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Evaluating Shoreline Prediction Models with Pre- and Post-2024 Noto Peninsula Earthquake Satellite Imagery

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1. Introduction

Change in shoreline, driven by human activities near coastal areas and natural forces, impact coastal ecosystems, human settlements and economic activities significantly. Therefore, accurately predicting shoreline dynamics and monitoring is essential for effective coastal management, disaster preparedness and hazard mitigation. The traditional methods used for calculating shoreline change are often time-consuming, expensive, and temporally unreliable. This study integrates open-source tools, CoastSat and AMBUR (Analyzing Moving Boundaries Using R), to streamline shoreline extraction, tidal correction, and future shoreline predictions. The research focuses Wajima, Japan, to assess the accuracy of shoreline predictions before and after the 2024 Noto Peninsula Earthquake.

2. Materials and Methods

2.1 Data & Study Area

The study area used was Wajima, Ishikawa, Japan as displayed in Figure 1. The data used for this study are 28 years of shorelines from 1987 to 2014, 2018, & 2023 to 2024, where shoreline of 2023, 2024 were used for validation. These Shorelines were extracted from optical satellites, where beach slope and shoreline elevation were calculated using DEM, and tidal data was obtained from Geospatial Information Authority of Japan (GSI). Table 1 shows the detailed description of the data and its sources.

2.2 Methodology

The CoastSat (Vos *et al.*, 2019) extract shorelines and perform tidal corrections, achieving around 10-meter accuracy. It processes multispectral images from Sentinel-2 and Landsat via Google Earth Engine, applying cloud masking and pan-sharpening. With the help of MNDWI, and Otsu's threshold (Otsu, 1979), it segments images into land and water pixels and extracting shorelines with the Marching Squares Algorithm (Cipolletti *et al.*, 2012). Tidal correction, including tidal data, beach slope, and shoreline elevation, normalizes the shoreline positions to mean sea level, providing an accurate long-term shoreline analysis.

The AMBUR (Jackson Jr *et al.*, 2012) toolkit was used to calculate shoreline change rates and predict future shorelines. It starts from collecting baselines along with shorelines, then generates transects at regular intervals. For this study 5 different intervals of 1 m, 25 m, 50 m, 75 m, and 100 m were used along the shoreline. Two transect types are used: perpendicular and near transects. These transects help measure shoreline positions over time. Shoreline positions are analysed by calculating intersection points and measuring distances from the baseline. Statistical methods, including End Point Rate (EPR), Linear Regression Rate (LRR), and Weighted Linear Regression (WLR) are used to calculate change rates. Predicting future shorelines depends on factors like shoreline change rates calculated using

Table 1: Input data used in this study.
USGS: United States Geological Survey , GEBCO: General Bathymetric Chart of the Oceans

Data	Year	Data Source
Landsat 5 TM	1987-1998, 2004-2011	USGS
Landsat 7 ETM	1999-2003	USGS
Landsat 8 OLI	2013-2014, 2018, 2023-2024	USGS
Photogrammetry DEM	2018	GSI
Bathymetry	2023	GEBCO
Tide Data	1987-2014, 2023, 2024	USGS

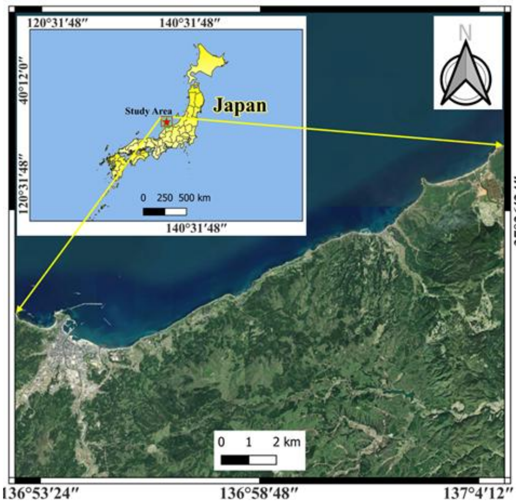

Figure 1: Study Area, Wajima, Ishikawa, Japan.

Table 2: Accuracy Assessment of Pre- and Post- Earthquake Shorelines Prediction
D I: Distance Intervals, T M: Transect Methods, N: Near, MAE: Mean Absolute Error, LRR: Linear Regression Rate, WLR: Weighted Linear Regression

D I	T M	MAE for Pre-Earthquake Shoreline using LRR	MAE for Post-Earthquake Shoreline using WLR
1 m	N	8.19	54.18
25 m	N	8.21	54.30
50 m	N	8.49	54.08
75 m	N	9.01	54.15
100 m	N	9.68	53.60

statistical methods (EPR, LRR, WLR), transect azimuth, offshore correction values, latest shoreline, and the forecast period for which the future shoreline position needs to be predicted.

