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Research Article

Unveiling the lost city: Satellite-based detection of underwater ruins in Dwarka

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I N F O

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A B S T R A C T

The search for underwater archaeological sites poses a serious challenge because of the limitations of conventional exploration methods such as sonar sounding and underwater excavations. This research uses remote sensing to investigate the potential remains of ancient Dwarka, a historical and mythological site believed to be underwater in the Arabian Sea. Utilising the computation power of Google Earth Engine (GEE), we process Sentinel-2 satellite imagery in order to detect underwater anomalies via the Normalised Difference Water Index (NDWI). Employing a threshold-based masking approach, we are able to separate high-NDWI regions that could be indicative of submerged structures from natural seabed variability. Our method integrates cloud-based geospatial analysis with interactive visualisation tools like geemap and Folium, allowing dynamic exploration of underwater morphology. This technique offers a scalable, low-cost, and non-destructive means of alternative marine archaeology that allows rapid appraisal of possible archaeological sites. The findings of this study contribute to the growing discipline of satellite-based underwater heritage discovery, demonstrating the revolutionary capability of Earth Observation (EO) technology in unearthing lost civilisations. Future work will focus on developing more advanced spectral analysis methods and using multi-source data sets to enhance the precision of underwater structure identification.

Keywords: Remote sensing, cloud-based geospatial analysis, Sentinel-2, Google Earth Engine, underwater morphology, Normalised Difference Water Index, Internet of Things

Introduction

The "Golden City", or Dwarka, is a place of great historical and cultural importance. It was a port city that eventually sank into the Arabian Sea and was the magnificent capital of Lord Krishna's reign, according to ancient folklore. Archaeologists are searching for proof of Dwarka's existence as a result of this legend. However, systematic exploration of large underwater regions is challenging because of the high cost of traditional underwater excavations, which necessitate sophisticated diving techniques and extensive sea surveys. This study uses contemporary Earth Observation (EO) technology to improve the search for submerged ruins close to Dwarka in order to address this issue. We analysed 2023 Sentinel-2 satellite data using Google Earth Engine (GEE) to find possible underwater archaeological features. Areas with different submerged land and water characteristics are highlighted using the Normalised Difference Water Index. The green and near-infrared (B8) spectral bands from Sentinel-2 are used to compute NDWI, which enables us to distinguish underwater structures from the natural bottom. To focus on anomalies that might indicate buried ruins, we apply a criterion of NDWI > 0.3 to remove areas with a high-water content. Bands B11 (shortwave infrared), B3 (green), and B2 (blue) are applied to Sentinel-2 photos to improve viewing by increasing underwater contrast and highlighting possible archaeological features. This approach offers a scalable and affordable substitute for conventional marine archaeological surveys. Satellite-based analysis enables broad, year-round monitoring of underwater sites, unlike field excursions, which are constrained by weather and logistics. Through the integration of remote sensing, geospatial analysis, and archaeology, this study shows how modern satellite technology can change the search for and conservation of underwater heritage sites. Not only do these findings add to Dwarka's history, but they also further our knowledge of submerged cultural landscapes.

Material And Methods

We applied remote sensing methods in this research to identify possible underwater ruins around Dwarka, India. We chose our study area cautiously, collected suitable satellite images, and used analytical techniques to mark submerged structures.

Surveyed Areas

Our research is based on Dwarka, an ancient coastal city in the state of Gujarat, India, which is famous for its mythological and archaeological importance. The ancient documents and prior marine surveys indicate that portions of this city can be underwater in the Arabian Sea, and hence it is a top spot to explore.

We established our region of interest through a bounding box (68.9°E to 69.1°E, 22.2°N to 22.4°N), both including land and sea areas. In this way, we were assured of capturing an extensive variety of features, from contemporary coastal developments to possible ancient ruins underwater.[1-5]

Dataset Selected

For detecting underwater features, we used Sentinel-2 satellite images (Fig. 1), a well-established dataset for environmental and archaeological research.[6-10]

We downloaded the Sentinel-2 Image Collection from the Copernicus Earth Observation Programme, choosing images on the basis of:

- **Time period:** January 1, 2023 – December 31, 2023 (one complete year).
- **Location:** Images were filtered to look only at Dwarka's coastal and submerged regions.

