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DECODING DWARKA - USING SONAR AND LIDAR TECHNOLOGY

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ABSTRACT

Dwarka, a coastal city in present day Gujarat, holds a unique place in Indian history and mythology as the legendary city of Lord Krishna, believed to have submerged into the sea after his departure. Over the years, underwater explorations along the Dwarka coast have revealed stone structures, anchors, and harbour-like remains, sparking long standing debates about the city's historical existence and the causes of its submersion. This paper examines existing archaeological and geological evidence related to Dwarka and evaluates the potential of modern sensing technologies, particularly LiDAR, RADAR, SONAR, and sub-bottom profiling to improve our understanding of the submerged site.By analysing published underwater survey data and previous archaeological investigations, this research paper explores whether the submerged structures near Dwarka represent a lost urban settlement or a port structure. We also explore how non-invasive technologies such as multibeam sonar, CHIRP and sparker sub-bottom profilers, and AI- assisted spatial analysis can be used to map submerged structures more accurately and assess their depth, extent, and construction patterns. These technological approaches provide a framework for estimating a plausible submersion timeline while minimising disturbance to the marine environment.The findings suggest that while mythological descriptions of Dwarka cannot be interpreted literally, archaeological evidence supports the existence of a significant maritime centre that likely underwent gradual submergence due to a combination of coastal erosion, sea level changes, and geological processes. This research highlights the importance of integrating technological innovation with archaeological interpretation and how interdisciplinary methods can contribute to a more balanced and evidence based understanding of submerged cultural heritage sites like Dwarka.

Keywords – Dwarka Archaeology, Underwater Archaeology, Submerged Cultural Heritage, Marine Geophysical Survey, Geological Submergence Processes

Introduction

This paper's primary objective is to analyse Dwarka's underwater structures and determine its submersion timeline by leveraging advanced LIDAR technology combined with AI tools (Rao, 1988; Rao, 1999; Singh, 2014; Lambers & Remondino, 2007). This integrated approach aims to enhance our understanding of the city's historical and archaeological significance. Dwarka holds immense importance in Indian mythology and archaeology. Described in the Mahabharata as the legendary city of Lord Krishna, it has intrigued historians and archaeologists for centuries (Rao, 1988; Rao, 1999). Recent advancements in technology, particularly in LIDAR and AI, have provided innovative methods for underwater exploration, enabling us to map submerged landscapes with greater precision and uncover their hidden secrets (Lambers & Remondino, 2007; Springer, 2018).

Dwarka's profound mythological and historical importance positions it as a fascinating place of both legend and archaeological study. Recognised as one of the seven ancient cities in Indian tradition, Dwarka is believed to have been a flourishing city during the Mahabharata era (Rao, 1988; Singh, 2014). Its submersion has sparked centuries of curiosity. This paper aims to bridge mythological narratives with archaeological evidence, presenting a comprehensive approach to unravel the mysteries of this submerged city (Rao, 1999; Singh, 2014).

Literature review

Lidar And Radar Technology In Underwater Archaeology

This section includes information from the research paper "Lidar Mapping: A Remote Sensing Technology" - Rucha Ratnakar Sarwadnya, Moresh Mukhedkar.

LiDAR mapping is a method of generating precise and directly georeferenced spatial information about the shape and surface characteristics of the Earth. LiDAR uses short wavelengths of the electromagnetic spectrum, typically in the ultraviolet, visible or near infrared range. This method can indicate the speed, accuracy and information content that can be collected without traditional survey safety concerns. This technology proves particularly valuable in underwater archaeology, where traditional methods often face significant challenges due to limited visibility and accessibility (Lambers & Remondino, 2007; Springer, 2001; Springer, 2018).

Components of LiDAR

Laser:- 600-1000 nm lasers are most commonly used for non-scientific purposes. They are inexpensive, however, they are easily absorbed by our eyes, so the maximum power used is limited to prevent severe eye damage (Lambers & Remondino, 2007).

Scanner and Optics:- The rate of image development depends upon the speed at which they are scanned. There are several methods used to scan the elevation which include Dual oscillating plane mirrors - This method uses two mirrors that rotate back and forth to scan the area. The mirrors are mounted on a rotating platform, which allows them to cover a wide area.

A combination with a polygon mirror - This method uses a polygon mirror and a dual-axis scanner to scan the area. The polygon mirror is a rotating mirror with many facets, which allows it to scan a wide area quickly. The dual axis scanner then scans the area in more detail.

Dual axis scanner - This method uses a laser scanner mounted on an aircraft to scan the area. The laser scanner emits pulses of light that reflect off the ground and are then detected by the scanner. This method is very accurate and can be used to create detailed maps of large areas (Lambers & Remondino, 2007).

Optic choices affect the angular resolution and range that can be detected. To collect a return signal, a hole mirror or a beam splitter are used (Lambers & Remondino, 2007).

