Remote Sensing Driven Lake Bathymetry Estimation using Sentinel-2 and Machine Learning

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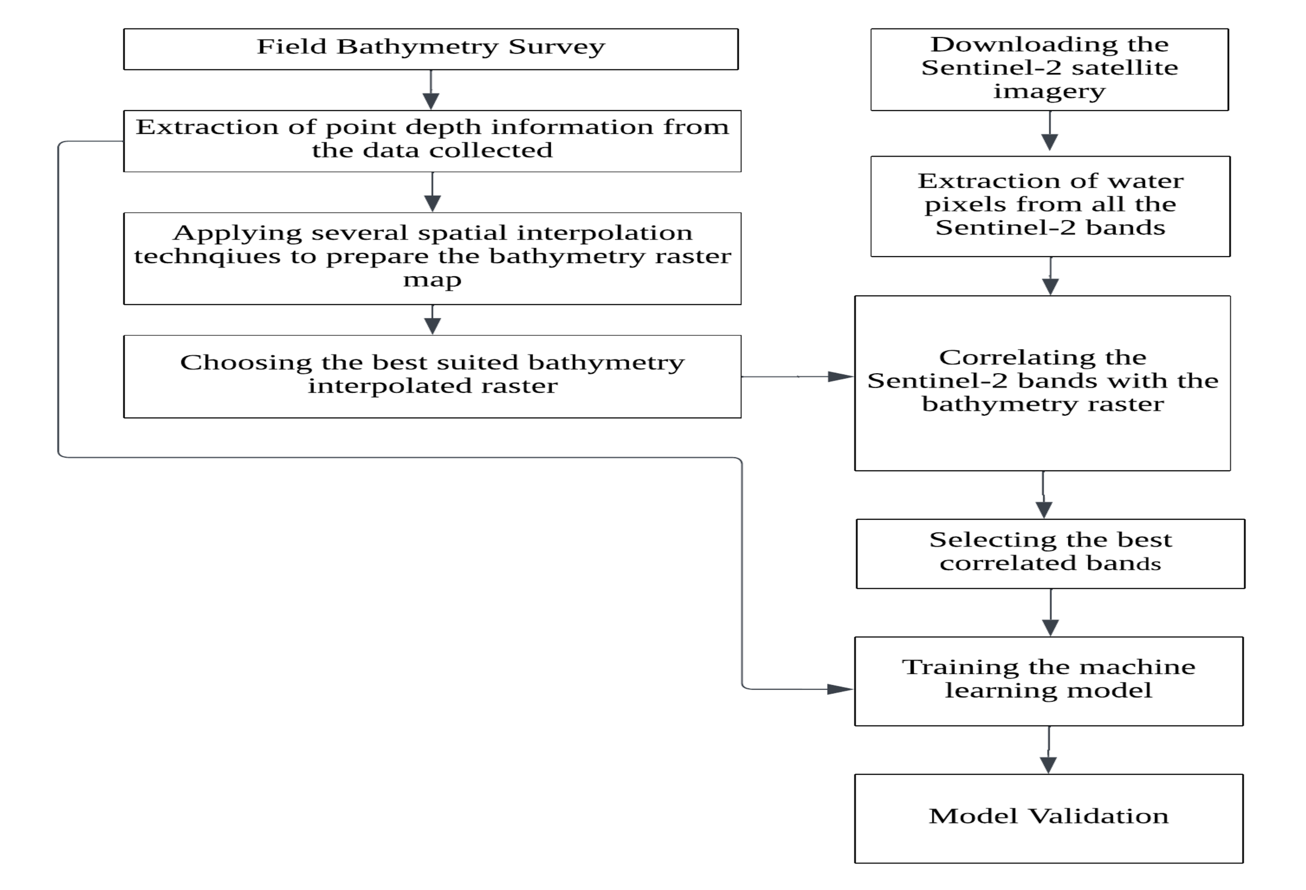
Abstract

