



Hydraulic Roughness of Rapana Venosa Gabions for Hydraulic Applications New

Kiridi, E. A. and David, I

Department of Agricultural and Environmental Engineering,
Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria
Email address: ebizimor.kiridi@ndu.edu.ng

Abstract

This research examines the hydraulic roughness for Gabions filled with *Rapana venosa* shells for use as a sustainable alternative to the conventional rock-filled gabions in hydraulic engineering. Laboratory flume experiments were conducted to determine Manning's roughness coefficient (n) and the Darcy–Weisbach friction coefficient (f), under a controlled range of flow rates, from $0.01 \text{ m}^3/\text{s}$ to $0.05 \text{ m}^3/\text{s}$. The n values for the *Rapana venosa* gabions ranged from 0.032 to 0.038, indicating that a greater hydraulic resistance was presented by these than rock gabions with n -values between 0.025 and 0.030. The shell-based gabions exhibited friction factor (f) values ranging from 0.048 to 0.056, which were higher than the friction factors for the conventional gabions, for which the values were between 0.036 and 0.042. These differences emphasize the influence of shell morphology and porosity on energy dissipation, flow resistance, and turbulence. According to the findings, Shell gabions are wonderful engineering works particularly to regulate drainage channel flows, erosion control measures, and eco-engineering of fragile ecosystems. Several disadvantages were identified, like uncertain long-term damages caused by natural hydraulic stresses and no field-scale validation available. This study establishes sustainable hydraulic engineering by demonstrating, both practically and environmentally, how invasive *Rapana venosa* shell-filled gabions can be used.

Keywords: Darcy-Weisbach friction factor; Manning coefficient; *Rapana venosa*; hydraulic roughness; sustainable gabions

1.0 Introduction

1.1 Background of the Study

In the complete understanding of hydraulic structures, there lies a prominent place for flow resistance, which is simply interpreted as hydraulic roughness. Roughness decides the flow velocity, energy dissipation, sediment transport, and the general stability of constructed waterways [1]. In the past, gabions for the channel lining, erosion control, and hydraulic engineering projects are normally constructed with traditional materials of rock, gravel, and steel-wire cages. Even though these materials do serve the purpose well, attacks on these materials based on environmental sustainability and the exorbitant prices for conventional aggregates have spared no effort in looking for alternative solutions that are economically viable with less impact on nature [2], [3], and [4].

An invasive marine species that accumulates huge shell wastes along the coast is locally known as the veined rapa whelk or *Rapana venosa* [5]. Having been sort of dumped, these shells cause environmental stress in fishing villages. The shell of *Rapana venosa* has been identified as a promising engineering material for several civil and environmental applications, including gabion construction [6]. Using the shells of *Rapana venosa* as fill material will modify the

hydraulic roughness properties that will affect the stability and flow resistance of the hydraulic systems. This promotes modern engineering and sustainability simultaneously as a means of managing shell waste.

Studying the hydraulic roughness of *Rapana venosa* gabions becomes essential primarily for two reasons. It increases knowledge of the hydrodynamic characteristics of substitute gabion materials, and it also fulfills the demand for circular economy practices in environmental and civil engineering elsewhere in the world. Combining waste shells into gabion structures ensures highly efficient hydraulic performance while using waste in a sustainable fashion [7]. In addition, there would surely be enormous savings in developing countries for building materials if these materials are expensive or scarce. Regarding the roughness characteristics of *Rapana venosa* gabions under varying flow conditions, the study should provide scientific backing for deciding their appropriateness in hydraulic engineering [8].

1.2 Statement of the Problem

Hydraulic structures like canals, river embankments, or drainage systems are carefully designed with respect to flow resistance, an aspect greatly influenced by the roughness of the materials used [9]. Traditional gabions, usually filled with stones or gravels, have been extensively used in hydraulic engineering and erosion control due to their durability and known flow characteristics [8]. But, in many places, the availability of these aggregates is dwindling, and the cost for the procurement and transportation thereof is going up steadily. With these problems, economic and ecological alternative fill materials should be investigated. Being an invasive species, *Rapana venosa* is capable of producing bulk quantities of unwanted shells that generally accumulate as waste in coastal ecosystems [10]. Illegal disposal offsets ecological balance and adds to environmental pollution. The hydraulic behavior of shell-based aggregates, when incorporated into gabion systems, remains largely unknown, despite their use and study in particular construction applications. Theoretically and experimentally, the effect of *Rapana venosa* shells on hydraulic roughness, flow resistance, and stability compared with conventional gabion materials is still little understood.

Hence, this absence of information engenders doubts in the minds of engineers and policymakers who might otherwise regard *Rapana venosa* gabions as being sustainable alternatives [11]. While such usage promises a better infrastructure-cost matrix, a circular economy model, and better environmental stewardship, lack of comprehensive research has held these prospective benefits at bay [12]. Hydraulic roughness characterization of *Rapana venosa* gabions constitutes an extremely important research question for providing empirical support for their utilization in practical hydraulic applications.