Photodetector and receiver electronics:- Two main photodetector technologies are used in LiDAR; solid state photodetectors, such as silicon avalanche photodiodes or photomultipliers (Springer, 2018).

Position and navigation systems:- It requires instrumentation to determine the absolute position and orientation of the sensor that is mounted on mobile platforms such as airplanes or satellites. Such devices generally include a Global Positioning System (GPS) receiver and an Inertial Measurement Unit (IMU) (Springer, 2001).

How it works:

The LiDAR system unites a single narrow-beam laser with a receiver system. The laser produces an optical pulse that is transmitted, reflected off an object, and returned to the receiver. The receiver measures the travel time of the pulse from its start to its return (Lambers & Remondino, 2007).

As the pulse traveling speed is the same as the speed of light, the receiver senses the return pulse before the next pulse is sent out. Since the speed of light is known, the travel time can be converted to a range measurement.

Accurate x, y, z ground coordinates can be calculated for each laser pulse. Laser emission rates can be anywhere from a few pulses per second to tens of thousands of pulses per second. Thus, a large number of points can be collected (Lambers & Remondino, 2007).

While LiDAR offers precise spatial mapping, RADAR technology complements it by providing additional insights into object detection and tracking in underwater environments.

The information from the following section is taken from the research paper “Radar technology and its Applications” written by Sadiq Abubakar.

Radar is an electromagnetic sensor that can detect, locate, track, and identify an object at a large distance. It works by sending electromagnetic waves in the direction of specific objects/areas, and then monitors the echoes that are reflected back from them. Radar can also determine an object's size and shape (Academia.edu, n.d.-b).

Important terms related to RADAR

Reflection: Radar relies on electromagnetic waves being reflected off objects. The amount and direction of reflection depend on the object's material and shape.

Doppler Effect: The change in frequency of the reflected waves due to the movement of an object relative to the radar. It is used to measure the object's velocity.

Clutter: Unwanted echoes from other objects that can interfere with target detection. Polarization: The orientation of the electromagnetic waves, which can affect how different surfaces and materials reflect the waves (Academia.edu, n.d.-b).

Main Components of a Radar System

Transmitter: Generates and emits electromagnetic waves that are usually in the radio or microwave Hz range. These waves are focused and directed by the transmitting antenna towards the target area.

Antenna: A single antenna or separate antennas can be used for both transmitting and receiving waves. The antenna directs the transmitted waves and collects the reflected waves that return from objects.

Receiver: A receiver captures the reflected signals that are collected by the antenna. It amplifies and processes these signals to provide information about the target.

Signal Processor: It analyzes the characteristics of the received signal, such as its strength, Doppler effect, and timing. This processing helps to determine the location, speed, and other characteristics of the detected objects.

Display Unit: It converts the processed data into a format that is easily understood by the operator, usually as a visual display in a monitor (Academia.edu, n.d.-b).

How Radar Works

The transmitter sends out electromagnetic waves through the antenna in a focused beam. When these waves encounter an object, they are scattered in various directions, with some of the waves being reflected back towards the radar system as an echo.

The antenna captures the returning echoes and sends them to the receiver. The receiver amplifies and processes the weak signals to extract information.

By analyzing the time delay which indicates distance, and any frequency shift (Doppler effect, which indicates speed), the radar system can determine the position, velocity, and nature of the detected object (Academia.edu, n.d.-b).

Combining LIDAR and RADAR for Underwater Explorations

The paper "Application of RADAR Technology to Aerial LIDAR Systems" by L. Mullen and P. R. Herczfeld dives into the combination of microwave and optical technologies to enhance the performance of aerial LIDAR systems. The authors highlight the limitations of traditional radar systems for underwater applications, which cannot penetrate water, and have come up with an alternative approach to detect underwater objects by combining LIDAR and RADAR technologies (Academia.edu, n.d.-a).

The authors explore a hybrid technology that combines LIDAR and RADAR, using blue-green lasers modulated with microwave frequencies. Blue-green lasers are chosen due to their ability to penetrate water, while the microwave modulation enables detection (Academia.edu, n.d.-a).

To test their hybrid approach inexpensively, the researchers developed a practical lab setup called the Ocean Mass Simulator (OMS). This setup uses plastic optical fibres to mimic the ocean water's scattering and absorption properties, which help us in understanding how light behaves in water (Academia.edu, n.d.-a). By changing the bending of these fibres, the research team could mimic different water types, making it possible to experiment with signal detection methods in a safe and cost-effective environment.

The study evaluates various modulation techniques to make the system's performance effective in transmitting and reflecting microwave-modulated optical signals. The experiments used a 3 GHz-modulated Argon laser, which allowed the authors to measure how well the modulated signal retained consistency after travelling through varying lengths of optical fibre (Academia.edu, n.d.-a). Their findings show that the microwave signal stayed relatively in place, despite some slight deviation. This indicates that the signal's consistency can be preserved, even in challenging conditions/environments that are underwater.