Urban lakes face increasing stress due to land-use changes, sedimentation, and pollution, making traditional bathymetric surveys inefficient. This study introduces a remote sensing and machine learning-based method to estimate bathymetry in Velachery Lake, a turbid, urban lake in Chennai. Using Sentinel-2 imagery and in-situ depth data, a Random Forest Regression model was trained, excluding blue, green, and red bands due to poor correlation in turbid waters. Instead, NIR, red-edge, and SWIR bands were more effective. Inverse Distance Weighting (IDW) provided the best spatial interpolation. The model achieved an RMSE of 0.05 m and R^2 of 0.77, and showed good transferability to Sembakkam Lake.

Introduction and Need for Study

- Accurate bathymetric data is essential for targeted dredging and restoration in polluted urban lakes, but traditional surveys are often unfeasible in turbid, debris-filled conditions.
- While conventional remote sensing methods work well in clear waters, they underperform in urban, shallow, and turbid lakes.
- Empirical and machine learning approaches, such as Random Forest Regression, provide a more adaptable solution. Using Sentinel-2 bands like NIR, SWIR, and Red Edge, these models can better capture depth-reflectance relationships, improving bathymetric estimates in such challenging environments.

Methods and Materials



Results and Discussion

Bathymetry Raster Analysis

Field-collected depth data were first processed in AutoCAD and exported in .dwg format, then imported into QGIS 3.34.1 and converted into a point shapefile for analysis. Four spatial interpolation methods—IDW, Ordinary Kriging (OK), Local Polynomial Interpolation (LPI), and Radial Basis Function (RBF)—were evaluated for generating a bathymetry raster of Velachery Lake. Despite RBF achieving the lowest RMSE (0.1207 m), it, along with OK, performed poorly near shorelines. LPI showed the highest RMSE (0.4719 m). IDW, with an RMSE of 0.2798 m, offered the best balance of accuracy and spatial consistency, especially along the lake's edges, making it the most suitable method.

