

# Enhancing Navigational Safety and Sustainability in Kerala's National Waterway 3: Integrating Hydrographic Insights and Advanced Vessel Design

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## Abstract

Inland Waterway Transport (IWT) is increasingly acknowledged as a sustainable and energy-efficient alternative to conventional road and rail transport, offering substantial advantages in terms of lower emissions, reduced fuel consumption, and cost-effectiveness. However, its potential remains largely untapped in regions like India's National Waterway 3 (NW-3) because of sedimentation, suboptimal vessel design, and infrastructure constraints.

This study investigates the 82-kilometre Alleppey–Kollam stretch of NW-3 in Kerala, integrating hydrographic survey data with vessel design optimization and advanced materials to develop a comprehensive strategy for sustainable inland navigation. Bathymetric analysis identified 11 critical depth bottlenecks (depth < 2.5 m), with 68% occurring near bridge crossings. Vessel assessment indicates that modern Glass-Reinforced Plastic (GRP) crafts, particularly solar-electric ferries, offer a 30–40% reduction in weight and are capable of operating safely at shallow drafts of approximately 0.6 m—well suited to the constrained sections of NW-3.

The adoption of solar-electric boats not only enhances navigability in shallow waters but also significantly contributes to environmental sustainability by reducing emissions and noise pollution, thereby addressing the rising traffic intensity and ecological concerns associated with conventional diesel-powered vessels.

**Keywords** *Inland waterway transport; Composite materials; Carbon allowance; Solar electric propulsion;*

## INTRODUCTION

Inland Waterway Transport (IWT) is one of the most sustainable and energy-efficient mode of transportation, particularly well-suited for the movement of bulk cargo and passengers through rivers, canals, and backwaters [1]. Compared to conventional land-based transport networks, IWT offers several advantages, including lower greenhouse gas emissions, reduced fuel consumption against the per ton of cargo transported, and decongestion of overburdened road and rail corridors [2].

In the Indian context historically, IWT played a critical role during the 19th and early 20th centuries by supporting regional trade in coastal states such as Assam, Kerala, Goa, and West Bengal. However, with the rapid expansion of rail and road infrastructure, the prominence of inland navigation declined steadily. To reverse this trend, the Government of India established the Inland Waterways Authority of India (IWAI) in 1986 with

the aim to develop, regulate, and promote inland waterways as viable transport alternatives [3].

Presently, India's inland waterway network includes multiple National Waterways, with seven classified as major corridors (**Table 1**). Among these, National Waterway-3 (NW-3) is particularly significant. Spanning approximately 205 kilometers from Kollam to Kottappuram in Kerala, NW-3 encompasses the West Coast Canal as well as vital links such as the Champakkara and Udyogmandal canals [3]. This corridor supports a varied fleet that includes houseboats, passenger ferries, dredgers, hydrographic survey vessels, and increasingly, solar-electric boats. These vessels cater to diverse operational needs such as tourism, public transport, sediment management, and cargo logistics.

However, the navigability and operational reliability of NW-3 are frequently affected by monsoon-induced sedimentation, estuarine inflows, and agricultural runoff, particularly from

the extensive paddy cultivation in adjacent areas. Although baseline hydrographic data is available through IWAI, the post-2018 Kerala floods have drastically altered sedimentation dynamics and increased the urgency for targeted hydrographic survey.

Hydrographic surveys are essential for identifying navigational bottlenecks and planning maintenance dredging. These surveys provide

critical data on underwater topography, depth variation, and siltation patterns, forming the foundation of navigation charting and operational planning [4], [5].

As per the standards outlined by the International Hydrographic Organization (IHO), the absence of regularly updated bathymetric information can result in vessel groundings, traffic disruptions, and elevated navigation risks [6].

**Table 1:** Classification details of the National Waterways in India (Ref: IWAI)

Class	Depth (in m)		Bottom Width (in m)		HC (in m)		VC (in m above HFL)	Bend radius (in m)	Vessel size (SPV)/ Comb (in Tonnes)
	River	Canal	River	Canal	River	Canal			
I	1.2	1.5	30	20	30	20	4	300	100/ 200
II	1.4	1.8	40	30	40	30	5	500	300/ 600
III	1.7	2.2	50	40	50	40	7	700	500/ 1000
IV	2.0	2.5	50	50	50	50	10	800	1000/ 2000
V	2.0	-	80	-	80	-	10	800	1000/ 4000
VI	2.75	3.5	80	60	80	60	10	900	2000/ 4000
VII	>2.75	-	100	-	100	-	10	900	2000/ 8000

Globally, inland waterways such as the Rhine, Danube, and Mississippi Rivers have adopted robust hydrographic monitoring and sediment management practices, often supported by AI-based forecasting and automation systems [7], [8]. In contrast, Indian waterways, including NW-3, often depend on intermittent, manually conducted surveys and ad hoc dredging activities. This leads to a persistent compromise in maintaining the Least Available Depth (LAD), adversely impacting the navigability of vessels with higher drafts. Consequently, vessel designers are compelled to adopt lightweight construction strategies to ensure safe operation in such constrained channels.

