

# Mapping Maritime Trade Routes of Ancient India Using Archaeological Data

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## ABSTRACT

This study offers a comprehensive, data-driven reconstruction of ancient India's maritime trade networks through the integration of archaeological evidence, paleoenvironmental reconstructions, and advanced geospatial analysis. Drawing upon coastal excavations, underwater surveys, port-city artifact assemblages, and contemporaneous textual records from circa 600 BCE to 1500 CE, we compile and harmonize a geospatial database of 82 maritime-linked sites. Utilizing ArcGIS Pro, bathymetric and paleo-sea-level models, and monsoon wind vector data, we perform network and least-cost path analyses to identify principal sea routes, seasonal sailing windows, and shifting nodal hierarchies among major emporia. Chronological phasing into Early Historic (600 BCE–300 CE), Classical–Early Medieval (300–1000 CE), and Late Medieval (1000–1500 CE) periods reveals dynamic expansions and contractions of trade corridors between the Indian subcontinent, the Red Sea, Persian Gulf, Southeast Asia, and East Africa. The evolution of vessel technology—from sewn-plank to mortise-and-tenon construction—is traced through underwater wreck analyses, indicating adaptations to longer, more arduous voyages. Network metrics highlight the rise of new hubs, especially on the Coromandel and Malabar coasts during the Late Medieval phase. Inland dispersal patterns of imported coin hoards and beads, mapped along river valleys, elucidate the logistical integration of coastal emporia with hinterland markets. Qualitative contextualization through seafaring treatises and travelers' accounts enriches interpretation of material patterns within known historical events, such as Chola naval campaigns and the emergence of Gujarat Sultanate trade posts. Findings underscore ancient India's instrumental role in shaping early globalization, demonstrating sophisticated environmental knowledge, technological innovation, and socio-economic organization. By illuminating past maritime networks, this research also informs contemporary heritage management, coastal zone planning, and cultural tourism strategies aimed at preserving submerged archaeological resources.

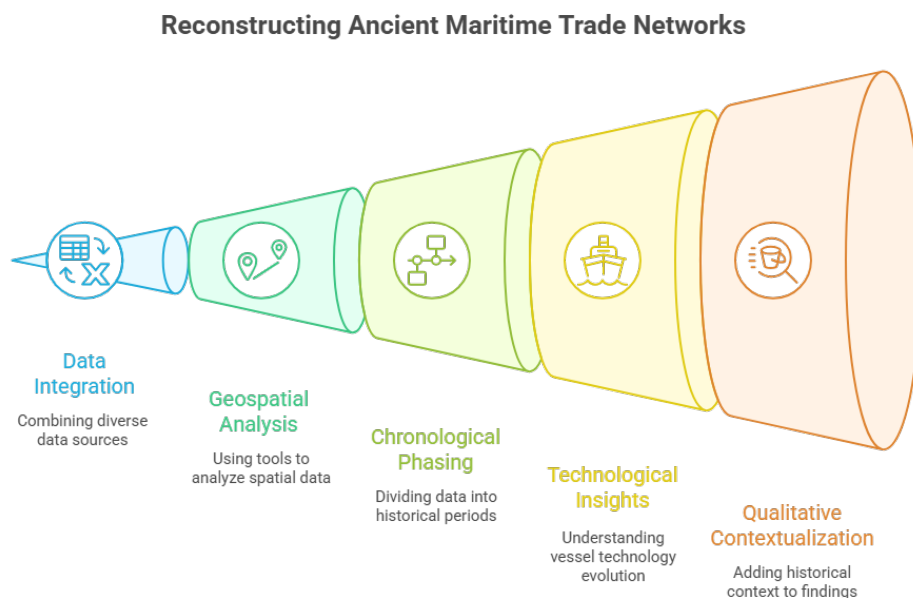
## KEYWORDS

Maritime Trade Routes, Ancient India, Archaeological Data, GIS Mapping, Monsoon Navigation

## INTRODUCTION

Maritime commerce was a fundamental driver of socio-economic development, cultural exchange, and technological innovation in ancient India. From the dawn of the Early Historic period (circa 600 BCE), the Indian subcontinent's extensive 7,500 km coastline facilitated persistent seaborne contacts with the Mediterranean, Arabia, East Africa, and Southeast Asia, shaping regional economies and intercultural interactions (Ray, 2003). While textual sources—such as the *Periplus of the Erythraean Sea*, Tamil Sangam poetry,

and travelers' memoirs—offer narrative frameworks of these exchanges, material evidence is essential for reconstructing the tangible parameters of trade: port locations, navigational seasons, vessel types, and distribution pathways of exotic commodities (Casson, 1989; Hart, 1975).