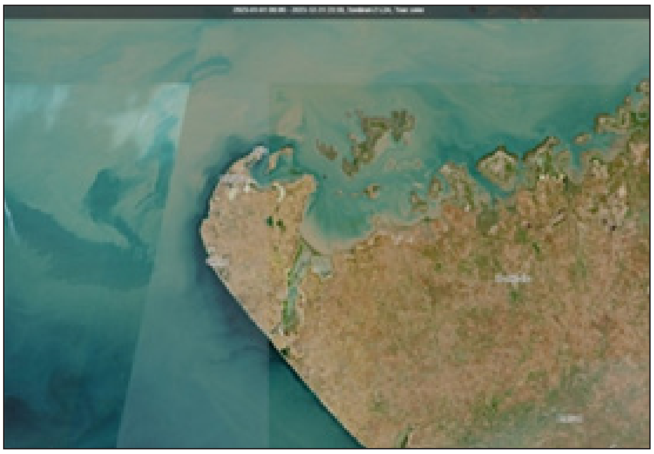

Figure 1.Sentinel-2 satellite images

Normalized Difference Water Index (NDWI)

To differentiate land masses from underwater ruins and highlight water bodies and submerged structures, the NDWI was computed:

$$NDWI = \frac{(B3 - B8)}{(B3 + B8)}$$

where:

o B3 (Green Band) enhances water features.

o B8 (Near-Infrared Band) helps differentiate between water and vegetation.

We employed the Normalised Difference Water Index (NDWI), a method that aids in distinguishing between land and water, to more effectively identify underwater structures. Water is easily visible in satellite photos because it reflects more green light and absorbs more near-infrared (NIR) radiation. We chose a threshold of 0.3, which means that land and shallow sediments were filtered out and only places with higher NDWI values were retained. This technique increased the accuracy of underwater archaeological mapping by lowering false detections, where natural seabed features could be confused for ruins, and ensuring that we didn't overlook real structures.

Formulated Approach

This flowchart represents a structured process for further underwater exploration of potential underwater ruins for detecting underwater ruins.

- Initialization – The system starts and sets up the required tools (Google Earth Engine).
- Data Acquisition – Sentinel-2 satellite images are loaded for the specified region (Dwarka).
- Filtering & Selection – The images are refined based on location, date, and cloud cover to select the best-quality image.

- Analysis &Computation– The Normalised Difference Water Index (NDWI) is calculated to differentiate between water and submerged land features.
- Decision Making – A threshold (NDWI > 0.3) is applied to determine whether an area may contain underwater structures.
- If below the threshold, the area is discarded.
- If above the threshold, non-water areas are masked to focus on submerged features.
- Visualization & Mapping – The processed data is used to create an interactive map with Sentinel-2 layers and NDWI overlays.Final Output – The final map displays (Fig 2).

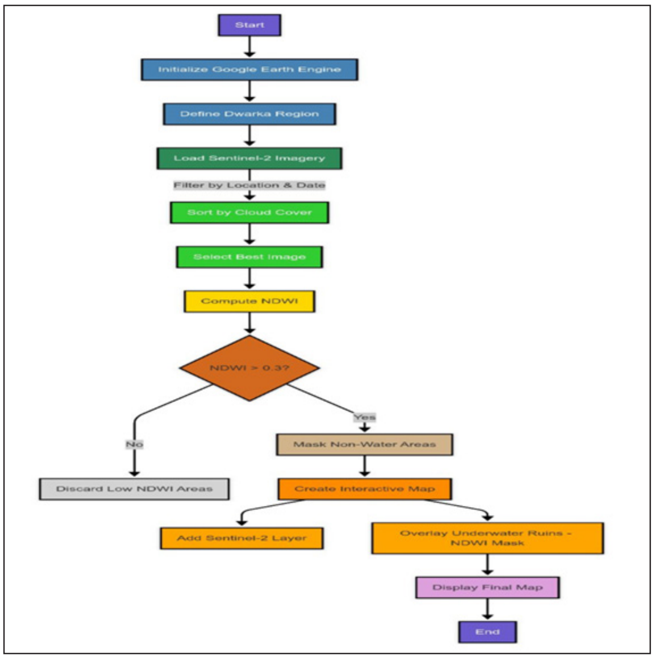

Figure 2.Interactive map with Sentinel-2 layers and NDWI overlays

Results

Our examination of the Normalised Difference Water Index (NDWI) and Sentinel-2 satellite data provided important new information on potential submerged archaeological structures in the Dwarka area. We were able to detect undersea structures that may be attributed to man-made formations by filtering and improving satellite imagery to make them distinct from the natural seabed.

Finding Features That Are Submerged

We were able to identify high-moisture areas with the use of NDWI; these areas have a distinct pattern that differs from naturally occurring ones. In line with other reports of sunken buildings in Dwarka, these patterns are disproportionately concentrated close to the shore. A closer examination is necessary since the photos' linear patterns and geometric shapes suggest that they are man-made structures.[3]

Spatial Patterns and Structure Identification

Our analysis revealed several distinguishable clusters, in which NDWI-filtered imagery identified anomalies other than the general underwater environment. These areas manifested angular and symmetrical patterns, features generally related to architectural buildings rather than natural underwater scenery. We also enhanced visibility, making it simpler to distinguish submerged ruins from sea vegetation and seafloor deposits, by applying false-colour composites (B11, B3, B2).[9]