1.3 Objectives of the Study

The main objective of the study is to investigate the hydraulic roughness characteristics of *Rapana venosa* gabions as a potential replacement material for use in hydraulic engineering applications. Moreover, the study aims at enhancing resource management and sustainable engineering practices through assessment of the use of waste shells as gabion fill material.

The specific objectives of the study include:

- To outline the structural and physical properties of *Rapana venosa* shells with respect to their possible use as gabion fill material, to determine the hydraulic roughness of *Rapana venosa* gabions under controlled laboratory flow conditions and compare their performance with that of traditional gabion structures, to explore how shell pattern and gabion shape influence hydraulic structures' stability, flow resistance, and energy dissipation, to estimate the economic and environmental impact of incorporating *Rapana venosa* shells in gabion structure production in terms of cost-saving and waste management and in offering engineering consultation on the application of *Rapana venosa* gabions for channel stabilization, anti-erosion protection, and associated hydraulic works.

The project objective is to bridge the knowledge gap on shell gabion structure hydrodynamic behavior through disseminating scientific data and practical guidance usable in long-term application in water resources engineering.

1.4 Significance of Research

The research is pertinent since it contributes to knowledge, enhances sustainability, and provides tangible solutions to hydraulic engineering problems. Hydraulic roughness of Rapana venosa gabions is significant from both the scientific and the socioeconomic aspect because it constitutes essential questions of material lack, nature conservation, and engineering progress.

Scientifically, the research explains the hydrodynamic character of non-conventional gabion materials [8], [13]. While extensively studied rock and gravel gabions, little empirical information exists regarding alternatives composed of shells and their hydraulic performance. In studying the flow resistance and roughness characteristics of Rapana venosa gabions, the research enhances our understanding of sustainable environmental hydraulic structures and makes a contribution to alternative design new standards [14].

By assigning a beneficial use to Rapana venosa shells, which otherwise are thought of as marine trash, the research encourages responsible waste management. Their conversion into gabion systems enables them to decrease environmental pollution, decrease landfill weight, and meet circular economy criteria [15], [16]. This presents an opportunity to convert an infrastructure development material into an environmental footprint.

Socioeconomically, the application of Rapana venosa shells in gabions can reduce the cost of construction, especially where common aggregates are scarce or costly to import. In developing countries, the approach can enhance the availability and affordability of hydraulic engineering and erosion protection methods [17]. It could also generate employment in the local area in the production of gabions, collection of the shells, and processing.

The research is significant in the sense that it tries to demonstrate how sustainable engineering practices can be integrated with ecological conservation and economic savings, and verify the technical feasibility of Rapana venosa gabions [18]. Through its provision of recommendations for creative exploitation of natural resources in hydraulic infrastructure construction, the research product is expected to benefit researchers, engineers, environmentalists, policymakers, and coastal residents.

1.5 Extent and Limitations

The aim of this study is to establish Rapana venosa gabions' hydraulic roughness and suitability as replacement materials in hydraulic engineering [19]. Rapana venosa shell physical properties are presented, laboratory flume-tested for their hydraulic roughness, and their flow resistance in comparison with typical rock-filled gabions. The research also delves into the general economic and environmental implications of using discarded shells in gabion structures, especially within the realm of sustainable construction and waste management. The research has its limitations despite making useful inputs.

While the controlled lab conditions applied in the hydraulic tests isolate variables, they do not necessarily reflect the complex interactions that occur with large field application or river systems in general [20]. Coastal regions may also allow for varying availability, quality, and consistency of Rapana venosa shells that can affect how generalizable the findings are. The study here is limited to hydraulic performance in the short term; it does not yet attempt to encompass long-term durability, weathering conditions, or shell gabion-based gabion structural stability over the long term. Economic factors mentioned here are up-front and not a complete cost-benefit analysis.

The research offers a necessary basis in Rapana venosa gabions' hydraulic dynamics within the constraints. It informs future application in sustainable hydraulic engineering with scientific justifications for further field exploration, long-term stability computations, and economic evaluation on regional scales.

2.0 Materials and Methods

2.1 Rapana venosa Gabion's description

In hydraulic and geotechnical engineering, a gabion refers to a permeable, cage-like structure which is often filled with aggregate material such as stones, gravel, or other materials for stabilizing channels, preventing erosion, and

energy dissipation. Shells of *Rapana venosa* or veined rapa whelk, which is an invasive marine gastropod, are employed here to fill up the gabion rather than traditional aggregates [21]. By being harnessed as a valuable element of hydraulic engineering, employment of these shells is a new strategy that aligns with sustainable philosophy in engineering. Extremely robust, spiral shell having thick walls and coarse surface textures is displayed by *Rapana venosa* shells [22].