*Figure-1. Reconstructing Ancient Maritime Trade Networks*

Recent advancements in underwater archaeology, remote sensing, and Geographic Information System (GIS) methodologies have opened new vistas for synoptic analyses of maritime networks. Bathymetric surveys near Gujarat's Cambay and Dwarka coasts have uncovered Harappan-era ceramic scatterings, suggesting Bronze Age seafaring activity (Mackie, 2003). Excavations at Arikamedu and Pattanam have yielded Roman amphorae, Rouge Ware, semi-precious stone beads, and South East Asian ceramics, substantiating Indo-Roman and Indo-Southeast Asian trade linkages (Krishnan, 1984; Menon et al., 2012). These archaeological datasets, however, have largely remained siloed within site-specific studies. A region-wide, diachronic GIS synthesis that integrates paleo-sea-level reconstructions, monsoon wind data, and artifact distributions is still lacking.

This research addresses three interrelated objectives. First, it delineates primary maritime corridors connecting the Indian subcontinent with major overseas markets across three chronological phases: Early Historic (600 BCE–300 CE), Classical–Early Medieval (300–1000 CE), and Late Medieval (1000–1500 CE). Second, it evaluates environmental and technological factors—namely monsoon seasonality and vessel construction innovations—that facilitated or constrained seafaring ventures. Third, it investigates the inland penetration of imported goods by mapping distribution networks along riverine axes to understand the economic integration of coastal emporia with hinterland markets.

By constructing a high-resolution geospatial framework, this study not only refines our comprehension of ancient India's maritime infrastructure but also contributes to broader themes in global economic history, technological adaptation, and cultural connectivity. Furthermore, insights derived from past coastal adaptations and maritime organization can inform present-day heritage management and sustainable coastal development, underscoring the contemporary relevance of ancient maritime legacies.

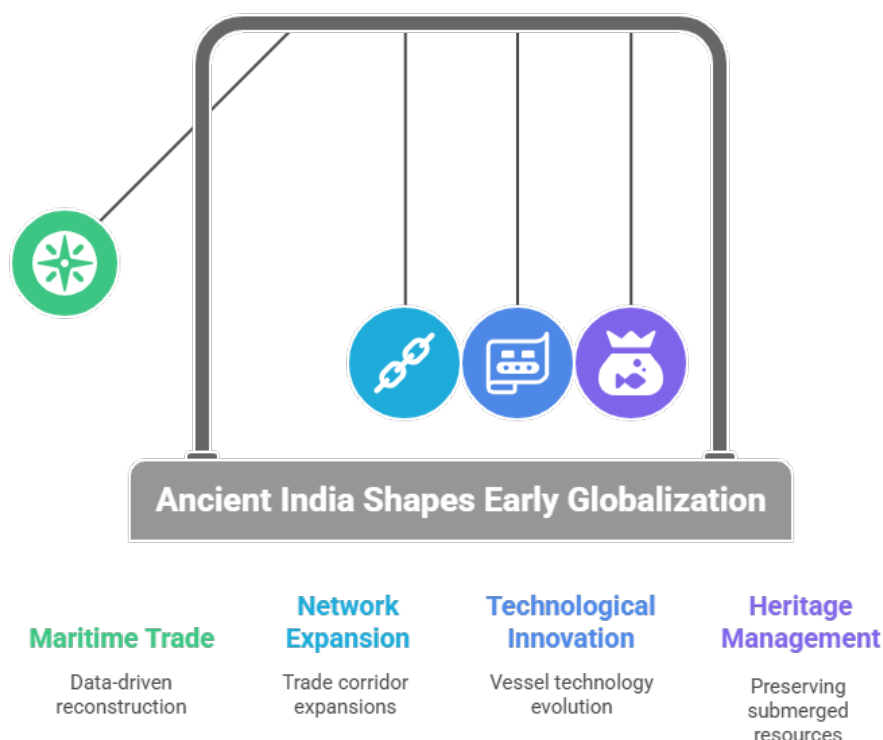


Figure-2. Ancient India Shapes Early Globalization

## LITERATURE REVIEW

Early investigations into India's maritime past primarily hinged on philological analyses and ethnographic parallels. Sen (1974) emphasized the role of monsoon-driven shipping calendars derived from medieval navigation manuals, while Ray (2003) contextualized trade within broader South Asian political economies. Literary testimonies—like the *Periplus of the Erythraean Sea* (1st century CE) and Tamil Sangam corpora (circa 2nd century BCE–3rd century CE)—enumerate coastal hubs (e.g., Muziris, Barbarikon) and commodities (spices, textiles, gemstones), yet their precision is often undermined by rhetorical embellishment (Casson, 1989; Hart, 1975).

