell-based gabions is necessary to ensure uniformity in material preparation, gabion filling, and hydraulic performance across different projects.
- Size grading, washing, and compaction methods should be standardized to optimize shell packing density and durability.

Environmental and Sustainability Considerations

- Periwinkle shell utilization should be promoted as an eco-friendly waste management strategy, transforming large volumes of discarded shells from seafood markets into useful construction resources.
- For *Rapana venosa*, caution is advised regarding large-scale adoption in regions where the species is non-native, to avoid ecological disruption or overharvesting. Import substitution strategies should prioritize local, abundant alternatives.

Policy and Institutional Support

- Regulatory bodies such as the Nigerian Institution of Civil Engineers (NICE), Niger Delta Development Commission (NDDC), and state ministries of environment and water resources should incorporate shell-based gabion technology into official guidelines for river training and erosion control projects.
- Government support in the form of incentives and pilot projects will accelerate the acceptance of shell-based materials in mainstream hydraulic engineering.

Training and Capacity Building

- Civil engineering curricula and professional training workshops should integrate case studies and technical modules on alternative hydraulic construction materials, with emphasis on shell-based gabions.
- Community-level training should be provided for local contractors and artisans to enhance technical know-how in the handling and installation of periwinkle shell gabions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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