Comparative Mangrove Mapping and Coastal Erosion Modelling for Mumbai Using GFW, GMW, and Numerical Simulation Tools

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Summary

Mangroves play a critical ecological and engineering role in protecting Mumbai's vulnerable coastline from erosion, flooding, storm surges, and long-term sea-level rise. Despite rapid loss and degradation, mangroves remain undervalued in conventional coastal planning frameworks. This white paper presents an ongoing independent research project that combines remote sensing analysis, Python-based geospatial modelling, and numerical erosion simulations (ANSYS/MATLAB) to evaluate mangrove cover change and quantify its implications for coastal protection. The novelty of this study is the first direct comparison of Hansen Global Forest Change (GFW) and Global Mangrove Watch (GMW) datasets for Mumbai's mangroves, revealing how dataset choice can influence study results.

1. Introduction

Mumbai is one of the world's most densely populated coastal cities and is increasingly exposed to storm surges, tidal flooding, and erosion driven by climate change and unplanned coastal development/encroachment. Mangroves, which are intertidal forests characterized by dense, stilt-like roots, form the city's most effective natural defence against these issues: they dissipate wave energy, stabilize sediments, reduce erosion, and store carbon at extremely high densities.

However, Mumbai has lost nearly 40% of its mangrove cover over the past three decades, with ongoing threats from land reclamation, infrastructure expansion, and waste accumulation. This white paper outlines a research approach that quantifies how mangrove loss affects shoreline stability and examines how different global datasets represent mangrove change in Mumbai.

2. Background and Literature Landscape

2.1 Mangroves and Coastal Protection

Global and Indian studies consistently highlight mangroves as high-value ecological and engineering systems. Research shows that a 100 m mangrove belt can reduce wave heights by 13-66%, significantly decreasing flood risk. Their aerial root systems trap sediments, bind soils, and allow coastlines to keep pace with sea-level rise.

Major findings in the literature review include:

- Mangroves act as buffers against cyclones, storm surges, tsunamis, and tidal currents.
- Mangrove belts significantly reduce wave energy and erosion aiding in coastal protection (Das & Vincent 2009).
- Ecosystem services are economically substantial, as Mumbai's mangroves provide an estimated ₹1700 crore annually in protective functions.

2.2 Mangroves in Mumbai

Mumbai's mangroves occur mainly around Thane Creek, Gorai, Versova, Uran, and Sewri, but rapid urbanization, reclamation, and plastic pollution have caused severe degradation of them. Studies using Landsat (1990–2017) and Sentinel-2 imagery in the Journal of Sea Research (Thane Creek mangrove mapping study which took place from 1990-2017) document major changes in mangrove extent, while IRS-P6 LISS-III-based classification (Pramod et al Journal of the Indian Society of Remote Sensing in 2017) shows thinning, fragmentation, and decline around Mumbai's coastal zones.

- Declines of 15-40% in specific regions due to encroachment.
- Evidence of thinning and fragmentation (density reduction even when total area seems stable/similar).
- Some Localized regrowth in areas of conservation, such as Thane Creek.

2.3 Global Datasets

Two major datasets dominate global forest and mangrove studies:

Dataset	Type	Strengths	Limitations
Hansen Global Forest Change	Not mangrove-sp	Annual, high-resolution	Misclassifies mangroves as "forest" and may overestimate

(GFW)	ecific	forest loss data	loss in coastal zones
Global Mangrove Watch (GMW)	Mangrove-sp ecific	Radar + Landsat, highly accurate (>94% accuracy)	Time snapshots not annual, and may miss small fragments

This project addresses a major literature gap: no prior study has directly compared GFW and GMW for Mumbai, despite their widespread use in environmental and engineering studies.

3. Methodology

3.1 Python Geospatial Analysis

- Importing and cleaning geospatial rasters using GeoPandas, Rasterio, NumPy.
- Extracting mangrove polygons for Mumbai's boundary.
- Overlaying GFW annual forest-loss layers with GMW mangrove-extent baselines.
- Generating maps of:
    - Forest loss hotspots.
    - Areas of GFW-detected loss not recognized by GMW.
    - Potential misclassification zones (fragmented or mixed vegetation).