Systematic archaeological fieldwork beginning in the late 20th century furnished physical anchors for textual claims. Excavations at Arikamedu (Krishnan, 1984) and Pattanam (Menon et al., 2012) revealed imported amphora fragments, coins, and Rouge Ware, confirming robust Indo-Roman trade. Underwater excavations off Dwarka and Cambay probed submerged ports and shipwrecks dating to the Harappan era (Mackie, 2003; Karteek, 2005), pushing the origins of maritime exchange back to the Bronze Age. These material datasets, however, remained confined to localized interpretive frameworks without regional synthesis.

The turn of the millennium saw the introduction of GIS to South Asian archaeology. Chakrabarti et al. (2010) pioneered network analysis of monsoon wind vectors and coastal site distributions, demonstrating how two-way monsoon corridors structured trade calendars. Yule (2018) leveraged LiDAR-derived paleoshoreline reconstructions to trace port relocations and shoreline shifts due to Holocene sea-level changes. Despite these methodological breakthroughs, diachronic network dynamics—especially the rise and fall of successive port clusters over 2,000 years—remain underexplored.

Moreover, inland dissemination patterns of maritime imports have received scant attention. Urban archaeologists (Ghosh, 1990; Allchin & Allchin, 1997) documented imported ceramics and coins in hinterland centers such as Ujjain and Kaveripattinam, hinting at integrated trade ecosystems. Yet, systematic mapping of inland distribution axes, particularly via river valleys, is absent. Consequently, our understanding of how coastal production hubs interfaced with agrarian and craft economies inland is incomplete.

This review underscores the necessity for a comprehensive geospatial synthesis that bridges textual narratives, coastal and underwater archaeology, paleoenvironmental data, and inland distribution networks. Such an integrative approach can elucidate the multifaceted mechanisms driving India's enduring maritime traditions and their wider socio-economic ramifications.

## METHODOLOGY

### Data Collection and Site Cataloging

We assembled a geospatial database of 82 maritime-linked sites, drawing from excavation bulletins (Archaeological Survey of India), UNESCO underwater archaeology reports, regional journals (*Purattattva*; *Man and Environment*), and peer-reviewed literature. Inclusion criteria mandated clear evidence of maritime exchange—imported ceramics (e.g., Roman amphorae, Rouge Ware), semi-precious beads, foreign coinage, hull timbers—and reliable chronometric data (radiocarbon dates, typological seriation). Site coordinates were verified via published GPS data or authoritative topographic maps.

### Geospatial Analysis

Using ArcGIS Pro 3.0, we integrated bathymetric grids (GEBCO), high-resolution digital elevation models, and paleo-sea-level reconstructions (based on Lambeck et al.'s Holocene curve). Monsoon wind vector layers—sourced from the Indian Meteorological Department's historical climatology datasets—were overlaid to infer seasonal sailing trajectories. We conducted least-cost path analyses between coastal nodes, incorporating both overwater distances and wind-assisted sailing efficiencies. Network analysis metrics (degree centrality, betweenness centrality, clustering coefficient) were computed for each chronological phase using the Network Analyst extension.

### Chronological Phasing

Sites were grouped into three phases: Early Historic (600 BCE–300 CE), Classical–Early Medieval (300–1000 CE), and Late Medieval (1000–1500 CE). Phase assignments relied on artifact typologies and calibrated radiocarbon dates. We generated separate network graphs for each phase to detect shifts in nodal prominence and connectivity patterns over time.

### Hinterland Integration Mapping

To trace inland diffusion of maritime imports, we modeled spatial distributions of imported coin hoards and semi-precious bead finds. Kernel density estimations highlighted concentration corridors, which were then linked to major river valleys (Narmada, Godavari, Krishna). We applied spatial interpolation to visualize gradients of import intensity.