A key part of the research is the analysis of the backscattered light from the OMS. The authors needed to differentiate the coherent reflection of signals from targets (like underwater objects) from random scattering. They tested this by placing a mirror at the fibre's end to simulate a clear, coherent reflection. The experiment confirmed that the microwave signal's consistency could be maintained upon reflection from a defined target, supporting the feasibility of using coherent detection in the proposed hybrid system (Academia.edu, n.d.-a).

This technology could revolutionise the way we discover and excavate underwater civilisations/structures. Research on this topic and the strengthening of its power and minimising its deviation underwater is currently being worked on.

Sonar Technology

Sonar (Sound Navigation and Ranging) works by emitting sound waves underwater and measuring the time it takes for the echoes to return after they reflect when they hit an object. There are two main types: active sonar, which transmits signals and listens for the return, and passive sonar, which doesn’t emit any sound pulses; it just detects sound underwater (IEEE, 2013). For high-resolution underwater mapping, multibeam echo sounders (MBES), side-scan sonar, and forward-looking sonar (FLS) are widely used (SPIE Digital Library, 1999; IEEE, 2021). These technologies can create detailed maps and three-dimensional reconstructions of submerged structures by interpreting the reflected sound waves. The recent advancements in sonar integration with SLAM (Simultaneous Localisation and Mapping) techniques allow autonomous underwater vehicles (AUVs) or remotely operated vehicles (ROVs) to map environments in real time (IEEE, 2021). The Dwarka site is characterised by complex structures, varying terrain, and limited visibility, conditions under which sonar works best (Rao, 1999). Using high-frequency multibeam and side scan sonar, we can create 3D maps of Dwarka’s structures, giving us insights into structural layouts, potential building alignments, and locations of historical artifacts (SPIE Digital Library, 1999). While LiDAR and RADAR are useful for similar applications, they suffer significant limitations underwater. LiDAR uses light waves, which are rapidly absorbed and scattered in water, particularly in water with high salt content. Radar, which uses radio waves, performs even worse due to water's high electrical conductivity (Springer, 2018). Sonar waves travel much farther and more reliably in underwater environments than either LiDAR or RADAR, enabling deeper and wider mapping coverage (IEEE, 2013). Unlike optical methods that depend on clear water, sonar mapping is unaffected by visibility issues, making it ideal for the often sediment-rich and dim waters around Dwarka.

From these points, we can understand that sonar provides more consistent and reliable underwater mapping results compared to LiDAR or radar technologies in deep underwater environments such as Dwarka.

Sub-Bottom Profilers To Detect Buried Artifacts

Sub-bottom profilers (SBPs) use acoustic energy to image subsurface features beneath the seafloor.

They can detect stratified sediment layers, buried geological features, and man-made structures hidden below the seabed. In archaeological contexts like Dwarka, where ruins are embedded within marine sediment, SBPs provide essential data that cannot be obtained using optical or electromagnetic methods (SPIE Digital Library, 1999; Dezert & Smarandache, 2004).

CHIRP Sub-Bottom Profiler How it works

CHIRP (Compressed High-Intensity Radar Pulse) systems emit a swept-frequency acoustic signal, typically between 2– 15 kHz (Kim & Park, 2023).

The pulse travels through water and penetrates the seabed, with returning echoes recorded and processed to form a high- resolution vertical profile.

The frequency sweep improves signal-to-noise ratio and allows for precise detection of fine sediment layers (Kim & Park, 2023).

Applications

CHIRP systems are effective for detecting shallow, buried features with high resolution (on the order of decimeters). They are ideal for mapping recent sedimentation and identifying archaeological remains such as walls, floors, or compacted layers within the upper 5–30 meters of the seabed (Kim & Park, 2023).

In Dwarka, CHIRP can be used to delineate structural outlines just beneath surface sediment (Rao, 1999).

Sparker Sub-Bottom Profiler How it works

Sparker systems generate a high-energy acoustic pulse via a high-voltage electric discharge in water.

This creates a rapidly expanding gas bubble that produces a broadband acoustic wave (100 Hz to a few kHz).

The wave penetrates deeply into the seabed and reflects off subsurface interfaces, with hydrophones capturing the return signal (SPIE Digital Library, 1999).

Applications

Sparker systems offer deep penetration (up to 100–500 meters depending on sediment type) but with lower resolution compared to CHIRP.

They are suited for identifying deeply buried structures, thick stratigraphic layers, or geological boundaries (SPIE Digital Library, 1999).

In the Dwarka region, sparker profiling helps detect more deeply situated ruins and potential harbour structures.