Glass-Reinforced Plastic (GRP) construction has emerged as a viable solution, offering lightweight,

corrosion-resistant, and structurally resilient alternatives to traditional materials like steel and wood [9]. Vessels built using GRP can operate effectively in shallow waters with drafts as low as 0.6 meters, making them especially suitable for solar-electric propulsion in environmentally sensitive and spatially constrained stretches like NW-3. In addition to reduced hull weight, GRP enhances energy efficiency and supports the integration of sustainable propulsion technologies [10].

Given these constraints and opportunities, a detailed hydrographic survey was undertaken along the Alleppey–Kollam stretch of NW-3—identified as the most traffic-intensive segment of the corridor. **Fig 1** shows the region in which the survey was conducted.





Fig 3: Bosch GLM 40 Distance Meter

II

**.NAVIGATIONAL CONSTRAINTS IN THE ALLEPPY-KOLLAM STRETCH OF NW-3**

**A. Bridge-Level Navigational Analysis**

To understand physical constraints affecting navigability in the Alleppey–Kollam corridor of National Waterway 3 (NW-3), detailed measurements of bridge parameters were undertaken. These included vertical clearance,

canal width at bridge locations, and available depth beneath the bridge spans.

Most bridges along the route provide a vertical clearance between 6–8 meters, which is generally sufficient for conventional inland vessels. However, certain low-clearance bridges pose constraints for vessels with higher air drafts. As shown in **Figure 4**.

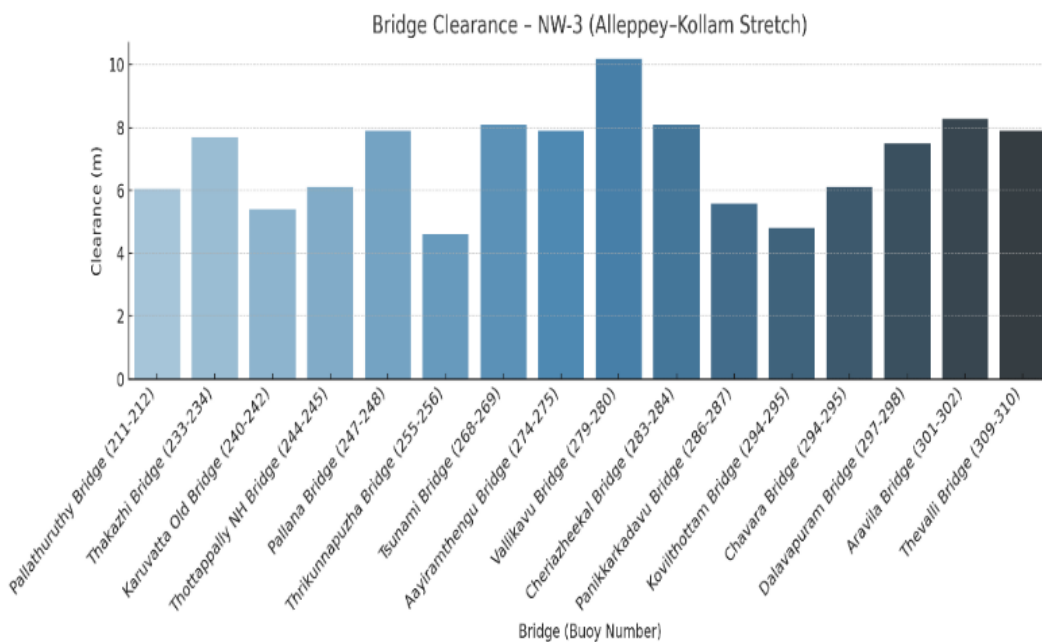


Fig 4: Bar chart showing the vertical clearance of the bridges

Vallikavu Bridge shown in **Fig 5** offers the highest clearance at 10.2 meters, while Thrikkunnapuzha Bridge shown in **Fig 6** is the lowest at 4.6 meters.