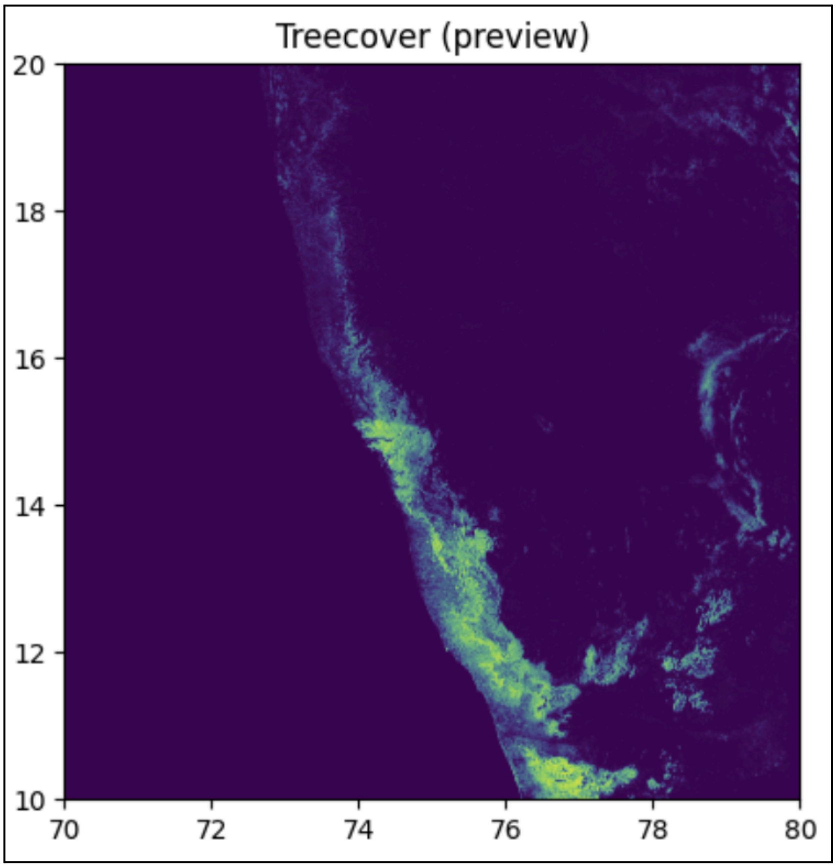

Image depicting Global Forest watch dataset geospatial raster for Indian subcontinent