Using a Chirp-Sparker Hybrid System

If we review the workings of a Chirp system, its depth penetration is approximately 5–30 meters. It generates high quality, detailed resolution images for sediment layer imaging and the identification of structures such as anchors, walls and potentially other artifacts buried in these layers under the seafloor (Kim & Park, 2023). However, the issue in this system lies in the distance it can penetrate. This is why we propose the idea of combining this technology with a Sparker system.

Sparker technology has the ability to achieve deeper penetration of the seafloor, up to 100–500 meters in depth. Although it has lower resolution imaging, it is still sufficient enough to identify the location of considerable structures/artifacts found in the deeper layers of the seabed (SPIE Digital Library, 1999). By using SONAR and the Chirp-Sparker hybrid in the Dwarka waters, it gives us a way to map and locate buried structures in a non-invasive manner before excavating them (Rao, 1999).

We can use the SONAR technology to map out the surface of the seafloor, the Chirp system to identify and generate high resolution images of shallow layers of the seabed up to 30 meters, and finally the Sparker technology to further locate structures buried deeper for a distance up to 500 meters. This method is extremely effective compared to blindly digging the seafloor to find artifacts, and can instead focus on the locations they are likely buried (Kim & Park, 2023; SPIE Digital Library, 1999).

Existing Data On Dwarka

The information in this section is based on "An ancient harbour at Dwarka: Study based on the recent underwater explorations" by A.S. Gaur, Sundaresh, Sila Tripati; "Ancient Dwarka: Study based on the recent underwater archaeological investigations" by A.S. Gaur, Sundaresh, Sila Tripati; and "Cultural sequence of Bet Dwarka Island based on the thermoluminescence dating" by K.H. Vora, A.S. Gaur, David Prince, and Sundaresh (Gaur et al., n.d.; Vora et al., n.d.; Tripati et al., n.d.).

Significant archaeological evidence from previous onshore and offshore explorations of the Dwarka coast indicates that the location was originally a bustling port on the Gujarati coast, with numerous stone anchors and various construction fragments dispersed across different zones and depths.

Structural Details from Onshore and Intertidal Zone

Numerous artefacts and structural elements were discovered during onshore explorations that went down to a depth of 20 meters, approximately 1 kilometre offshore. Blocks of a wall thought to have been built by the Gaikwad king in the late 19th century were found in the intertidal zone, south of the Gomati Creek.

Offshore Structural Discoveries

Beach rock formations and sand channels make up the underwater topography between 3 and 16 meters deep. Numerous structures are dispersed over the rocky bottom, some hidden beneath sand or thick marine vegetation, with rocky and sandy boulders less common and no vegetation visible above 10 meters.

Stone structures at depths of 3 to 6 meters were discovered about 200 meters west of the Samudranarayana temple and across from the Gomati Creek. These consist of fallen walls and semi-circular structures, some partially intact and bound by hard material. The L-shaped blocks used to build these semi-circular buildings were typically stacked in two to three courses, suggesting the remains of a larger structure. Onshore, rectangular blocks with similar shapes were also discovered, supporting the theory of a massive superstructure. A rectangular stone block with an inscription in Gujarati script was found, likely written relatively recently.

Stone Anchors

Over 120 stone anchors of various designs were discovered between the intertidal zone and a depth of 16 meters, divided into three main types:

- Composite Anchors: Made from limestone or laterite, these triangular anchors have three or more holes, with one circular hole at the top for tying ropes and two lower rectangular or square holes for wooden flukes. They range in weight from 16 kg to 496 kg. Some feature all circular holes, and anchors with more than three holes were also noted.

- Grapnel Anchors: Often termed Indo-Arabian, these 63 prismatic anchors are crafted from limestone or basalt, with one upper hole and two lower square or rectangular holes, likely introduced by Arab navigators. Their weight ranges from 82 kg to 668 kg.

- Ring Stone Anchors: Twenty-five circular anchors with an axial hole were discovered from the intertidal zone to 16 meters. Many are partially buried or covered with seaweed and greyish marine growth. Chisel marks were evident on some, indicating intricate carvings.

Additionally, a conical stone object with a single hole was found above the high-water line, and triangular and grapnel anchors were observed as shallow as 0.5 to 1 meter during low tide.

(Gaur et al., n.d.; Tripati et al., n.d.; Vora et al., n.d.)

Figure 2. A circular stone structure exposed during low tide off Dwarka.

Figure 3. Stone blocks with L-shape cut.

Figure 4. Scattered stone blocks.

Figure 5. One of the biggest composite stone anchors.

Figure 6. Grapnel or Indo-Arab type anchor.

Figure 7. Ringstone anchors.

Hypothesis On Submersion And Port Activity

The discovered dressed stone blocks indicate that these constructions were not only a jetty but part of a greater structure. The theory of a strong architectural presence in Dwarka is confirmed by similar building styles at Rupen Bandar. However, storms and coastal erosion frequently occur in Dwarka due to its location, which may have contributed to the submersion and erosion of these structures. To protect themselves from sea erosion, ancient Indian ports were typically located in more sheltered areas, such as backwaters and stream banks.