This will restrict the designer to limit the air draft of the vessels operating in this region.



**Fig 5:** Vallikavu Bridge, Kollam, Kerala (Buoy Number 279-280)



**Fig 6:** Thrikkunnapuzha Bridge Alleppey, Kerala (Buoy Number 255-256)

Bridge-level width measurements revealed considerable variation. While Aravila Bridge as shown in **Fig 7** allows a maximum horizontal clearance of 42 meters, ensuring unimpeded passage for medium barge traffic, Kovilthottam Bridge shown in **Fig 8** has a constricted width of just 8 meters. This will have a direct impact on the breadth of the vessels operating in this region. **Fig 9** shows the bar chart with the horizontal

clearance of each bridge.

Channel depth was also measured beneath each bridge. Depths less than 2.5 meters were classified as critical, based on the recommended Least Available Depth (LAD) benchmark for safe inland navigation. As shown in **Fig: 10**, locations such as Dalavapuram and Kovilthottam regularly fall below this threshold.



**Fig 7:** Aravila Bridge, Parakkadavu, Kollam, Kerala (Buoy Number 301-302)



Fig 8: Kovilthottam Bridge Chavara, Kerala (Buoy Number 294-295)

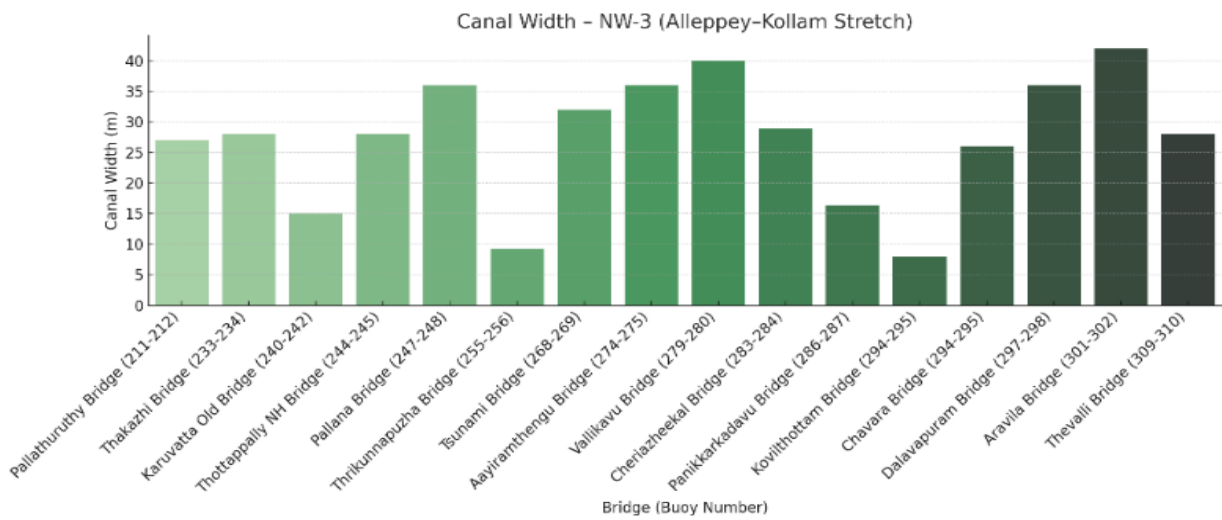


Fig 9: Bar chart showing the horizontal clearance of the bridges

A scatter plot between bridge width and depth Fig: 11 indicates a weak correlation, highlighting that wider bridges do not necessarily guarantee adequate depth.