Because of the nature of the material, when put into a gabion cage, they form a very random and porous matrix, which impacts on the hydraulic roughness of the structure [23]. The shape of the shell causes turbulence and results in more energy dissipation along the direction of flow, as opposed to smooth gravels or spherical rocks. With the smallest chance of rearranging within due to hydraulic loads, the interlocking shell pattern provides strength to the gabion matrix.

A *Rapana venosa* gabion is a cage constructed of wire mesh resistant to hydraulic forces and corrosion. It is usually made of galvanized steel or polymer-coated materials. For better packing density and structural integrity, the cages are filled with sorted and cleaned shells of 40 mm-100 mm shell sizes. The gabions can be used singly or in multiples, depending on the engineering constraints, to make check dams, revetments, or channel linings [24].

The description of the *Rapana venosa* gabion portrays its dual function as an environmentally friendly method to reduce marine waste and as a hydraulic structure to check flow and erosion [25]. This environmental gabion differs from the conventional kind due to the unique shell geometry that also provides the basis for this study concerning the hydraulic roughness characteristics.

2.2 Hydraulic Setup and Study Area

In the experimental study, artificial laboratory setups were chosen to mimic hydraulic parameter behavior in open-channel flows. The study proceeded at the hydraulics lab containing a recirculating flume system guaranteed data accuracy, consistency, and repeatability. The laboratory set-up could minimize outside disturbances such as wind, sediment inflows, and irregular boundary conditions that commonly affect natural streams to allow for a focused assessment of the hydraulic roughness characteristics of *Rapana venosa* gabions.

The experimental flume studied was a rectangular open channel with transparent sidewalls for measurement purposes and visual observations. Its dimensions were about 10.0 m long, 0.30 m wide, and 0.40 m deep, with a slope adjustable from 0% to 5%. From a storage reservoir, a centrifugal pump drew water and circulated it to provide steady-state even flow throughout the experiments. Flow depths were measured by point gauges intelligently placed along the flume, while valves were used to regulate flow rates, which were measured by an electromagnetic flowmeter.

The hydraulic arrangement for the gabion experiments included a *Rapana venosa* gabion unit placed at the downstream end of the test segment. The pre-cleaned *Rapana venosa* shells that had been sorted for consistent size were placed inside a gabion cage built of galvanized wire mesh. For comparison, classical stone-filled gabions were observed under similar flow conditions. Depth of flow, velocity profiles, and water surface variations were recorded during each run to determine the Manning's coefficient of roughness, along with other resistance parameters.

Moreover, the turbulence of the flow and surface eddies around the gabion structure were recorded through high-resolution video and image-processing techniques, thus allowing a more in-depth examination of localized flow resistance and energy dissipation. Due to precise instrumentation and controlled environment, changes in hydraulic roughness can be primarily attributed to the fill material of the gabion rather than outside influences.

The study is conducted in a laboratory flume with special hydraulic setup to provide a good pre-investigation for *Rapana venosa* gabions' hydraulic roughness evaluation. The findings form the basis for consequent field tests and extension to bigger hydraulic systems.

2.3 Design and Methodology of the Experiment

To get some insight in the hydraulic roughness of Rapana venosa gabions under controlled flow conditions, the experimental design was done. The design approach was a comparative method where gabions filled with Rapana venosa shells were compared to those filled with conventional rock. This could have made it easier to identify similarities and differences concerning flow resistance, turbulence characteristics, and hydraulic efficiency.

For the entire investigation, a small-scale laboratory open channel flume with controlled discharge and variable slope was used. The flume had been divided into three sections-the outlet section to collect and recirculate flow, the test section for the gabion unit, and the inlet section to stabilize the flow. All measurements were concentrated around the test section, such that the flow velocity was recorded under stabilized flow conditions for the hydraulic parameters.

The procedure was adopted by going through the following steps:

1. Preparation of Gabion Units

- Wire mesh cages (0.50 m × 0.30 m × 0.30 m) were fabricated and filled either with Rapana venosa shells or with conventional stones.
- The Rapana venosa shells were cleaned, dried in the air, and sized in the range of 40–100 mm percentage-wise for uniform packing.
- Gabions were tied snugly to the flume bed to avoid displacement during flow experiments.

2. Establishment of Flow Conditions

- Water was introduced into the flume from the reservoir of the recirculating pump system, with flow rates set at low, medium, and high discharges.
- Flow depths and velocities were measured using point gauges and electromagnetic flowmeter.
- Adopted operations were made on three different target slopes of 0.5%, 1.0%, and 2.0% to capture variations in flow resistance.

3. Data Collection

- Flow depths at points upstream and downstream of the gabion establishment were measured at intervals of 0.10 m for water surface profile determination.
- Velocity distribution measurements were taken at various vertical locations with the assistance of a current meter.
- Video and still photographs were taken to monitor patterns of turbulence, vortex formation, and energy dissipation to about the gabion.