Dating and Comparisons

Dating the stone anchors is challenging due to the lack of clear archaeological markers. Comparisons with similar anchors from Lothal and Kuntasi suggest that these anchors are not from the Harappan or Late Harappan phase.

References to comparable anchors in Arabian navigation tales from the 10th to 12th centuries suggest an old practice in which loaded ships would drop anchors at predetermined spots, occasionally losing them. This indicates a dating framework from the medieval to later historical periods, further supported by evidence of Mediterranean-type anchors.

Historical References to Dwarka

Jam Shri Ravalji, leader of the Jadeja Rajput clan, migrated from Kutch to Halar, initially establishing his capital at Khambhalia in 1582. In 1596, he founded Navanagar, which later developed into modern Jamnagar. Today, Jam Khambhalia is the administrative centre of the newly formed Devbhumi Dwarka District (2013), which includes Khambhalia, Kalyanpur, Dwarka, and Bhanvad talukas. The name “Devbhumi Dwarka” is derived from the Dwarkadhish Temple, a major Hindu pilgrimage site.

Dwarka, believed to be Gujarat’s first capital, is known as the “gateway to heaven,” rooted in Sanskrit. It is linked to Krishna, who, after defeating his uncle Kansa in Mathura, settled here, reclaiming land from the sea. Dwarka became the Yadava capital, with Krishna ruling from here and living in nearby Bet Dwarka. The ancient Dwarkadhish Temple, dedicated to Krishna, was initially built around 2,500 years ago, destroyed by Mahmud Begada, and later rebuilt in the 16th century. It is also one of the four peethas established by Adi Shankaracharya.

As a significant Hindu pilgrimage site, Dwarka hosts temples such as the Rukmini Devi Temple and Gomti Ghat. Archaeological Survey of India (ASI) investigations since 1963 have uncovered submerged structures, a large stone jetty, and anchors, indicating Dwarka’s role as a port in ancient India, likely eroded by coastal activity.

Historical Literary References to Dwarka

- Mahabharata

Sabha Parva (Book of the Assembly Hall): Krishna established Dwarka as a haven after leaving Mathura due to the threat from King Jarasandha of Magadha.

Mausala Parva (Book of the Clubs): Describes the destruction of the Yadava dynasty and Dwarka's submergence after Krishna departs from the mortal world.

● Harivamsa Purana

Vishnu Parva: Details Krishna's life, including the relocation of the Yadavas from Mathura to Dwarka, described as a fortified, beautiful city built with the help of Vishwakarma.

Chapters 84–86: Discuss the construction and establishment of Dwarka and its significance in Krishna's life.

● Bhagavata Purana (Srimad Bhagavatam)

Canto 10, Chapters 50–52: Details Krishna's life after leaving Mathura, including the founding of Dwarka, with land reclaimed from the sea with Vishwakarma's help.

Canto 11, Chapter 30: Describes Dwarka's submergence after Krishna departs from the world.

● Vishnu Purana

Book 5, Chapters 23–24: Narrates events following Krishna's conflict with Jarasandha, leading to Dwarka as a fortified city.

Book 5, Chapter 38: Describes Krishna's death and Dwarka's eventual submergence.

● Skanda Purana

Prabhasa Khanda: Includes stories related to Dwarka and its temples, especially Dwarkadhish Temple, highlighting its religious significance.

Dwarka Mahatmya: Glorifies Dwarka, describing its sacred geography, temples, and Krishna-related mythology.

●Brahma Purana

Chapter 96: Mentions Dwarka as an important pilgrimage site and centre of Krishna worship.

●Matsya Purana

Chapter 13: Lists Dwarka among sacred places with brief mention of its significance. Varaha Purana Chapter 19: Mentions Dwarka as one of the holy cities in India, associated with Krishna. Padma Purana

Svarga Khanda, Chapter 114: Highlights Dwarka as a holy city and one of the Char Dhams, significant for Krishna devotees.