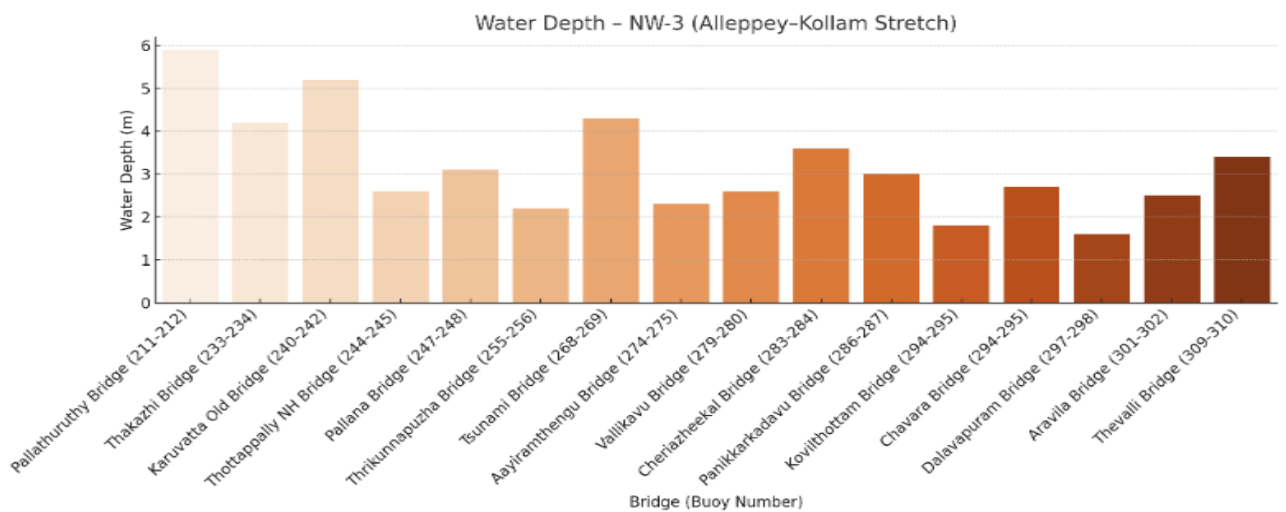


Fig 10: Bar chart showing the depth of the channel enroute the bridges

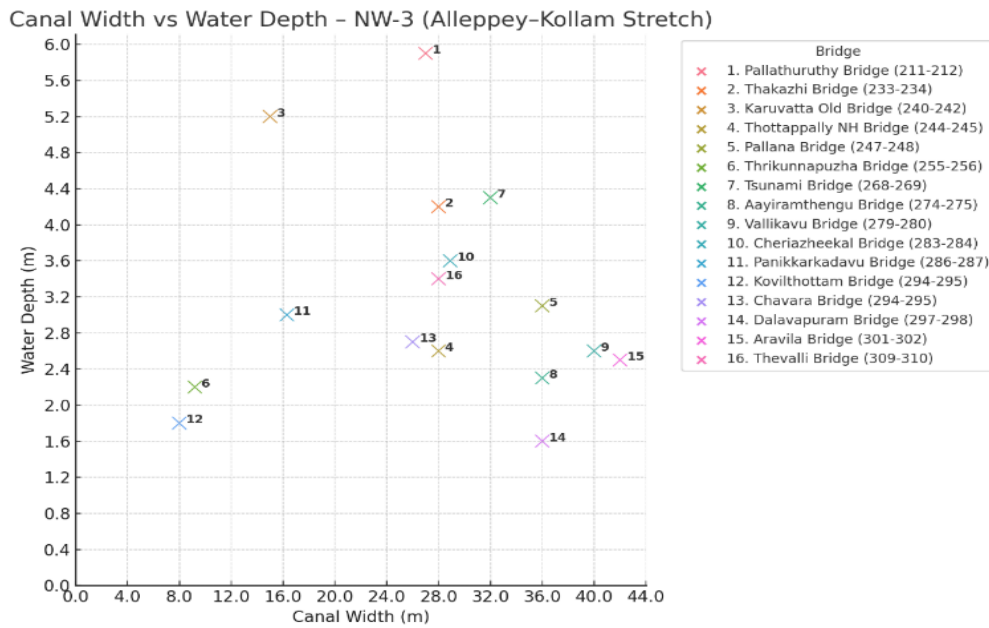


Fig 11: Scatter Plot between canal width and water depth

III.

IMPLICATIONS FOR VESSEL OPERATIONS

The prevailing hydrographic constraints—particularly sub-2.5 m depths in certain zones—pose challenges for vessels with higher drafts and construction with traditional materials like wood and steel. As ongoing dredging cannot always guarantee consistent depth, vessel designs must adapt to these limitations to ensure uninterrupted navigation.

A. Concept Design Proposal: GRP-Based Shallow Draft Vessel

From the route survey and the hydrographic analysis, it was found that The diverse fleet operating in these waters includes cargo barges, passenger ferries, and a thriving fleet of over 1,400 houseboats. Th boats in this region are traditionally used to operate on diesel engines with an approximate RPM of 200 to 900.

