

Assessing mangrove health in a fragmented urban coastline of Mumbai, India

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1. Background

Mangroves occupy intertidal zones between roughly 30°N and 30°S, and they sequester three to five times more carbon per unit area than terrestrial tropical forests while serving as nursery habitat for commercial fish species [1,2]. Despite this, they remain among the most threatened coastal ecosystems. Their complex root systems and muddy waters make them receive less public attention than coral reefs. Estimates put the annual value of mangrove ecosystem services at USD 1,940,000/ha/year, which includes provisioning, regulating, and cultural services [3]. The fringing mangroves in Mumbai alone provide an estimated USD 8.37 million per year in monetised services and USD 5.66 million from flood control, USD 1.94 million from wastewater treatment, and USD 0.65 million from fisheries support [4]. The valuation is only as good as the monitoring behind it, and this is where urban mangroves break the usual trend. The mangroves in Mumbai are fragmented by urban development, legally protected on paper, and encroached upon in practice by settlement and industry. To cope with the encroachment or the rate of change, satellite-based assessments have a better chance than conventional ground surveys alone (Figure 1).

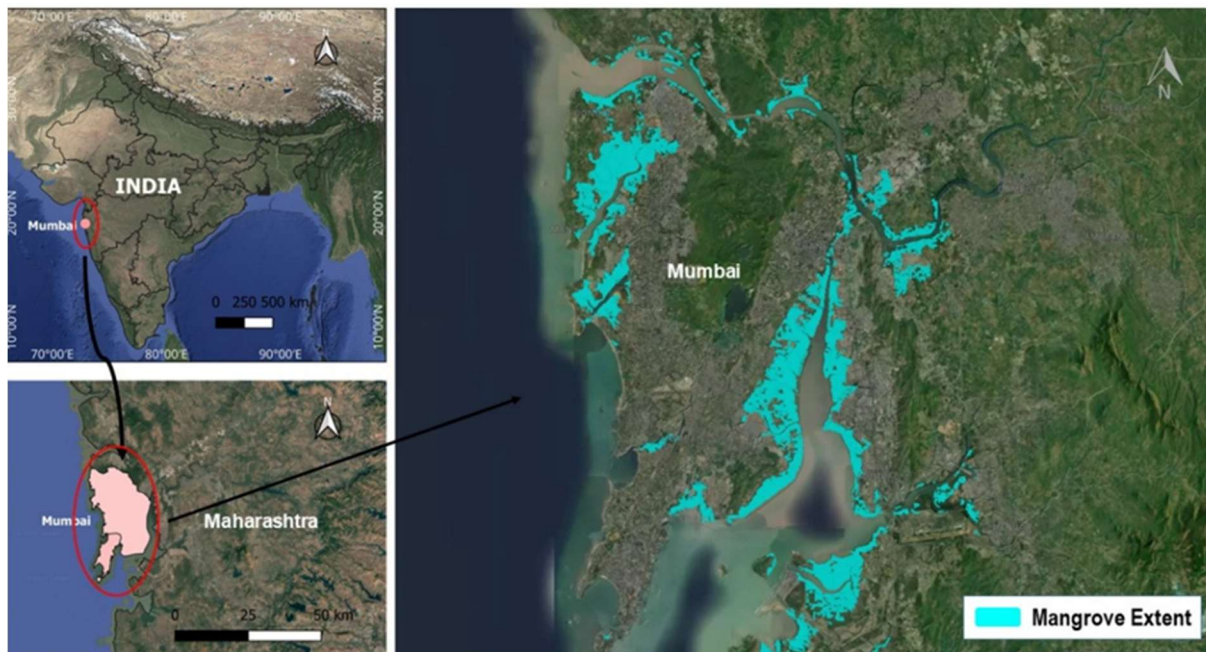


Figure 1. Map showing the extent of mangroves along the Mumbai coast.
(Source: Prepared by authors using QGIS & Google Earth Pro)

What does ‘health’ mean for a mangrove?

Mangroves are evergreen, but their phenology is not linear. Leaf fall follows a bimodal pattern, peaking at the end of each dry season [5]. Mangrove decline is not just a matter of area lost. Canopy structure and ecosystem function degrade even where cover persists, which reduces the services these systems provide long before the trees vanish from the satellite image [6]. Shrestha *et al.* [7] frame mangrove health across four strand-level dimensions-structural integrity (canopy cover, height, and biomass), physiological status (chlorophyll content, water stress, and nutrient level), biophysical condition (leaf area index and productivity), and disturbance level (deforestation, dieback, and fragmentation) which require detection of change across multiple time points rather than a single image date.

2. Urban mangroves under the microscope: The Mumbai case

Maharashtra’s mangrove cover totals 315 sq. km (2023) (Figure 2). Mumbai suburban accounts for roughly 64 sq. km while Mumbai city, the more heavily built-up island district, covers only 2.0 sq. km [8]. The city’s mangroves are a fragmented, discontinuous belt spread along Thane Creek, Versova, Malad, and the northern suburbs, making Mumbai a useful test case for health assessment methods designed around a continuous canopy. Ten species belonging to five families and eight genera occur in the Mumbai mangroves. *Avicennia marina* dominates, at around 78% tree density and 50% importance value, alongside *Sonneratia alba*, *Rhizophora mucronata*, and *Ceriops tagal* [9].