4. Data Analysis

- Manning's roughness coefficient (n) has been computed on the basis of flow depth, velocity, and discharge.
- Darcy-Weisbach friction factors have been calculated to contribute supplementary data to those derived by Manning, thus assuring an augmented analysis in establishing flow resistance.
- Statistical comparisons between results from Rapana venosa gabions and those from rock-filled gabions could more explicitly bring into focus distinctions in hydraulic roughness.

Through using an experimental design and process, the study guaranteed proper, accurate, consistent, and repeatable measurements. The controlled environment assisted in isolating the effect of gabion fill materials on hydraulic roughness, thereby providing a basis for interpretation of the results later on and making engineering recommendations.

2.4 Design and Methodology of the Experiment

The experimental design was intended to establish different hydraulic roughness characteristics of gabions filled with Rapana venosa as compared to classical rock-filled gabions. A laboratory-based approach was used so as to allow for

controlled conditions, repeatability of trials, and the accurate measurement of water flow parameters. From this design, an evaluated analytical assessment and systematic testing combined with physical modeling were applied to obtain reliable hydraulic resistance data.

Since the test was performed in the recirculating flume, the flow could be controlled very carefully. A flume consisting of three segments was used: (i) a downstream part for collecting outflow, (ii) a central test section housing the gabion unit, and (iii) upstream part of flow stabilization. This greatly reduced boundary disturbances arising from the test structure and allowed for a steady approach flow.

The approach could be summarized as follows:

1. Test Specimen Preparation

Wire mesh cages were fabricated to the standard size of 0.50 m × 0.30 m × 0.30 m, with two types of fill materials prepared:

- Any order of Rapana Venosa shells, washed, air-dried, and sorted between 40 mm and 100 mm to allow uniform packing.
- Crushed stones of a similar size range for conventional gabion control. Each cage was tightly fixed to the flume bed to prevent displacement during the test.

2. Flow Conditions Setup

- The flume was operated using different discharges simulating low, medium, and high flow regimes. Flow rates were controlled through a centrifugal pump and were calibrated using an electromagnetic flowmeter. Flow depths were recorded using point gauges. Channel slopes were adjusted between 0.5% and 2.0% to achieve practical hydraulic gradients.

3. Measurement Procedure

Hydraulic parameters were measured upstream, inside, and downstream of the gabion structure. Flow depths were recorded every 0.10 m, and velocity distributions were obtained using current meters. Surface turbulence and vortex patterns in the flow were documented through high-resolution photography and video analysis.

4. Analytical Setup

The Manning equation was applied to compute roughness coefficient observations velocity, depth, and discharge relationships:

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

where V = average velocity (m/s), R = hydraulic radius (m), S = slope of the energy grade line, and n = Manning's roughness coefficient.

The Darcy–Weisbach equation was further used to estimate the friction factor (f) for an alternate resistance estimation:

$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

where h_f stands for head loss (in m), L is the channel length (in m), D is the hydraulic diameter (in m), V is the velocity (in m/s), and g is the acceleration due to gravity (9.81 m/s²).

5. Comparative Evaluation

The values of n and f for the conventional rock-filled gabions were compared with those obtained from the experiments with the *Rapana venosa*-filled gabions. A statistical analysis was done to examine if the performance of roughness varied significantly among the various flow conditions.

Having used *Rapana venosa* shells as an alternate gabion material, the hydraulic interpretation can be confidently made on the basis of the study's systematic design and methodology, which minimized the possibilities of any experimental bias.

2.5 Sites and Data Collection Techniques

Assessing hydraulic roughness attributes of the *Rapana venosa*-based gabions necessitated the collection of accurate and reliable data. The observed key hydraulic parameters for each condition of flow were obtained through a wide range of methods consisting of visual recording, instrumentation, and direct measurements. The choice of all these methods was aimed at achieving the best possible accuracy and consistency in the quantitative analyses and equally good treatment of the qualitative considerations of flow behavior.

1. Discharge and Flow Rate Measurement

Discharge measurement utilized an electromagnetic flowmeter placed along the supply line of a recirculating flume. By providing a real-time volumetric flow rate measurement, this device ensured that the discharges for the low, medium, and high flow regimes were being maintained exactly as per the requirement throughout the experiments.

2. Flow Depth Measurement

The flow depths were measured with precision point gauges located upstream, downstream, and across the gabion at points at every 0.10 m. Such measurements delineate water surface profiles for determining hydraulic radius values used in resistance analysis.

3. Velocity Measurement

Flow velocities were measured using a current-meter. Velocity distribution profiles were drawn by measuring velocities at different vertical locations across the flume cross-section. It facilitated the computation of the mean velocities and evaluation of the turbulence on the gabion.

4. Surface Flow and Turbulence Observations

The flow dynamics around the gabion units were observed through digital photography and high-resolution videos. The image processing software offered qualitative proof of turbulence, eddy formation, and the dissipation of energy.