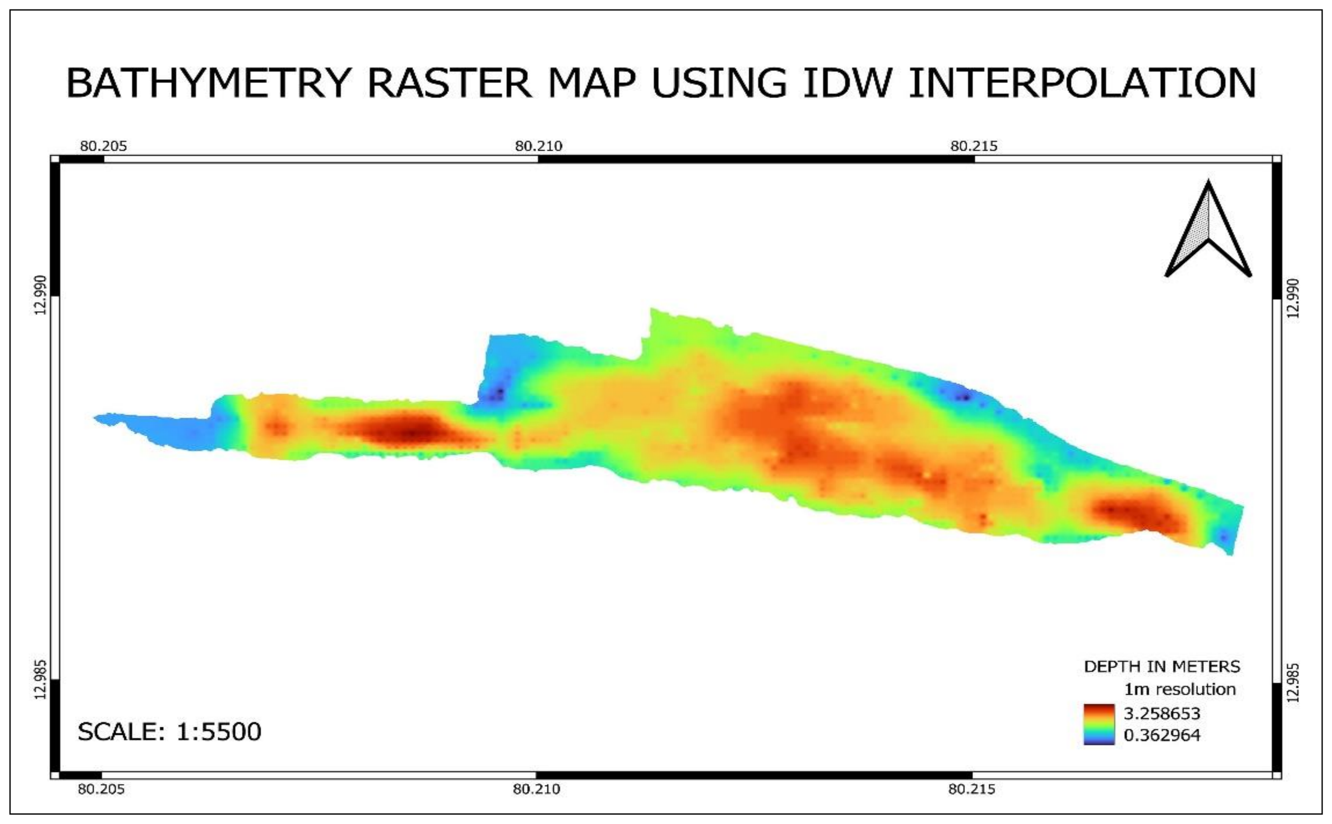


Figure 1. Bathymetry Raster from Inverse Distance Weighting Interpolation

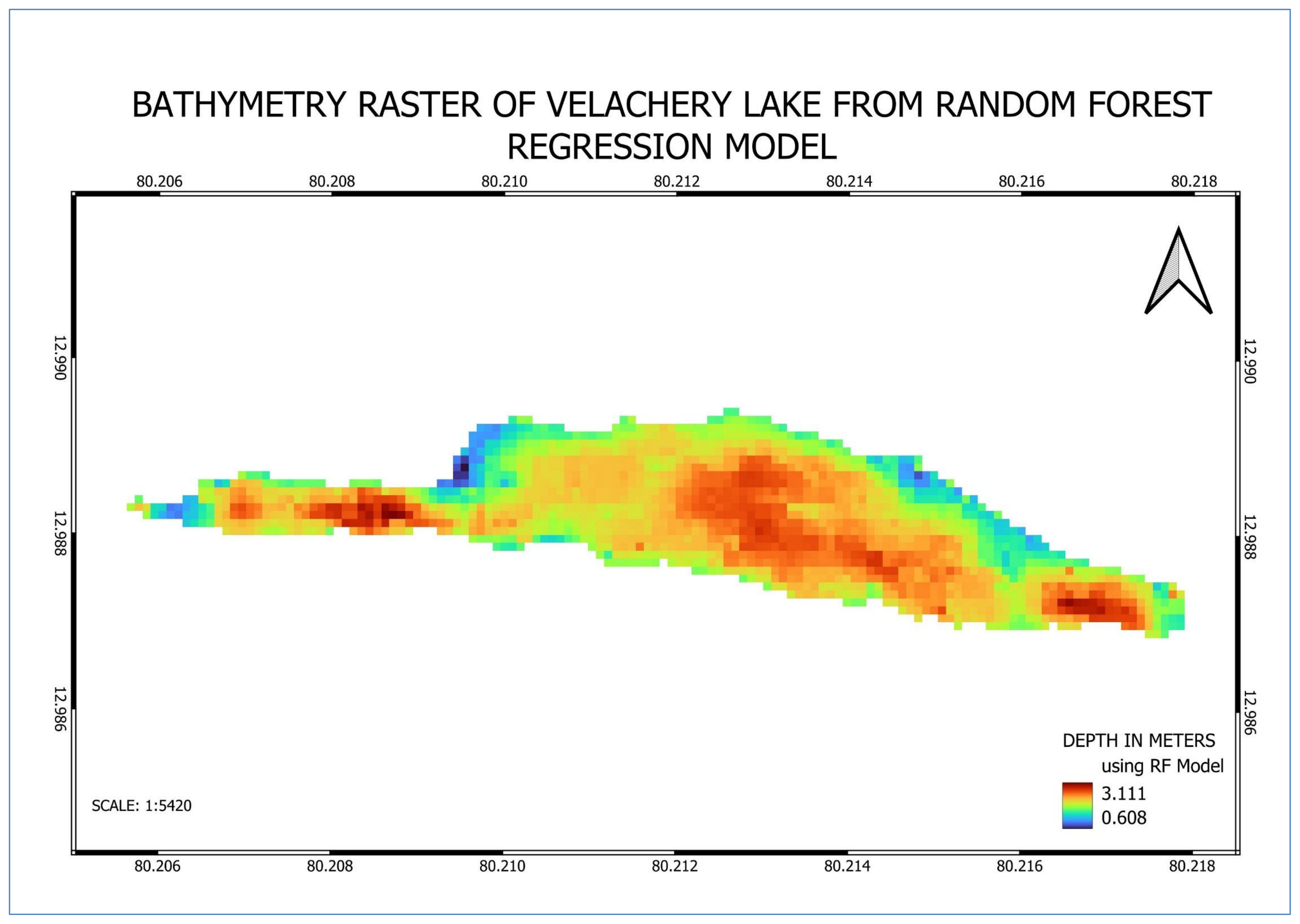


Figure 2. Bathymetry raster generated from Random Forest trained model.

Bathymetry Raster Analysis

This study examined the correlation between Sentinel-2 bands and bathymetric depth in the turbid waters of Velachery Lake. Unlike in clear waters—where blue wavelengths are typically favored for their deeper penetration—the analysis showed that longer wavelengths are more effective in turbid environments. The blue (B2) and green (B3) bands had weak correlations with depth (r = -0.1516 and -0.0999), while the red (B4) and red-edge bands (B5–B8A) showed stronger negative correlations, with values up to -0.4599. These findings align with past research, indicating that in sediment-rich waters, red to SWIR bands provide better bathymetric sensitivity. Scatterplots of bands B2 to B12 reinforced this trend, highlighting the importance of longer wavelengths for accurate depth estimation in turbid urban lakes.

Bathymetry Raster Analysis