The reliance on diesel as a fuel has caused considerable damage to the environment. Several studies have linked the emissions produced by diesel vessels, particularly CO<sub>2</sub>, NO<sub>x</sub>, and PM to the air and water quality deterioration observed within fragile ecosystems such as Vembanad Lake. So the problem is multidimension, the

hydrographic constraint is one of the few the second being the pollution caused by diesel boats. the prevalence of shallow channel segments and limited vertical and horizontal clearances—a shallow-draft, lightweight vessel tailored for low-energy operation is essential. Based on these requirements, a **Glass Reinforced Plastic (GRP) catamaran solar-powered vessel** is proposed. This vessel is engineered with a draft of just **0.6 meters**, ensuring year-round operability through the most sediment-prone and constrained segments of the waterway.

B. Details of the concept design of a solar ferry operating in the NW-3

The vessel is designed to accommodate **30 passengers**, making it suitable for both public transport and eco-tourism operations. A key innovation lies in the adoption of GRP construction, reduces vessel mass by **40–70%** vs. steel, directly lowering drag and energy [11]. This is particularly vital in shallow and sediment-prone channels where energy losses due to drag are amplified.

From a propulsion standpoint, the lightweight design is highly complementary to solar-electric power systems. By reducing the energy required

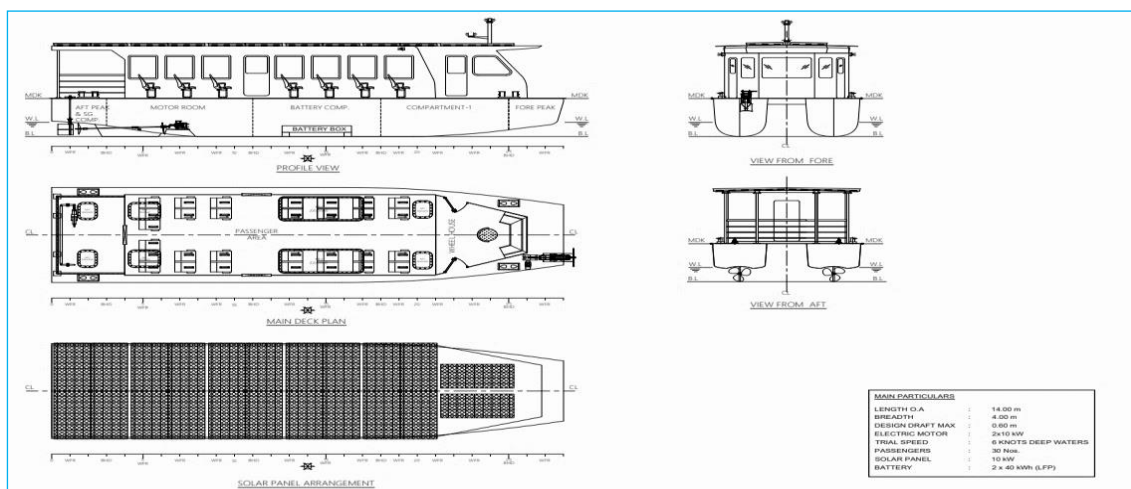
for movement, the GRP construction **lowers the power demands** placed on the solar-electric drive, thus increasing the operational efficiency and endurance of the vessel. This synergy between material selection and propulsion strategy results in a highly optimized vessel that meets the dual objectives of **navigational adaptability** and **environmental sustainability**.

The vessel operates with a **draft of just 0.6 meters**, enabling safe passage through nearly all critical zones identified in the survey. This draft capability is particularly important in stretches

such as Kovilthottam and Dalavapuram, where depth conditions continue to fall below the standard Least Available Depth (LAD) of 2.5 meters. By ensuring reliable operability even in such constrained segments, the design effectively eliminates the need for continuous dredging in select routes, thereby reducing operational costs and ecological disruption. The design is proposed (**Fig:12**) as a Catamaran type to have adequate stability and higher deck area for the passengers. The Principal Particulars of the vessel is shown in **Table: 2**

**Table 2:** Principal Particulars of the concept design for the Inland Vessel

Parameter	Specification
Type	Catamaran
Length Overall (O.A.)	14.00 m
Breadth Overall (O.A.)	4.00 m
Draft	0.60 m
Trial Speed	6 knots (in deep waters)
Main Engines	2 × 10 kW Electric Motors
Solar Panels	10 kW
Battery	2 × 40 kWh (LFP - Lithium Iron Phosphate)
Passenger Capacity	30 Persons
Classification	IRS or IACS Inland Vessel Rules



**Fig 12:** General Arrangement Drawing of the GRP Solar ferry

**C. Cost Benefit Analysis when compared with the conventional diesel ferries.**

The comparative economic analysis between diesel and solar power systems, as shown in **Table 3** and **Figure 13**, offers a clear insight into the total cost of ownership (TCO) over a 20-year period. The evaluation considers both the initial investment and the recurring operational and maintenance costs associated with each system, presenting a comprehensive view of long-term economic feasibility.