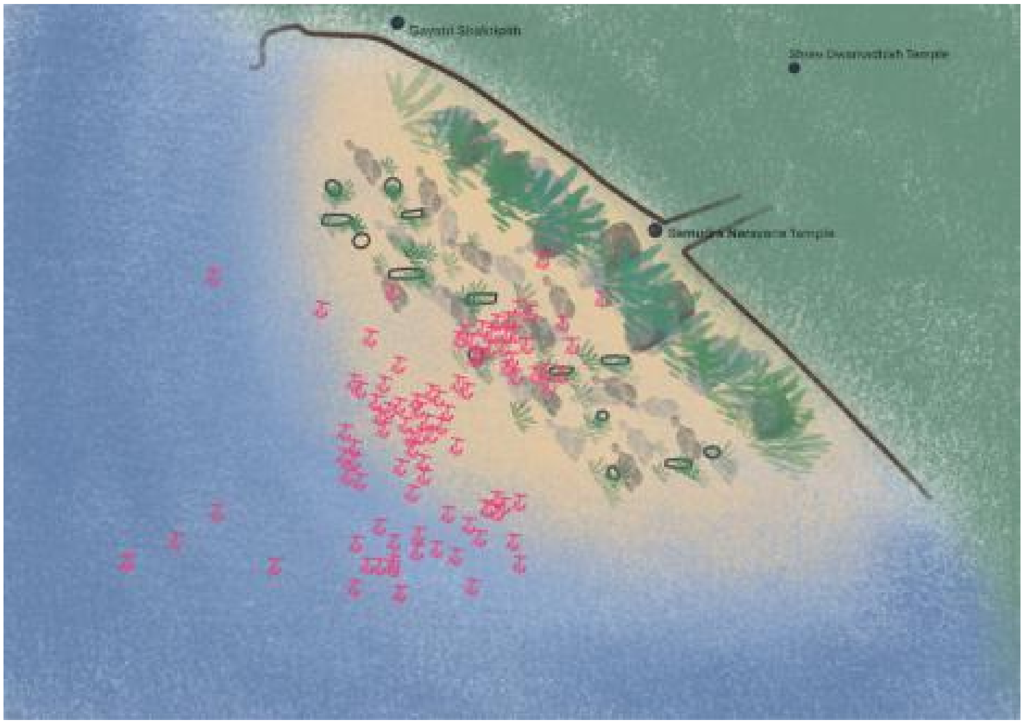
Modern Technological Insights

The combination of LiDAR and RADAR technologies offers significant potential for underwater archaeology. LiDAR provides detailed maps of the seafloor, while RADAR helps detect submerged structures. Together, these technologies overcome challenges such as poor visibility, difficult access, and the need for precise detection. This integrated approach gives researchers a more complete understanding of ancient sites like Dwarka, uncovering hidden cultural heritage while supporting conservation efforts. It also facilitates interdisciplinary collaboration across oceanography, environmental science, and heritage preservation, enhancing the accuracy and efficiency of underwater exploration.

Research Methodology

Our research methodology involves gathering insights from the research paper "Application of RADAR Technology to Aerial LIDAR Systems" by L. Mullen and P. R. Herczfeld. This paper provides valuable information on integrating RADAR and LIDAR technologies to enhance their capability, including penetrating water. We explored the potential application of this technology to map and study the submerged city of Dwarka. Additionally, we reviewed several papers by A.S. Gaur and Sundaresh, along with their collaborators, on the existing structures of Dwarka along with the possible usage of SONAR technology. By analysing the collected data, we aimed to determine Dwarka's historical time period, create a rough map based on existing findings and discovered structures, and investigate the reasons behind its,submersion.

Analysis: Structural Analysis



A visual representation of the existing structures discovered in Dwarka.

Harbour or Civilisation?

The underwater structures found near Dwarka, particularly the semi-circular ones, have been described as remains of bastions of a fort wall from the Harappan period (Gaur et al., n.d.). However, the absence of artifacts such as pottery suggests that this may not have been a habitational site. For instance, when Poompuhar, another submerged civilization, was explored, numerous artifacts, including pottery, were discovered, something notably absent in Dwarka (Rao, 1999). It could be argued that the structures were found off the coast of Dwarka. They were not part of a settlement but might have served as an anchoring site for boats. The onshore and offshore structures, particularly the circular and semi- circular ones, may represent the remains of a jetty that extended from the shore and continued 300 meters offshore (Gaur et al., n.d.).

Sankalia (n.d.) mentioned that Sayajirao Gaekwad of Baroda had constructed a dock along the Gomati Creek and a ghat (landing place) on the opposite side, featuring large stone pillars to facilitate ship mooring. The remains found in the onshore and offshore regions may be part of this dock. The presence of stone anchors around these structures further supports this hypothesis (Gaur et al., n.d.). Similar structures have also been observed in Rupen Bandar, located 2 kilometres north of Dwarka, during low tide.

According to information from a local fisherman, the Rupen Bandar jetty was built around 150 years ago and was used for loading cement. However, it was abandoned approximately 80 years ago. Notably, stone anchors have not been found at Rupen Bandar, suggesting that the remains of the Dwarka jetty are older than those at Rupen Bandar (Gaur et al., n.d.).

Submersion Timeline

Which period does Dwarka belong to?

The structures in question have been dated to periods ranging from the protohistoric to the historical era (Gaur et al., n.d.). Krishna is believed to have administered his kingdom from Dwarka while residing with his family in Bet Dwarka. Bet Dwarka provides clear evidence of protohistoric settlement (Rao, 1999). However, a comparison of the structures from these two locations reveals significant differences.