A Random Forest Regression (RFR) model was developed using in-situ depth data from Velachery Lake and Sentinel-2 imagery to estimate bathymetry in turbid waters. Due to poor correlation with depth, visible bands (B2–B4) were excluded, while NIR, Red Edge (B5–B7), and SWIR (B11–B12) bands—known for better performance in turbid conditions—were used as inputs. The model achieved strong accuracy with an RMSE of 0.05 m and R^2 of 0.77. To assess generalizability, the model was validated on Sembakkam Lake, yielding an RMSE of 0.01 m and R^2 of 0.72, confirming its robustness and transferability for bathymetric mapping in similar turbid urban lakes..

Conclusions

This study demonstrates an effective approach for bathymetric mapping in shallow urban lakes by integrating dual-frequency echosounder data, Sentinel-2 imagery, and machine learning. In Velachery Lake, Sentinel-2's Red Edge and NIR bands proved valuable for detecting depth variations in optically shallow zones influenced by bottom reflectance. The method offers a scalable, cost-effective alternative for bathymetry in data-limited, turbid urban water bodies, supporting better sediment management and restoration planning.

Acknowledgements

We gratefully acknowledge M/S NISVO MARINE SURVEYS LLP for conducting the bathymetric survey of the lake, providing critical data essential for the accuracy and success of our study.