The initial capital cost for the solar system is substantially higher than that of the diesel engine. However, operational and maintenance costs present a stark contrast between the two options. Diesel systems demand continuous fuel consumption, which is subject to market price fluctuations and inflation. Additionally, they

require regular maintenance, such as oil changes, filter replacements, and periodic servicing. These recurring expenses result in a steep and steadily increasing cumulative cost curve for the diesel system, as illustrated in **Figure 13**. On the other hand, the solar system, once installed, operates on free solar energy and incurs minimal maintenance costs, leading to a much flatter cost progression over time. It is evident that the break-even point—where the cumulative costs of diesel and solar systems intersect—occurs around the 5th year. Beyond this point, the solar system becomes the more economical choice, with savings compounding as the years progress. This makes the solar system an attractive option when compared with diesel.

**Table 3:** Comparative Economic Analysis: Diesel vs. Solar (Cost in INR Lakhs)

Comparative Economic Analysis: Diesel vs. Solar (Cost in INR Lakhs)														
Year	Diesel Boat								Solar Boat					
	Initial cost	Fuel cost	Cum. Fuel cost	Lube oil cost	Cum. Lube oil cost	Engine overhaul cost	Cum. Overhaul cost	Total Cost	Initial cost	Grid cost	Cum. Grid cost	Battery replace cost	Battery cost cum.	Total Cost
Yr 0	150	0	0	0	0	0	0	150	250	0.00	0.00	0.00	0.00	250.00
Yr 1	150	19.10	19.10	0.38	0.38	0.57	0.57	170.06	250	1.68	1.68	0.00	0.00	251.68
Yr 2	150	20.06	39.16	0.40	0.78	0.60	1.17	191.12	250	1.76	3.44	0.00	0.00	253.44
Yr 3	150	21.06	60.22	0.42	1.20	0.63	1.81	213.23	250	1.85	5.30	0.00	0.00	255.30
Yr 4	150	22.11	82.34	0.44	1.65	0.66	2.47	236.45	250	1.94	7.24	0.00	0.00	257.24
Yr 5	150	23.22	105.55	0.46	2.11	0.70	3.17	260.83	250	2.04	9.28	0.00	0.00	259.28
Yr 6	150	24.38	129.94	0.49	2.60	0.73	3.90	286.43	250	2.14	11.43	0.00	0.00	261.43
Yr 7	150	25.60	155.53	0.51	3.11	0.77	4.67	313.31	250	2.25	13.68	50.00	50.00	313.68
Yr 8	150	26.88	182.41	0.54	3.65	0.81	5.47	341.53	250	2.36	16.04	0.00	50.00	316.04
Yr 9	150	28.22	210.64	0.56	4.21	0.85	6.32	371.17	250	2.48	18.52	0.00	50.00	318.52
Yr 10	150	29.63	240.27	0.59	4.81	0.89	7.21	402.29	250	2.61	21.13	0.00	50.00	321.13
Yr 11	150	31.12	271.39	0.62	5.43	0.93	8.14	434.96	250	2.74	23.87	0.00	50.00	323.87
Yr 12	150	32.67	304.06	0.65	6.08	0.98	9.12	469.26	250	2.87	26.74	0.00	50.00	326.74
Yr 13	150	34.31	338.37	0.69	6.77	1.03	10.15	505.28	250	3.02	29.76	0.00	50.00	329.76
Yr 14	150	36.02	374.39	0.72	7.49	1.08	11.23	543.11	250	3.17	32.93	50.00	100.00	382.93
Yr 15	150	37.82	412.21	0.76	8.24	1.13	12.37	582.82	250	3.33	36.25	0.00	100.00	386.25
Yr 16	150	39.71	451.92	0.79	9.04	1.19	13.56	624.52	250	3.49	39.74	0.00	100.00	389.74
Yr 17	150	41.70	493.62	0.83	9.87	1.25	14.81	668.30	250	3.67	43.41	0.00	100.00	393.41
Yr 18	150	43.78	537.41	0.88	10.75	1.31	16.12	714.28	250	3.85	47.26	0.00	100.00	397.26
Yr 19	150	45.97	583.38	0.92	11.67	1.38	17.50	762.55	250	4.04	51.31	0.00	100.00	401.31
Yr 20	150	48.27	631.65	0.97	12.63	1.45	18.95	813.23	250	4.25	55.55	0.00	100.00	405.55