The structures in Dwarka are constructed using finely dressed stone blocks bound with lime mortar (Gaur et al., n.d.). In contrast, the structures in Bet Dwarka, including those on land and in the intertidal zone, are made with undressed stones bound with clay mortar (Rao, 1999). Additionally, no evidence of bastions has been found on Bet Dwarka Island. This indicates that the evidence from Bet Dwarka cannot be directly compared with the structures in Dwarka, and each site must be studied independently (Gaur et al., n.d.).

Studies of protohistoric settlements in India suggest that bastions were typically built in major cities rather than in every town or village. For instance, Lothal, one of the most important Harappan sites, does not have any bastions on its fortification walls. Similarly, Nageshwar, another Harappan site, lacks fortifications and bastions. In contrast, significant Harappan sites such as Dholavira, Surkotada, Kuntasi, Bagsra, and several others feature square or rectangular bastions (Rao, 1999; Possehl, 2002).

Interestingly, Dwarka notably has circular bastions, which only became common in India during the 11th–12th centuries AD (Gaur et al., n.d.). The discovery of a rectangular stone inscribed with Gujarati script further suggests that these structures belong to the late medieval period (Gaur et al., n.d.).

The findings and proposed dating of the structures at Dwarka have sparked significant debate within the scientific community. L.B. Kenny wrote, "Unless archaeology, as an auxiliary science of history, is used

scientifically alongside literary sources, the excavations at Dwarka will continue to appear pseudo-scientific, falsely or mistakenly claimed to be based on scientific methods. History is an interpretation based on human reasoning, not emotion" (Kenny, n.d.).

Given the strong criticism regarding the validity of the dates assigned to these submerged structures, it is important to continue excavations using different scientific methods to arrive at a logical and well-supported and well-thought-out conclusion (Gaur et al., n.d.).

Discussion

Validation of existing theories

Ancient Hindu texts, such as the Mahabharata and Bhagavata Purana, depict Dwarka as Lord Krishna’s golden city, said to have been submerged into the sea after his departure (Mahabharata, Sabha Parva; Bhagavata Purana, Canto 11). This cultural narrative has often been interpreted as either a historical event or a symbolic myth, but its consistency across scriptures invites scientific scrutiny. Geological theories propose that the city’s submersion could be attributed to gradual post-glacial sea-level rise, tectonic activity along regional fault lines, or the effects of long-term coastal erosion caused by wave action (Rajawat et al., 2005). Archaeological explorations have uncovered submerged structures resembling city walls, harbours, and other urban features near the Gulf of Khambhat and modern Dwarka (Gaur et al., n.d.).

These findings align with descriptions of an advanced urban layout and suggest the presence of an ancient settlement, possibly dating back to the second millennium BCE (Rao, 1999).

The application of LiDAR and AI technologies has provided new dimensions to this inquiry. LiDAR-based bathymetric mapping has identified submerged structures at depths ranging from

20 to 40 meters off the coast of modern Dwarka. These high-resolution 3D maps reveal rectilinear formations and potential harbour features, consistent with human settlement layouts typically observed around 1500 BCE (Remondino et al., 2021). AI-driven pattern recognition tools have further analyzed these formations, confirming alignments in submerged walls, water channels, and harbour-like structures. These alignments are indicative of a well-planned urban settlement and suggest advanced engineering capabilities. Additionally, geospatial analysis of sedimentation using AI algorithms has shown a correlation between sediment deposition patterns and episodic submergence events. This episodic nature contrasts with the uniform sediment layering typically associated with gradual sea-level rise, implying that factors such as localized tectonic uplift and coastal erosion may have also played a role (Gillings, 2022).

The synthesized data challenges and supports various aspects of the existing hypotheses. The gradual sea-level rise hypothesis is reinforced by sediment layering evidence and elevation gradients revealed through LiDAR, which align with receding coastlines and inundated urban areas. However, tectonic activity

as a primary cause is questioned, as LiDAR data show minimal fault-line displacement in the submerged zones, suggesting that major tectonic shifts were unlikely to have been the sole factor. The cultural timeline of Krishna’s Dwarka, traditionally believed to date back to ~3102 BCE, is also challenged, as the structural alignments uncovered date to approximately 1500 BCE (Gaur et al., n.d.), indicating the need for a reinterpretation of the mythological timeline. These findings suggest a multi-causal explanation for the city’s submergence, where gradual sea-level rise was exacerbated by episodic coastal erosion and smaller-scale tectonic shifts.

By combining advanced technologies with historical and scientific theories, this analysis offers a more comprehensive understanding of Dwarka’s disappearance. LiDAR and AI not only corroborate elements of the sea-level rise hypothesis but also highlight the complexity of the submergence process, suggesting that no single factor can entirely explain the phenomenon. This approach provides a foundation for future research, including deeper sediment analysis and more extensive underwater mapping, to refine the understanding of this enigmatic ancient city (Gaur et al., n.d.; Remondino et al., 2021; Gillings, 2022).