3. Results and Conclusions

In this study, EPR, WLR, LRR statistical method was performed on the shorelines with different transects intervals of 1 m, 25 m, 50 m, 75 m, and 100 m, using the near transect method. Table 2 shows the Mean Absolute Errors (MAE) at various distance intervals where the shorelines were predicted for the period before and after the 2024 Noto Peninsula Earthquake.

The predicted shoreline for Wajima before 2023 earthquake was based on the shorelines change which were derived using shoreline positions for 28 years from 1987-2014. Among the 3 statistical method, LRR method demonstrated the best accuracy, with MAE of 8.19 m to 9.68 m. The 1-meter interval showed the lowest error of 8.19 m (MAE). The histogram of Figure 3a shows the distribution of distances between predicted and observed shorelines for the 1-meter transect interval. The mean distance was 8.19 m, with the median distance of 4.98 m, this indicates that most of the deviations were small. The spatial distribution of shoreline prediction errors shows 62% of the prediction had an error below 6.90 m, while 27% was in the range from 6.90 m to 17.0 m range. Only 0.4% exhibited a deviation exceeding 95.50 m. These findings confirm that the LRR-based shoreline predictions for 2023 aligned well with observed shorelines, demonstrating high model reliability under stable coastal conditions.

For post-earthquake shoreline prediction, the results show significant differences between the predicted and the observed shorelines for 2024. From the 3 statistical methods WLR exhibited the lowest MAE, with a value of 53.6 m at the 100-meter interval as shown in Table 2 and Figure 3b. The spatial distribution of shoreline prediction errors, shows 35% of the shoreline's shifts were within 27.1 m, followed by 24% between 27.10 and 57.50 m, 20% between 57.50 and 88.80 m, 13% between 88.80 and 121.70 m, and 8% exceeding 121.70 m.

To further investigate the shoreline extraction accuracy, observed shoreline shifts were validated against data from GSI, where they conducted a study using Synthetic Aperture Radar (SAR) images, assessed land emergence and deformation following the earthquake. Their findings revealed a significant seaward shift of 150 to 200 m due to tectonic uplift. The observed shoreline shifts of this research showed a maximum shifts of 243 m. These findings were validated with the report from Geospatial Information Authority of Japan (2024) identifying substantial land emergence. This validation confirmed the accuracy of the shoreline extraction results.

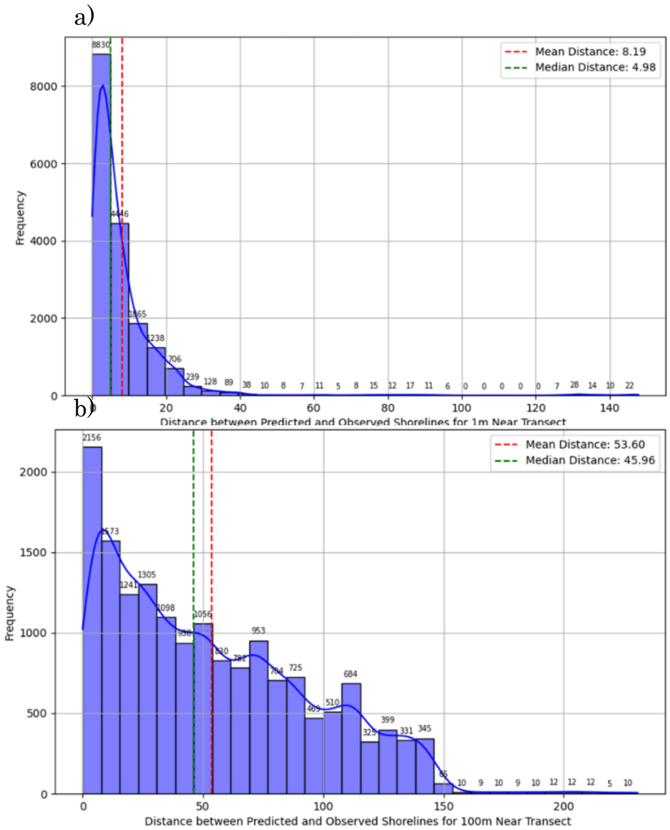

Figure 3: a) Accuracy Plot for Pre- Earthquake Shoreline Prediction, b) Accuracy Plot for Post- Earthquake Shoreline Prediction

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