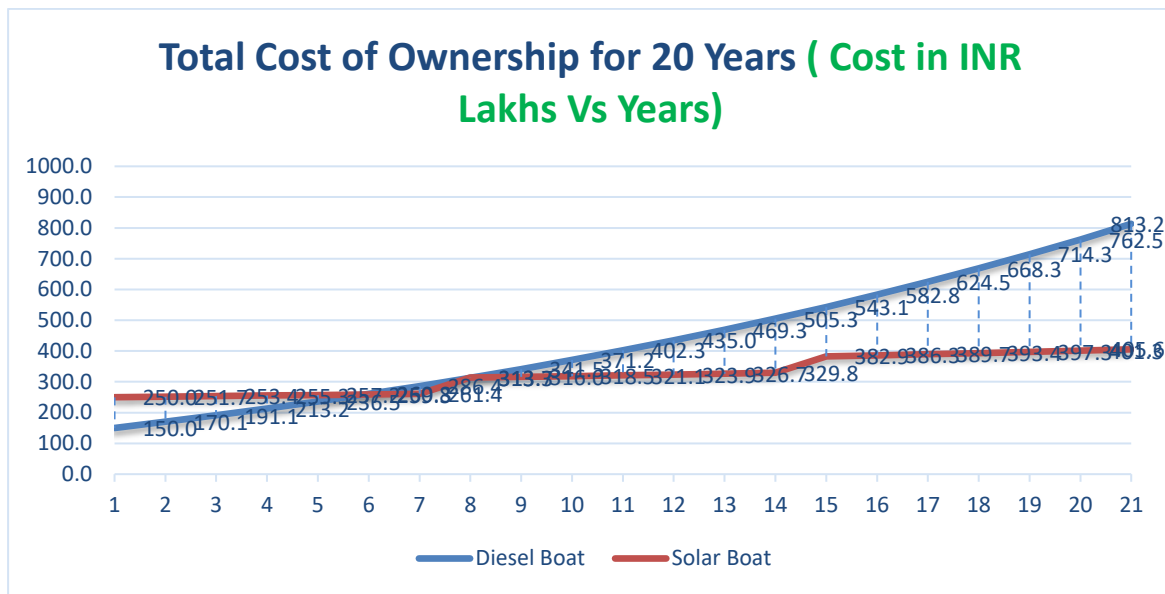


Fig 13: Total Cost of Ownership for 20 Years (Cost in INR Lakhs Vs Years)

#### SIGNIFICANCE OF GRP CONSTRUCTION

GRP refers to composite material comprising of two basic phases, a polymer element (most often a thermoset plastic i.e polyester, vinyl ester or epoxy resin) with covalently bonded molecules providing superior strength [12]. Polymeric composites such as GRP have become a mainstay in the marine sector, used extensively in leisure crafts, patrol boats, and offshore platforms due to their durability in harsh marine conditions [13]. In the evolution of material technologies, composites represent a paradigm shift—marking the current phase in material innovation that enables high-performance structural solutions [14]. Rubino et al. [15] estimates almost 80 % of ship hulls (less than 20 m long) are GRP made.

#### IV. ADVANTAGES AND DISADVANTAGES OF BOATS BUILT IN GRP

##### A. Advantages of using GRP in boat building

The reduction of maintenance in GRP boats is notable for several reasons. Firstly, GRP hulls are constructed as one continuous piece, devoid of joints or gaps, effectively eliminating the risk of leaks typically associated with caulking.[16] Unlike wooden hulls which may suffer from plank shrinkage when exposed to the sun, GRP hulls remain unaffected by such issues, ensuring a consistently watertight seal without the need for

re-caulking. Additionally, GRP's inert nature significantly reduces the risk of corrosion as it does not undergo chemical reactions like metals. The construction process is also simplified with GRP, as once a mould is created, identical hulls can be reproduced efficiently and consistently, requiring less time and labour. Furthermore, the skill level required for GRP boat construction is reduced once basic training is received, contributing to greater accessibility and affordability in boat manufacturing and maintenance.[17]

Advancements in ship design—such as weight reduction and improved fuel efficiency—have also contributed to lowering emissions and mitigating environmental harm [18–22].