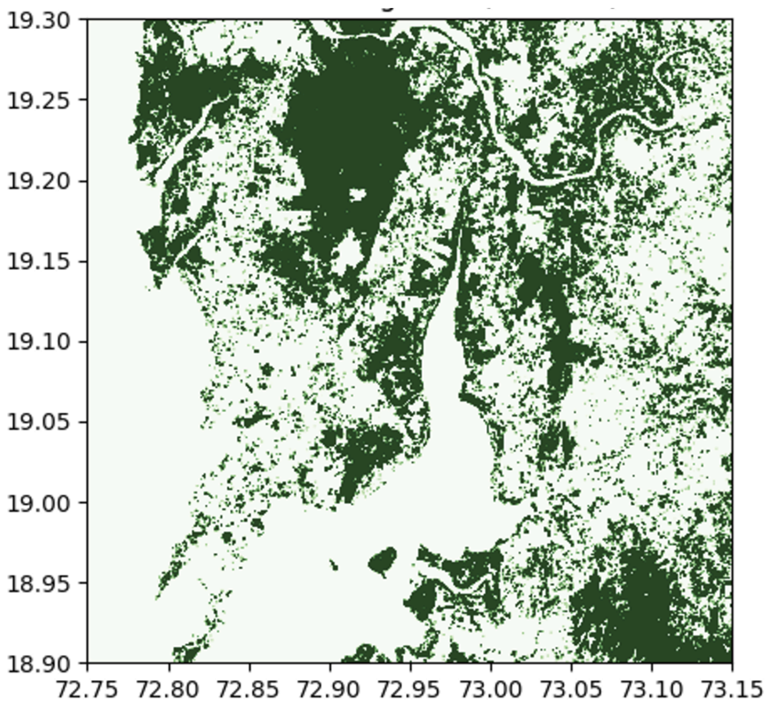

Image depicting Global Forest Watch Dataset Mumbai region forest cover

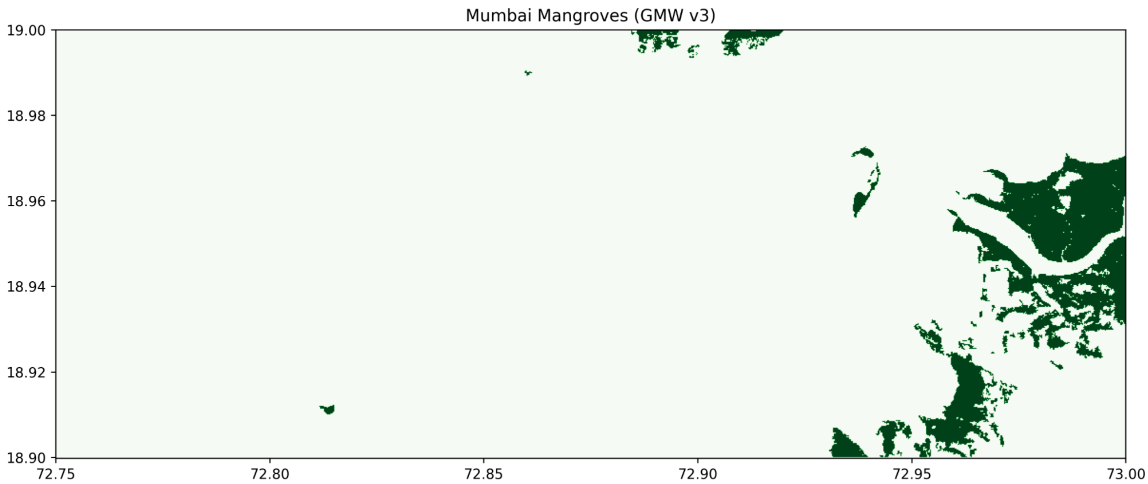

Image depicting Global Mangrove Watch Dataset Mumbai region mangrove cover

3.2 Comparative Dataset Analysis

The project evaluates:

1. **Spatial agreement** - (overlap, mismatch area).
2. **Temporal contrast** - (GFW's annual vs. GMW's snapshot years).
3. **Classification sensitivity** - (GFW capturing all tree types vs. GMW capturing only true mangroves)

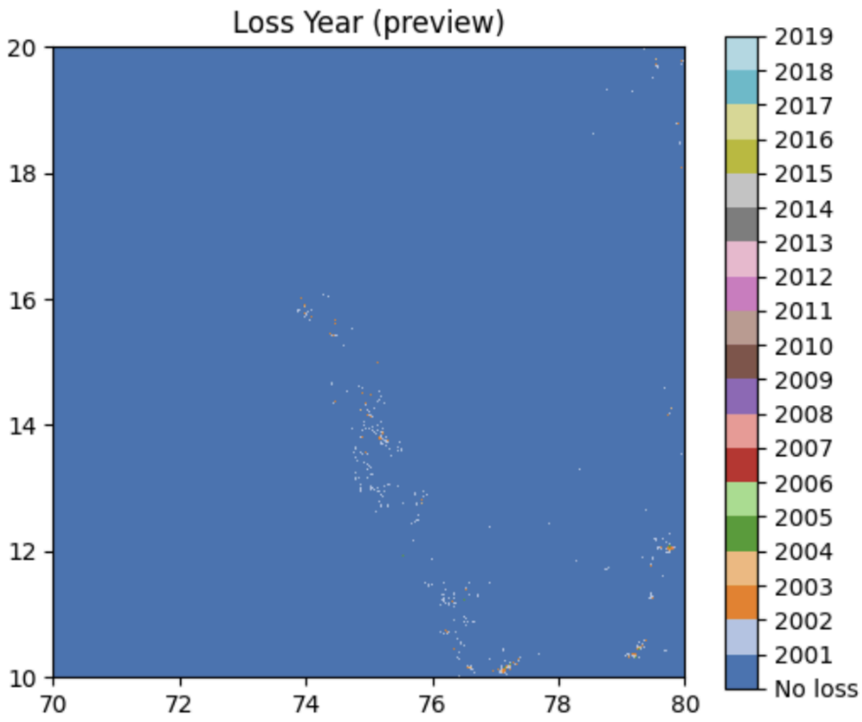

Image depicting GFW's annual loss year dataset for Indian subcontinent

3.3 Numerical Modelling of Erosion (ANSYS + MATLAB)

A simplified physical model simulates:

- Mangrove root deflection of wave forces
- Bed shear stress reduction
- Sediment retention and erosion rate changes
- Long-term stability under various mangrove-loss scenarios

Some of the models draw from:

- Literature values for drag coefficients of mangroves

- Root density and stem spacing data of common mangrove species
- Historical erosion maps from Maharashtra's west coast

4. Key Findings (Preliminary)

4.1 Dataset mismatch has major implications

- GFW often reports more "forest loss" because it is not able to distinguish mangroves from other coastal vegetation.
- GMW provides more accurate boundaries but lacks annual change data which GFW does.
- In fragmented areas of Mumbai (such as Versova, Gorai), the two datasets disagree significantly, which may lead to incorrect estimates of erosion risk.

4.2 Mangrove loss correlates with erosion-prone zones

- Indian west-coast studies show that 45% of the coastline is eroding, and erosion is most severe where mangroves have degraded/are sparse .
- Mumbai sites with the highest loss match erosion hotspots documented in SOI/IRS coastal analyses.

4.3 Numerical simulations support field evidence

- Preliminary ANSYS/MATLAB modelling suggests that mangrove roots can reduce tidal-current speeds by up to 80%, aligning with already published ADCIRC model results.
- Even partial thinning of mangroves (not total loss) significantly increases bed shear stress and long-term erosion potential.

5. Implications for Coastal Engineering and Planning

This research highlights some critical implications:

1. **Dataset choice affects risk assessments**
   - Engineers relying on GFW may overestimate mangrove loss in Mumbai.
   - Policymakers using GMW alone may underestimate short-term degradation.
2. **Combining datasets provides the most reliable picture**
   - GFW - most suitable for annual monitoring
   - GMW - most suitable for accurate mangrove boundaries

3. **Mangrove protection is more cost-effective than seawalls**
    - Literature strongly supports hybrid solutions: mangrove belts plus engineered defences are the most effective.
4. **Mumbai requires site-specific erosion modelling**
    - Areas like Gorai, Sewri, and Uran need urgent mangrove restoration, not reclamation.

6. Conclusion

This white paper synthesizes environmental, remote sensing, and engineering perspectives to demonstrate the crucial and irreplaceable role of Mumbai's mangroves in coastal protection. The project's comparative analysis of GFW and GMW datasets fills a major research gap and provides a more accurate foundation for erosion modelling. By integrating Python geospatial analysis with ANSYS/MATLAB simulations, this work contributes a novel and practical approach for policymakers, coastal engineers, and conservation planners to work on research related to mangroves.

The ongoing research will in the future refine mismatch quantification, validate results with higher-resolution datasets (Sentinel-2), and run full-scale erosion simulations for multiple future scenarios of mangrove loss and restoration.

7. Sources

- https://www.dw.com/en/saving-mumbais-natural-mangrove-buffer-against-rising-tides/a-47992557
- https://www.nature.org/media/oceansandcoasts/mangroves-for-coastal-defence.pdf
- https://pubmed.ncbi.nlm.nih.gov/24233722/
- https://www.mdpi.com/2072-4292/10/10/1669
- https://link.springer.com/article/10.1007/s12040-023-02047-8
- https://india.mongabay.com/2019/07/why-the-city-that-never-stops-comes-to-a-standstill-when-it-rains/
- https://www.tandfonline.com/doi/full/10.1080/21513732.2014.997292#d1e757
- https://drs.nio.res.in/drs/bitstream/handle/2264/8819/J_Sea_Res_180_102162a.pdf?isAllowed=y&sequence=1
- https://publisher.unimas.my/ojs/index.php/JCEST/article/view/3339
- https://www.sciencedirect.com/science/article/abs/pii/S2095927323003110
- https://www.mdpi.com/2072-4292/13/19/3978