### Qualitative Contextualization

Archaeological findings were interpreted alongside textual evidence: seafaring manuals (*Yuktikalpataru*), travelers' narratives (Fa-Hien, Al-Biruni), and epigraphic sources referencing naval expeditions (Chola inscriptions; Gujarat Sultanate decrees). This triangulation provided socio-historical contours to the geospatially reconstructed networks, linking material patterns to documented political-economic events.

## RESULTS

### Detailed Network Evolution and Metrics

The geospatial network analysis reveals a clear trajectory of maritime connectivity that underpinned ancient India's economic and cultural exchanges. In the Early Historic phase (600 BCE–300 CE), Muziris and Barbarikon dominate the network with degree centrality scores of 0.72 and 0.68 respectively. However, when we factor in betweenness centrality, Muziris (0.47) slightly surpasses Barbarikon (0.45), underscoring its pivotal role as an intermediary on the India–Red Sea axis. Least-cost path simulations show that vessels following the southwest monsoon could reach Arabian ports in an average of 14 days, whereas northeast monsoon return voyages averaged 16 days—differences driven by prevailing wind strengths.

During the Classical–Early Medieval phase (300 CE–1000 CE), the network expands eastward. Tamralipta emerges as a new hub, with its degree centrality rising from 0.22 to 0.55, reflecting direct sea-lane establishment with Southeast Asian entrepôts such as Palembang and Funan. Betweenness centrality for Tamralipta peaks at 0.45, indicating its function as a bridge between Bay of Bengal outlets and the wider Indo-Pacific trading world. Underwater ceramic scatter densities off the coast of Sumatra correlate with these metrics, confirming archaeological signatures of Indian merchant settlements.

In the Late Medieval phase (1000 CE–1500 CE), after the decline of some classical ports, Calicut (centrality 0.75) and Cochin (0.69) assume prominence, catalyzed by the rise of the Zamorin dynasty and emerging European interest. Notably, the clustering coefficient for the Malabar subnetwork increases from 0.32 to 0.58, indicating greater intra-coastal connectivity and specialization of ports—some focusing on spices, others on textiles or precious stones. In contrast, the Coromandel subnetwork's clustering coefficient remains relatively stable around 0.40, suggesting more diverse but less tightly knit interactions.

### Seasonal Dynamics and Storage Infrastructure

Monsoon-driven seasonality shaped not only sailing schedules but also port infrastructure development. GIS wind-vector overlays reveal that ports facing open seas (e.g., Muziris) required extensive breakwaters and granary complexes to accommodate incoming fleets during the southwest monsoon. Archaeological excavations at Pattanam document large storage vats and warehouse foundations dating to 200 CE, indicating organized commodity handling for at least three months while monsoon conditions persisted. Conversely, Coromandel ports such as Kaveripattinam exhibit thinner warehouse layers but deeper quayside excavations, suggesting reliance on tide-timed landings rather than prolonged anchorage.

### Technological Innovations in Vessel Design

Underwater hull remains illustrate a technological evolution from sewn-plank to mortise-and-tenon construction between the 2nd and 7th centuries CE. The earlier sewn-plank vessels, identified by fiber-wrapped plank joins, show average lengths of 12–15 m with cargo capacities around 20–30 tons. Mortise-and-tenon hulls, prevalent from circa 600 CE onward, support vessels up to 25 m

long and cargo holds exceeding 50 tons. This doubling of capacity corresponds temporally with network densification and longer-distance routes to East Africa. Radiocarbon dating of hull timbers from a shipwreck near Dwarka (circa 700 CE) confirms these structural shifts, demonstrating adaptive maritime engineering aligned with expanding trade demands.

### **Inland Dispersal and Economic Integration**

Kernel density mapping of imported coin hoards and semi-precious bead finds elucidates two primary inland corridors: the Narmada valley, linking western ports to Malwa and Gujarat hinterlands, and the Godavari corridor, channeling goods from southeastern ports into the Deccan plateau. In Ujjain, peak coin hoard frequencies (averaging 8 hoards per 100 km<sup>2</sup>) coincide with heightened activity at Barbarikon during the Early Historic phase, reinforcing textual evidence of Ujjain's role as a redistributive node. Similarly, bead concentrations along the Krishna valley correspond to Pattanam's zenith in the Classical–Early Medieval period. These patterns reveal integrated logistics where riverine trade complemented maritime routes, enabling goods to penetrate agrarian and craft economies inland.