##### B. Disadvantages of using GRP in boat building

Once a vessel design is chosen and mould are made, there is little flexibility in altering the choice of vessel, further emphasizing the importance of careful planning and market research. To ensure consistent quality and adherence to safety standards, maintaining a core group of qualified technicians is imperative, although this poses its own challenges in terms of recruitment and retention. Additionally, the use of chemicals in boat manufacturing poses risks of fire and health hazards, necessitating stringent safety protocols and training programs. Furthermore, the initial investment required for establishing a boat

manufacturing operation is considerable, requiring careful financial planning and risk assessment to mitigate potential losses.

Although composite materials are increasingly used across various industries—from construction to wind turbine manufacturing—the global management of composite waste remains largely unresolved. Landfilling continues to be the most economically viable disposal method, while efforts to adopt bio-based alternatives or recycling approaches face obstacles such as high costs and the absence of standardized guidelines.[23]

The mechanical strength of the plastic matrix is notably improved through the addition of glass fibres, traditionally using borosilicate-based E-glass. This tensile strength is further enhanced by the application of organosilane coatings. Depending on the intended application of the GRP, various coatings, fillers, and primers are incorporated. In the case of boat hull manufacturing, polymer-based paints are commonly applied, which can contribute to the accumulation of microplastics in marine ecosystems [24,25].

GRP vessels, particularly those coated with anti-fouling paints, have long been associated with significant environmental risks due to the presence of heavy metals, booster biocides, and microplastic particles in their composition [26,27,28].

End-of-life disposal options for composite materials, such as incineration and landfilling, can lead to adverse environmental impacts [29]. Several studies have explored strategies to minimize the ecological footprint associated with the disposal of composite vessels [29, 30].

#### **D. General Precautions to be followed for GRP Construction**

Careful attention must be paid to the correct ratio of catalyst to resin to prevent the occurrence of a "HOT MIX," which could lead to spontaneous ignition. Any resin emitting smoke should be promptly removed from the shop and doused with water, as should any spills. Other fire hazards, include solvent cleaners, styrene monomer, and

rags contaminated with flammable liquids, require appropriate extinguishing methods such as Carbon Dioxide or Dry Powder extinguishers or water spray. In terms of health hazards, all materials used in boatbuilding are toxic if ingested, with catalysts posing a particular risk of burns and potential blindness upon contact with skin or eyes. Adequate fire extinguishers and eye wash stations should be readily available, alongside a comprehensive First Aid Kit. Ventilation in the workshop should facilitate a complete air change every 1-1.5 hours, with precautions taken to limit atmospheric styrene levels to 100 ppm [31]. Additionally, protective measures like face masks may offer relief during laminating or sanding activities. Delivery and storage of materials, especially resins, present logistical challenges, particularly in tropical climates where shelf life can be compromised by higher temperatures. Attention to storage conditions and timely rotation of stock is essential to ensure material integrity. Reinforcement materials, supplied in sealed packaging, require careful inspection for contamination upon delivery to maintain their bonding properties. These considerations are critical for ensuring safety and quality in boatbuilding operations, particularly in regions where environmental conditions pose additional challenges

#### **V. CONCLUSION**

The hydrographic survey of the Alleppey–Kollam stretch of National Waterway-3 has revealed persistent navigational challenges, including insufficient channel depth, limited bridge clearances, and sedimentation near key bottlenecks. These constraints significantly affect the safe and efficient movement of vessels, especially during low water conditions, and highlight the need for vessel designs that are better suited to shallow and dynamic inland waterways.

In this context, the proposed **Glass Reinforced Plastic (GRP) solar-electric vessel** presents a practical and forward-thinking solution. With a shallow draft of 0.6 meters, lightweight hull construction, and low energy requirements, the

design ensures continuous operability even in the most constrained segments of NW-3. The use of GRP provides key advantages such as corrosion resistance, reduced maintenance, and ease of replication through mold-based fabrication, while its integration with solar-electric propulsion supports sustainable, low-emission operations.

This vessel is particularly well-suited for inland regions like Kerala, where ecological sensitivity, tourism, and clean mobility are top priorities. Its adoption could significantly reduce the dependence on frequent dredging, lower operational costs, and set a new standard for green inland water transport in India.

By aligning material innovation with environmental and navigational needs, the proposed design offers not just a technical solution but a scalable model for the future of inland vessel construction.

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