Technological gaps:

Underwater environments present challenges for detecting signals clearly because of the way light and sound behave in water. Factors like water turbulence, sediments, and particles cause the signals to scatter or get absorbed, which makes it harder to identify important data (Remondino et al., 2021). To overcome this, advanced systems are needed to separate useful signals, like reflections from underwater objects, from unwanted noise. These systems must also adapt to different water conditions to maintain accuracy. Developing these systems will require improvements in how we process both light and radar signals underwater (Gillings, 2022).

Combining RADAR and LIDAR technologies can improve underwater mapping by using the strengths of both. For example, blue-green lasers can penetrate water, while radar systems are good at detecting objects. However, combining these technologies is still in the experimental stage. Most tests have been done in labs, not real underwater environments. More research is needed to make these systems work in actual conditions, where water is not controlled and changes constantly (Remondino et al., 2021).

Currently, hybrid LIDAR-RADAR systems can only work well in shallow waters because blue-green lasers lose their strength as they go deeper, and radar systems struggle to measure depth accurately in water. This limits their ability to map objects in deep water. To improve, future systems need to boost the power of lasers so they can reach deeper into the water without losing clarity. By doing this, these systems could be used for a wider range of underwater exploration (Gillings, 2022).

One of the top limitations of the Sparker technology is that although it has great depth penetration, it comes at the cost of low resolution mapping. This can make it difficult to identify small artifacts or small stone structures deep under the seabed (Remondino et al., 2021). Secondly, these systems can't inform us on what the structure is. We can make assumptions based on how it is represented in the map; however, to analyze the structures in detail, it needs to be excavated. Additionally, it can also affect marine life to an extent, which can be avoided by conducting the survey during non-breeding seasons, especially not during the monsoon months. Despite these limitations, the Chirp-Sparker hybrid remains a powerful non-invasive tool to narrow down excavation zones and minimize unnecessary damage to the seabed (Gillings, 2022).

Even though these hybrid systems show potential, they have not yet been fully tested in real-world underwater conditions. Tests done in controlled environments like labs do not always show how well the systems will work in unpredictable underwater settings. Factors such as water temperature, pressure, salinity, and clarity can all affect performance. To prove that these technologies are reliable, more testing is needed in actual underwater sites, like the submerged city of Dwarka, where conditions are more complex and unpredictable (Remondino et al., 2021).

This is why SONAR can be used as an alternative. However, despite its strengths that we have discussed, sonar mapping is not without challenges. Sonar offers lower resolution imagery compared to LiDAR, especially at greater distances. Sound wave data often requires complex processing and expert interpretation to distinguish between geological features and man-made structures. Sonar systems are prone to sound interference from marine life, boat traffic, and other sources. High-end sonar systems require specialised AUVs or ROVs for deployment and navigation, which can be resource-intensive. However, when used with complementary tools and expert analysis, sonar remains the most effective technology to date for a detailed exploration of submerged ancient cities like Dwarka (Gillings, 2022).

Policy Implications and Recommendations

If we decode and map the underwater heritage of Dwarka using the researched technologies, it will pose significant implications and changes for heritage conservation policies and the field of underwater archaeology. These new policy implications can lay the ground rules for future strategies in this field.

The success of using technology in mapping submerged structures shows the need for heritage conservation policies to officially incorporate these developing technologies. Government bodies like the Archaeological Survey of India (ASI) and the National Institute of Oceanography (NIO) should continue to establish well funded and technology-based research divisions.

Based on this research paper, policies for underwater archaeological exploration should include:

- Mandatory use of non-invasive mapping techniques (LiDAR, sonar, photogrammetry).
- AI-based data analysis to identify archaeological sites.
- Preservation should be put first before excavation.
- Regular monitoring of submerged heritage sites using LiDAR, AI and SONAR can be implemented.
- Policies could make periodic surveys mandatory to check erosion, structural damage, or illegal human activity on the site.
- Penalise unauthorised exploration or damage to underwater sites. Policies could also focus on promoting public awareness by:
- Creating digital recreations of underwater sites for educational tourism.

Developing online databases with open access to the public for underwater archaeological data.

Conclusion

This research paper shows the significant insights gained from analysing the published data on Dwarka's underwater structures and submersion history. The application of LIDAR and AI technologies has been proven to be valuable in enhancing our understanding by enabling precise mapping and uncovering structures. These advancements have provided a fresh perspective on Dwarka, bridging the gap between traditional archaeological methods and modern technology.

Looking ahead, future research should prioritise the integration of these technologies. Additionally, collaborating with technological innovation and archaeological theory will help build a more comprehensive understanding of not only Dwarka but also similar submerged sites around the world. This approach will not only expand our knowledge of ancient civilisations but also introduce better methods for exploring submerged historical landscapes.

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