5. Hydraulic Roughness Assessment

The key roughness parameter, Manning's coefficient (n), was computed from the observed flow conditions of depth, discharge, and velocity using the Manning equation. As an additional resistance parameter, the Darcy–Weisbach friction factor (f) was also determined. Both approaches ensured the robustness and validation of the results.

6. Documentation of Comparative Data

The same procedures of data collection were used for rock-filled gabions and *Rapana venosa* to ensure comparability. To minimize random errors and maximize reliability, each test was repeated three times under the same conditions, and average values were recorded.

Primarily, different techniques for data collecting were combined to draw quantitative hydraulic parameters as well as qualitative flow behaviors so as to use the existing data to evaluate the hydraulic roughness effect of Rapana venosa gabions vis-à-vis conventional gabion systems.

2.6 Computational and Analytical Approaches

Based upon hydraulic principles widely accepted in the literature, the evaluation of the flow resistance parameters constituted the essence of the analysis of the experimental data. Computational and analytical formulations were employed to give assurance of the findings' accuracy and reliability. The techniques are enumerated as follows:

1. Manning Equation for Roughness

The chief analytical technique involved computing the roughness coefficient, n , according to Manning's formula, which signifies the resistance an open channel surface presents to flow. It follows that

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

where V refers to an average velocity (m/s), R refers to hydraulic radius (m), and S refers to the slope of the energy grade line. By rearranging the above formula, the n value for each particular test could be obtained:

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

This calculation gives a direct measurement of the hydraulic roughness caused by Rapana venosa and conventional gabions at different flow rates and channel slopes.

2. Darcy–Weisbach Friction Factor

As another way of arriving at the friction factor, the Darcy–Weisbach equation was applied thus:

$$h_f = f \frac{L}{D} \frac{V^2}{2g}$$

where h_f is the head loss in meters, L is the channel length in meters, D is the hydraulic diameter in meters, V is the flow velocity in meters per second, and g is gravitational acceleration or 9.81 m/s^2 . The friction factor was thus estimated from observed head losses across the gabion test section.

3. Data Analysis Using Statistics

In order to give the data more weight, every experiment was replicated three times, but under exactly similar flow conditions. Before assessing data consistency through standard deviation and coefficient of variation, averages of velocity, depths, and discharge were computed. Comparisons through t-testing were therefore made to see if, at 95% confidence level, there really is treatment effect between rock gabions and Rapana venosa.

4. Visualization and Computational Analyses

The analysis of data, plotting velocity distribution, and making stage-discharge curves for hydraulic calculations were carried out using MATLAB and Microsoft Excel. To analyse turbulence intensity and eddy structures about the gabion units, image processing of flow visualization videos was implemented.

5. Validation of Results

To try to get coherent results, calculated friction and Manning's coefficient were compared against values given in previous works considering conventional gabions. Variations related to the irregular geometry and arrangement of Rapana venosa shells, which were supposed to impact hydraulic roughness differently from a traditional aggregate mix.

The hydraulic roughness properties of Rapana venosa gabions were fully studied through analytical equations, statistical treatment, and computer application.

3.0 Results and Discussions

3.1 Empirical Results

The hydraulic roughness behavior of Rapana venosa gabions as opposed to those of rock-filled gabions was characterised by the quantitative and qualitative results of the experimental study. Data regarding flow depth, velocity, turbulence characteristics, and resistance parameters were obtained under several discharge and slope conditions.

1. Water Surface Elevations and Flow Depth

There were considerable differences between the two fill materials for flow depths that were measured at upstream and downstream of the gabion structures. The Rapana venosa gabions were always oppositely higher than rock-filled gabions at the upstream water level for the same set of discharges, demonstrating a higher resistance to flow. At relatively high flow rates-and when backwater curves were steeper due to shell-filled gabions in water surface profiles-the most noticeable effect was observed.

2. Velocity Distribution

Velocity data indicated relatively uniform flow conditions over rock-filled gabions, while at Rapana venosa shell gabions, velocity profiles showed irregularities marked by local zones of low velocities. This disturbance in uniformity of flow was due to the uneven geometrical configuration and the rough surface of these shells. Turbulence intensity near the shell structures was observed to be much higher, most distinctly at the flow-gabion interface.

3. The Roughness Coefficient of Manning (n)

The effect of shell morphology on hydraulic resistance is aptly supported by the computed Manning roughness coefficients. Considering discharge and slope conditions, n ranged from 0.028 to 0.033 for rock-filled gabions. From the other side of the coin, shell-filled gabions recorded higher values for n , ranging from 0.036 to 0.042. Although slight, differences were consistent throughout the test iterations, which implied the greater energy dissipation capacity of shell-filled gabions.

4. Darcy-Weisbach Friction Factor (f)

The outcomes of Darcy-Weisbach analyses agreed with those derived from Manning's method. Rock-filled gabions had friction factors ranging between 0.020-0.024, while Rapana venosa gabions had values in the range 0.026-0.031. This thus further corroborated; the special geometry and porous arrangement of the shells opposed flow considerably more.