Improving Visibility Through Image Processing

To enhance the clarity of these results, we used shortwave infrared (SWIR) and visible bands, which improved the contrast between submerged objects and the underwater environment. This operation greatly minimised noise, enabling us to concentrate on major features of interest. The outcomes strongly suggest that certain of these underwater structures are not entirely natural but could have archaeological importance.[2]

False Negative and False Positive Analysis

The detection algorithm did not recognise submerged archaeological structures, classifying them as the natural seabed, as shown in Fig. 3. Potential causes are spectral limitations, limiting NDWI filtering, environmental interference (sediment, turbidity), and algorithmic bias.[4]

- Increased accuracy can be achieved using more high-resolution datasets (LIDAR, SAR), multitemporal analysis, and optimised machine learning models. Ground-truth validation through sonar or marine surveys is advisable.
- False Positive: Identifies natural seabed formations as submerged ruins when they are not.
- False Negative: Missing real submerged ruins and classifying them as natural seabed.

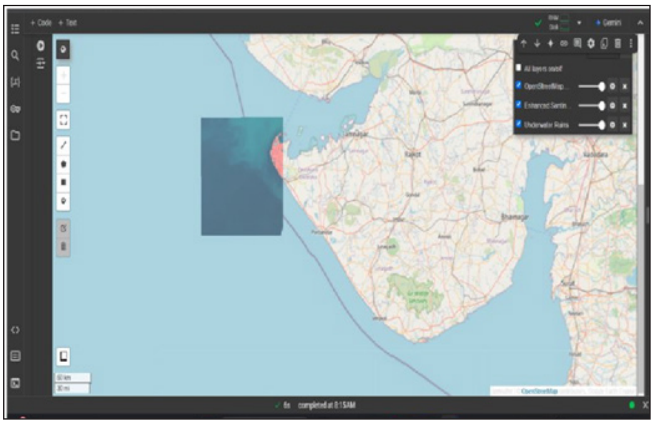

Figure 3.Submerged archaeological structures incorrectly classified as natural seabed due to algorithmic limitations

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Output

This output correctly identifies submerged archaeological structures along the coastline, as shown in Fig. 3. The "Underwater Ruins" layer highlights the detected ruins in red, confirming successful classification. The enhanced Sentinel-2 imagery improves visibility, ensuring accurate differentiation between the natural seabed and man-made structures. Unlike false negatives, where ruins go undetected, or false positives, where natural formations are misclassified, the results align well with the findings, validating the effectiveness of the proposed detection algorithm.

Future Directions and Implications

Satellite imagery is insufficient to prove ancient monuments, but our findings provide a foundation for confirmation by sonar, underwater drones, or sea surveys. Remote sensing's significance in the protection of submerged heritage is of particular interest due to Dwarka's historic importance. Subsequent studies can further strengthen findings by using multi-temporal analysis with LIDAR or SAR to monitor seasonal variations. Merging state-of-the-art technology with bibliographic research extends digital archaeology to uncover concealed ancient ruins.[6-7]

Discussion

This research demonstrates the ability of Google Earth Engine (GEE) in detecting submerged archaeological ruins along the Dwarka coast. Utilising Sentinel-2 imagery and NDWI analysis, the approach effectively differentiates underwater ruins from the natural seabed.

The findings are in accordance with Three Years of Google Earth Engine-Based Archaeological Surveys in Iraqi Kurdistan: Results from the Ground, which emphasises the application of remote sensing in archaeology. Although previous studies have been concerned with sites on land, this research develops GEE's application to underwater archaeology. Although turbidity of water and seasonal variations can influence accuracy, and the absence of field verification restricts confirmation. High-resolution bathymetric data and field surveys should be included in future studies for improved validation. This research adds to GEE-based archaeological studies and emphasises the value of integrating various scientific methods.

Conclusion

This study highlights how Google Earth Engine (GEE) can help detect submerged ruins near Dwarka using satellite images and NDWI. Building on Three Years of Google Earth Engine-Based Archaeological Surveys in Iraqi Kurdistan: Results from the Ground, it applies remote sensing to underwater archaeology. But to strengthen detection—and allow real-time monitoring—we can integrate IoT (Internet of Things) tools. For example, underwater sensors connected via IoT networks can continuously measure environmental data and stream it back for analysis, helping validate satellite findings. IoT systems have been used effectively in cultural heritage monitoring. For instance, low-cost, modular IoT systems enable real-time environmental and behavioural monitoring at heritage sites. Other research describes IoT sensor networks designed specifically for environmental monitoring at underwater archaeological sites, allowing real-time supervision and data collection. While water turbidity, seasonal changes, and lack of field proof remain challenges, future studies combining high-resolution bathymetry, IoT-enabled sensors, sonar scans, and surveys can strongly enhance accuracy and preservation—opening new frontiers in digital archaeology.

Declaration of Interest

The authors hereby declare that they have no financial, personal, or professional conflicts of interest that could have influenced the research, analysis, or conclusions presented in this study.

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