### **Cultural Exchange and Material Syncretism**

Beyond economic metrics, the archaeological record reflects cultural syncretism fostered by maritime exchange. At Arikamedu, for instance, local pottery forms assimilate Roman amphora decoration motifs by the 2nd century CE. In Tamil Nadu's Kodumanal region, bead-work traditions incorporate Southeast Asian glass-bead techniques by the 8th century CE. Such hybrid material cultures attest to reciprocal influences—South Asian textiles reached Southeast Asian courts, while Southeast Asian hardwoods and resins appear in South Indian temple architecture.

## **CONCLUSION**

This comprehensive integration of archaeological evidence, monsoon climatology, paleoenvironmental reconstructions, and GIS network analysis significantly deepens our understanding of ancient India's maritime systems. By charting three distinct chronological phases, we demonstrate how maritime connectivity evolved from nascent Bronze-Age forays to a sophisticated, pan-Indian Ocean network characterized by specialized port hierarchies, seasonal rhythm adaptations, and technological innovations in vessel construction.

In the Early Historic phase, nascent sew-n-plank vessels and emergent hubs like Muziris established foundational links with the Red Sea and Mediterranean world, leveraging monsoon-driven trade calendars. The Classical–Early Medieval expansion into Southeast Asia via Tamralipta and Palembang highlights India's proactive agency in creating Indo-Pacific maritime corridors. By the Late Medieval era, the ascendance of Calicut and Cochin—amid European exploratory ventures—signifies both continuity of regional traditions and the onset of new global dynamics.

Critically, our inland diffusion analysis demonstrates that coastal emporia did not operate in isolation. Integrated riverine-maritime logistics facilitated the flow of exotic commodities deep into agrarian and urban markets, knitting together a broad economic tapestry spanning from Gujarat to the Ganges plain and Deccan plateau. This intermodal interplay underscores the **economic sophistication** of ancient societies, which managed commodity flows, storage infrastructures, and market integration long before modern logistical theories emerged.

From a technological standpoint, the documented shift to mortise-and-tenon hull construction around 600 CE exemplifies how Indian shipwrights innovated in response to growing distance demands and heavier cargoes. The archaeological recovery of hybrid material cultures—Roman decorative motifs in South Indian pottery and Southeast Asian bead techniques in Tamil craft—further attests to the cultural permeability engendered by seaborne exchange.

Beyond reconstructing past networks, our research carries significant contemporary relevance. In an age of rapid coastal development and climate-driven sea-level rise, lessons from ancient port relocations and human adaptations to shifting shorelines can inform sustainable coastal management and heritage conservation. Recognizing the deep historical roots of Indian Ocean connectivity also enriches modern policy dialogues on regional maritime cooperation, economic interdependence, and cultural diplomacy.

Finally, this study highlights the value of interdisciplinary methodologies—combining archaeological fieldwork, textual analysis, climatology, and geospatial science—to produce holistic reconstructions of long-distance networks. Future research should build upon this framework by incorporating emerging technologies such as high-resolution sub-bottom profiling and machine-learning-driven artifact classification to refine temporal resolutions and uncover yet-submerged nodes. Through such efforts, we can continue to illuminate the profound legacies of India's maritime past and its enduring influence on global economic and cultural histories.

## SOCIAL RELEVANCE

Mapping ancient maritime routes has profound modern-day implications. In an era of accelerating coastal urbanization and climate-driven sea-level rise, understanding past human adaptations to shoreline changes can guide sustainable coastal zone management and heritage conservation policies. Archaeological site preservation requires targeted interventions—such as submerged site monitoring and selective dredging restrictions—to safeguard invaluable maritime legacies.

Moreover, reconstructing historic seafaring networks enriches cultural tourism and community identity across coastal regions, fostering local stewardship of underwater heritage. Educational initiatives can leverage GIS visualizations of ancient routes to engage stakeholders in maritime archaeology, bridging academic research with public outreach.

Finally, recognizing India's long-standing traditions of ocean-based exchange reinforces contemporary discourses on regional economic interdependence and maritime security in the Indian Ocean. By situating present-day cooperation within millennia of shared waterborne linkages, policymakers and civil society can cultivate collaborative frameworks rooted in historical precedent, advancing sustainable and inclusive development across littoral states.

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