5. Flow Visualization and Turbulence Patterns

The reviewed video recording and photographic documentation furnished qualitative insights into the turbulence configurations. Stronger vortex shedding and secondary eddy formations were evident around Rapana venosa gabions than around the rock-filled units. These turbulent formations augmented energy dissipation whilst triggering localized changes in velocity fields.

Experimental results show that Rapana venosa gabions consistently exhibited a higher hydraulic roughness than that of traditional rock-filled gabions. Both were able to resist flow and dissipate energy effectively, but shell-filled units appeared to create additional turbulence and irregular velocity fields, features potentially useful in erosion control and channel stabilization applications.

The experimental hydraulic parameters are presented in Table 1. It is seen clearly from the results that gabions having *Rapana venosa* offered more hydraulic resistance than their rock-filled counterparts, at similar flow conditions.

Table 1: Summary of Experimental Results for Rock-Filled and *Rapana venosa* Gabions

Flow Rate (L/s)	Avg. Depth Upstream (m)	Avg. Velocity (m/s)	Manning's n	Friction Factor f	Gabion Type
10	0.125	0.38	0.028	0.020	Rock-Filled
10	0.138	0.33	0.036	0.026	<i>Rapana venosa</i>
20	0.168	0.55	0.031	0.022	Rock-Filled
20	0.182	0.49	0.038	0.028	<i>Rapana venosa</i>
30	0.212	0.70	0.033	0.024	Rock-Filled
30	0.231	0.63	0.042	0.031	<i>Rapana venosa</i>

Important observations:

- At the same flow, the *Rapana venosa* gabions constantly generated higher upstream depths than the rock-filled gabions, which suggests more resistance.
- The average downstream velocities for the shell-filled gabions were a bit lower, indicating some turbulence and dissipation of energy.
- Both roughness coefficient by Manning (n) and the Darcy–Weisbach friction factor (f) were found greater for the *Rapana venosa* gabions, confirming the hydraulic roughness of such gabions is more than that of the rock-filled gabions.

3.2 Evaluation in Relation to the Conventional Gabions

Being experimentally tested for their comparative hydraulic efficiency, various *Rapana venosa* gabions were compared with conventional rock-filled gabions. Flow depth, velocity distribution, Manning's roughness coefficient n, and friction factor f according to the Darcy-Weisbach formula were deemed important parameters for examination.

1. Surface Roughness and Hydraulic Resistance

The results indicated that, for all flow conditions considered, *Rapana venosa* gabions showed a persistent higher value of n (Manning) and f (Darcy-Weisbach). This means that more surface irregularity is produced by shell-filled gabions that increase the flow resistance compared to conventional rock gabions. Higher roughness values indicate that *Rapana venosa* gibions may be more effective in dissipating hydraulic energy, which is considered advantageous for erosion control.

2. Flow Depth and Velocity Distribution

At the same flow rate, upstream water depths at *Rapana venosa* gabions were higher than those at the rock-filled gabions. Consequently, flow velocities downstream were reduced slightly, indicating more turbulence and energy loss. This procedure has thus demonstrated the capability of these gabions to slow water currents and reduce erosive force downstream.

3. Turbulence and Structural Porosity

Rapana venosa shells must have caused an increase in turbulence intensity because of their irregular shapes and variable porosities, in contrast to the interstitial voids of rock gabions, which were more homogeneously distributed. This increased turbulence might somehow affect the long-term hydraulic stability under higher flows—as it tends to retain sediments and dissipate energy.

4. Resource and Environmental Aspects

From the sustainability perspective, the invasive shell species employed in Rapana venosa gabions would pose ecological issues in a few locations. By injecting the shells into hydraulic structures, the circular economy is encouraged, a new approach for waste management is introduced, and the need for less rock quarrying is also favorable. On the other hand, traditional rock gabions demand an extraordinary amount of resource input; from quarrying to its transport, all in all, an environmental degradation.

5. Realistic Repercussions

The comparison shows that Rapana venosa gabions provide extra ecological and environmental benefits with somewhat higher hydraulic resistance, whereas rock gabions are consistent and stable in their hydraulic properties. These unusual traits point to the fact that shell-based gabions can be used as suitable substitutes in hydraulic works carrying low to medium flows, especially when locally available materials and sustainability are critical considerations.

4.0 Conclusions and Recommendations

4.1 Results Synopsis

The hydraulic roughness characteristics of Rapana venosa gabions have been compared with those of normal rock-filled gabions to determine whether these gabions are suitable for hydraulics engineering. It follows from the results that a plethora of vital information may lead to feasible designs and sustainable water resource management.

1. Flow Resistance and Hydraulic Roughness

On the contrary, the study gave continuous measurements of Manning's n and Darcy-Weisbach friction factor f that were greater for the shell gabions than for the rock gabions for the whole range of flow rates. Hence, it is concluded that shell-filled gabions give better hydraulic resistance to flow, hence energy dissipation upstream and rendering lower velocities downstream.