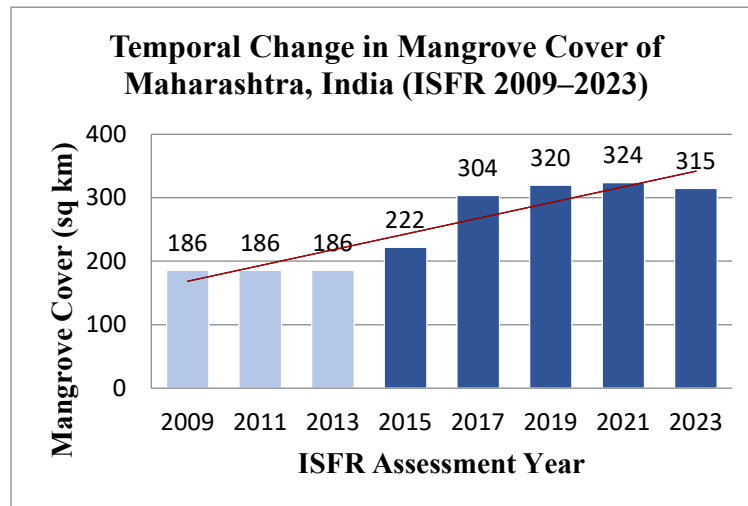


Figure 2. Temporal change in mangrove cover of Maharashtra (sq. km) based on biennial assessments by the Forest Survey of India (ISFR 2009–2023). (Data source: FSI 2009–2023; Graph generated by authors)

Geospatial analysis framework

A geographical information system (GIS) allows researchers to overlay independent spatial datasets, tidal boundaries, substrate maps, and encroachment records against vegetation indices to surface patterns that none of those layers shows individually. Google Earth Engine (GEE), a cloud-based platform, processes large volumes of satellite imagery without local downloads or dedicated computing hardware [10]. Tools built on GEE, such as MANGLEE, calculate multiple spectral indices across the entire coastline in a single workflow [11]. The pre-monsoon dip in normalized difference vegetation index (NDVI) (March–May) reflects water stress, depicting the window when early degradation signals are most detectable, since stressed vegetation shows the sharpest spectral contrast against healthy canopy at the time of year [12]. Sentinel-2’s red-edge bands, which are sensitive to chlorophyll stress, have detected subtle degradation that Landsat’s coarser resolution misses [13]. To contextualize the evolution of assessment techniques, we compared three methodological approaches and depicted them in Table 1.

Table 1. Comparison of methodological approaches applicable to urban mangrove health assessment.

Parameter	Traditional field survey	Remote sensing (spectral)	Machine learning / deep learning
Spatial coverage	1–5 ha/day	10,000+ ha per acquisition	10,000+ ha (near real-time)
Temporal frequency	Quarterly to annual	Weekly to monthly	Near real-time once deployed
Accuracy	Very high (ground truth)	Variable; NDVI is a proxy	Up to 90% (U-Net); training data dependent
Cost & resources	High; labour-intensive	Low-moderate; archive data free	High initial; low recurring
Data output	Height, DBH, species density	NDVI, EVI, SAVI, GNDVI	Classified maps, predictions
Best application	Ground-truth, species-level calibration	Regional change detection, phenology	Automated large-scale mapping
Limitation	Not scalable; cannot detect broad spatial patterns	Cannot resolve sub-pixel fragmentation	Requires labelled training data; risk of overfitting

Abbreviations: NDVI = Normalized Difference Vegetation Index, EVI = Enhanced Vegetation Index, SAVI = Soil-Adjusted Vegetation Index, GNDVI = Green Normalized Difference Vegetation Index, and DBH = Diameter at Breast Height.

Health trends in urban mangrove patches

The Mumbai mangroves showcase what urban ecosystem management lacks: a belt that has been simultaneously degraded and more recently, targeted for conservation (Figure 3). Leaf proline metabolite levels in *R. mucronata* at Carter Road (Bandra) reveal stress and productivity gradients within a single mangrove patch, providing evidence that health varies at a sub-kilometre scale even within one urban stand [14]. Thane Creek has also seen a teak defoliator (*Hyblaea puer*) outbreak that defoliated mangrove strands, weakening both canopy resilience and carbon sequestration capacity [15]. Coastal road construction adds a third, on-going pressure, clearing mangrove cover directly and fragmenting it indirectly through altered tidal flow and sediment deposition.

3. Future directions for mangrove health assessment

Combining remote sensing, GIS, and machine learning on cloud platforms is producing results that field-based methods alone cannot match in speed. Kanjin and Alam [16] tracked forest degradation across multiple years in the Sundarban Biosphere Reserve using Google Earth Engine with Sentinel-1/Sentinel-2 data and deep learning models, generating maps in hours rather than months manual analysis would take. For a fragmented, fast-changing system like the mangroves at Mumbai, that speed matters; whether it translates into faster policy response is a separate question this literature has not yet answered for Mumbai specifically. Speed alone does not solve the ground-truthing problem. The Mumbai mangrove and non-mangrove boundaries are blurred by mixed land cover in a way that satellite classification struggles with on its own, so local ground-truth data analysis stays essential. Community-based monitoring, pairing local ecological knowledge with satellite data, has worked in regions where field access is restricted by encroachment or political barriers [17].



Figure 3. A view of *Avicennia marina* patches in the intertidal region along the Mumbai coast near Bandra. (Photo credit: Captured by the authors)

4. Conclusion

No single ‘mangrove health index’ has global acceptance. For Mumbai's fragmented patches of mangroves, a fusion-based index, integrating structural integrity, functional vigour, and environmental stress, would capture dimensions that a single spectral index, such as NDVI, misses on its own. Such a metric could also feed into UN SDG Target 14.2, on sustainable management and restoration of marine and coastal ecosystems, by giving Mumbai a standardized, comparable measure of mangrove condition over time.

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6. References

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