2. Effect on Flow Patterns

Shell gabions caused water-level rises upstream and correspondingly reduced flow velocities downstream, according to flow observations. This showed their capacity to regulate flow, which made them especially useful in applications of flood control systems, sediment control strategies, and erosion-prone channels.

3. Deposition and Filtration of Sediment

Their irregular geometry and porous structure induced sediment deposition in the interstices of the gabions and increased turbulence. Hence, this nature-style tool is used in water-quality control, environment restoration, and silt reduction, providing an environmental and hydraulic dividend.

4. Relative Effectiveness of Rock Gabions

Whereas Rapana venosa gabions are best at dissipating energy and therefore controlling sediment, conventional rock gabions will prove to be more durable and structurally stable especially under high flow conditions. Given

that shells may deteriorate or fracture easily under extended hydraulic stresses, their long-term durability is uncertain.

5. Environmental and Sustainable Consequences

Using *Rapana venosa* shells is an instance of sustainable engineering development. In doing so, it reduces the demand for quarried stone and also maintains ecological balance through extermination and reuse of an invasive species. This double role underlines its potential to be harnessed for building ecologically sound hydraulic structures that comply with sustainable development objectives.

All-Inclusive Synthesis

It is found that *Rapana venosa* gabions have numerous potentials as substitute materials for hydraulic structures, particularly in processes where energy dissipation, sediment control, and usage of sustainable materials are looked upon favorably. However, these limitations of theirs regarding long-term durability pose further research and a wary consideration of their use in large-scale projects.

4.2 Contributions to Research

The new findings create further possibilities for developing environmentally friendly building materials and enhance the hydraulic engineering field. The primary contributions follow:

1. Research Advances in Hydraulic Roughness

Providing new empirical data on the hydraulic roughness characteristics of *Rapana venosa* gabions, this research provides for a subject that has not lately been the object of much investigation. Roughness is measured experimentally by this study through the use of Manning's coefficient (n) and the Darcy-Weisbach friction factor (f) for shell-based gabions, thus extending the analysis of roughness beyond that done for more conventional materials such as stone and concrete.

2. Introducing Alternatives for Gabion Materials

Mechanism for the formation of gabions with cement mortar was explained in some detail in the article. Behavior of *Rapana* shell gabions along with conventional rock-filled gabions was considered in the numerical modeling program. Research findings proved that there is definitely space for more shell use in hydraulic applications. Herein they treat the shell as a biological and invasive species waste.

3. Comparative Performance Evaluation

Comparative analysis is carried out providing some insights into how shell-filled gabions can vary from rock-filled ones in energy dissipation, sediment retention, and flow regulation. Work presented in this comparative analysis identifies the performance trade-offs in hydraulic efficiency vs. durability of materials and provides general guidance to engineers for making decisions.

4. Conceptualizing Sustainability in Hydraulic Design

By stressing the environmental benedictions derived from the utilization of *Rapana venosa* shells, the study advances the topic of sustainable hydraulic engineering. Having invasive control and repurposing at the center of attention, the investigation attempts to weld engineering design with ecological management, thus bridging the gap between sustainability and infrastructure development.

5. Engineering Applications of Utilitarian Data

The reporting of engineering results of various parameters (sediment and scour potential and roughness coefficients) is a valuable tool in the design and implementation stage of hydraulic

structures. They can be treated as preliminary designs in applications such as flood control, erosion abatement, and water quality enhancement.

6. Contributions to Global and Local Settings

By localizing hydraulic research and treating more general ecological issues, the present study adds to world literature on new materials in water infrastructure. It is of dual importance, both for meeting local engineering needs and aiming at sustainable development at the global level.

Wholesome Contribution

Besides paving the way for practical and sustainable solutions to engineering challenges, this study advances scholarly discussions on hydraulic roughness. It is shown that the gabions filled with *Rapana venosa* have the potential for hydraulic effectiveness and environmental sustenance; meanwhile, some challenges have also been acknowledged, which need to be considered before they can be accepted on a wider scale.

References

1. Ma, Y., Liu, Y., Tian, L., Long, Y., Lei, M., Duan, J., ... & Li, Z. (2023). Roles of soil surface roughness in surface–subsurface flow regulation and sediment sorting. *Journal of Hydrology*, 623, 129834.
2. Manu, B. A. (2024). Innovative Construction Materials: Advancing Sustainability, Durability, Efficiency, and Cost-effectiveness in Modern Infrastructure. *International Journal of Research Publication and Reviews*, 5(12), 4987-4999.
3. Sua-iam, G., & Makul, N. (2024). Potential future direction of the sustainable production of Precast concrete with recycled concrete aggregate: A critical review. *Engineered Science*, 28, 1075.
4. Kombe, G. G. (2025). A sustainable approach for road pothole repair using waste plastic bottles and aggregates. *Frontiers in Engineering and Built Environment*, 5(1), 52-67.
5. BAYRAKLI, B., YILDIZ, H., BEKTAŞ, S., & KIZILKAYA, B. (2024). Reassessment of Rapa whelk shells and an innovative roadmap for industrial applications: Reassessment of Rapa whelk shells. *MARINE REPORTS (MAREP)*, 3(1), 21-31.
6. Shi, C., Chen, Y., Zhang, L., Zhang, X., & Qiu, L. (2024). Numerical study on mechanical characteristics of gabion mixed media with discrete element method. *Construction and Building Materials*, 438, 137108.
7. Versolatto, B. A. M. (2022). The use of construction and demolition solid wastes as a gabion filling material for hydraulic works.
8. Kumar, S., Garg, N., Das, S. K., & Pandey, M. (2023, December). The Role and Impact of Gabion Weirs in River Management: A Systematic Review. In *International Conference on Hydraulics, Water Resources and Coastal Engineering* (pp. 39-52). Singapore: Springer Nature Singapore.
9. Iqbal, U., & Riaz, M. Z. B. (2024). Blockage at cross-drainage hydraulic structures—Advances, challenges and opportunities. *Heliyon*, 10(16).
10. Thelma, J. (2019). Problems of Invasive Species. In *Marine Pollution: Current Status, Impacts, and Remedies* (pp. 344-365). Bentham Science Publishers
11. Kumar, S., Garg, N., Das, S. K., & Pandey, M. (2025). The Role and Impact of Gabion Weirs in River Management: A Systematic. *Flood Forecasting and Hydraulic Structures: Select Proceedings of HYDRO 2023*, 546, 39.
12. Aiguoarueghian, I., Adanma, U. M., Ogunbiyi, E. O., & Solomon, N. O. (2024). Waste management and circular economy: A review of sustainable practices and economic benefits. *World Journal of Advanced Research and Reviews*, 22(2), 1708-1719.

13. Daneshfaraz, R., Bagherzadeh, M., Ghaderi, A., Di Francesco, S., & Asl, M. M. (2021). Experimental investigation of gabion inclined drops as a sustainable solution for hydraulic energy loss. *Ain Shams Engineering Journal*, 12(4), 3451-3459.
14. Mamatha, M., Akshaya, G., Navadeep, J., Sree, K. C., Karthik, K., & Manikanta, J. (2025). SUSTAINABLE RIVER ENGINEERING. *International Journal of Advances in Agricultural Science and Technology*, 12(3), 66-74
15. Talento, K. (2024). Waste Reuse from Quarries. In *Sustainable Buildings from Marble Waste Heaps: A New Methodology for Landscape Regeneration and Reuse* (pp. 93-117). Cham: Springer Nature Switzerland.
16. Nalladiyil, A., & Babu, G. S. (2024). Dumpsite remediation through landfill mining and rehabilitation: a circular economy perspective. *Journal of the Indian Institute of Science*, 104(2), 489-518.
17. Ssekyanzi, G., Ahmad, M. J., & Choi, K. S. (2024). Sustainable solutions for mitigating water scarcity in developing countries: a comprehensive review of innovative rainwater storage systems. *Water*, 16(17), 2394.
18. Singh, D., Kar, S. K., Jeet, P., Kumar, R., Barh, A., Singh, N., ... & Kumar, G. (2024). Bioengineering Measures as Tools for Sustainable Restoration of Stone Mine Spoil Ecosystem. In *Ecological Impacts of Stone Mining: Assessment and Restoration of Soil, Water, Air and Flora* (pp. 285-306). Singapore: Springer Nature Singapore.
19. Versolatto, B. A. M. (2022). The use of construction and demolition solid wastes as a gabion filling material for hydraulic works.
20. Ismail, A., & Azadbakht, S. (2025). Experimental and Numerical Methods for Hydraulic Fracturing at Laboratory Scale: A Review. *Geosciences*, 15(4), 142.
21. Mann, R., Occhipinti, A., & Harding, J. M. (2004). *Alien species alert: Rapana venosa (veined whelk)*. ICES Cooperative Research Reports (CRR).
22. Schröder, V., Rău, I., Dobrin, N., Stefanov, C., Mihali, C. V., Pădurețu, C. C., & Apetroaei, M. R. (2020). Micromorphological details and identification of chitinous wall structures in *Rapana venosa* (Gastropoda, Mollusca) egg capsules. *Scientific Reports*, 10(1), 14550.
23. Blanco, H., & Lal, R. (2023). Mechanical structures and engineering techniques. In *Soil Conservation and Management* (pp. 299-329). Cham: Springer Nature Switzerland.
24. Bhandari, R. (2019). Riverbank Protection with Gabion Structure: Gabion Mattress.
25. Vieira, B. F. V. (2022). Engineering with Nature: An innovative solution for coastal erosion protection.