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Temporal dynamics of land loss in Ghoramara island, Sundarban: A moving average approach

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Abstract

Ghoramara Island, situated in the Hooghly estuary of the Bay of Bengal within the Sundarban delta, represents one of the most acutely threatened coastal landmasses in India. Once spanning approximately 18.54 km² in 1954, the island has experienced severe and accelerating erosion, shrinking to a mere 2.71 km² in recent years. This paper presents a quantitative trend analysis of the island's land area reduction over the period 1970-2020 using two classical time-series smoothing techniques: the Simple Moving Average (SMA) and the Exponential Moving Average (EMA). Observational area data for 14 time points spanning five decades were obtained from published satellite imagery and remote sensing studies. SMA with a window size of 3 was applied to capture the long-term trend, while EMA with a span of 3 was used to emphasize the rate of recent area loss. Both methods confirm a consistent and accelerating. The EMA, being more sensitive to recent observations, reveals a sharp downward trajectory in the final years of the study period, which is not fully captured by the SMA. These findings underscore the urgency of policy intervention for conservation, relocation, and climate adaptation for the island's remaining population. The methodology demonstrated here offers a simple yet mathematically sound framework applicable to other vulnerable coastal and island ecosystems.

Keywords: Ghoramara Island, Sundarban, climate change, coastal erosion, simple moving average, exponential moving average, land area reduction, sea-level rise

1. Introduction

The Sundarban delta, shared between India and Bangladesh, constitutes the world's largest mangrove ecosystem and is home to millions of people living in close proximity to the Bay of Bengal. Within this delta, a number of low-lying islands are experiencing rapid land loss due to the combined effects of global warming, sea-level rise, coastal erosion, and tidal inundation. Among these, Ghoramara Island stands out as a particularly dramatic case, having lost more than 85% of its total land area over the past seven decades.

Ghoramara is located in the Hooghly estuary, approximately 150 km south of Kolkata (approximately 21.74°N, 88.15°E). The island was once a thriving agricultural community with an estimated area of 18.54 km² in 1954. Successive decades of erosion, driven by rising sea levels, increased cyclone frequency, and the loss of protective mangrove buffer zones, have reduced the island to approximately 2.71 km². This catastrophic reduction has led to large-scale displacement of the island's population and loss of agricultural land, freshwater sources, and biodiversity.

The quantification and trend analysis of such land loss is important for several reasons. First, it provides a scientific basis for policy decisions regarding relocation and conservation. Second, it enables the identification of periods of accelerated erosion. Third, it helps in projecting future trajectories of land loss under continued climate change scenarios. While remote sensing and GIS-based studies have documented the extent of erosion ^[1, 2], the application of mathematical trend-smoothing tools from time-series analysis to this ecological problem remains relatively unexplored.

Moving averages are widely used in fields such as financial analysis, signal processing, and meteorology to reduce noise in time-series data and reveal underlying trends ^[3].

In this paper, we apply two variants — the Simple Moving Average (SMA) and the Exponential Moving Average (EMA) — to the observed yearly land area data of Ghoramara Island [4]. The SMA treats all past observations within a window equally, while the EMA assigns exponentially decreasing weights to older observations, making it more responsive to recent changes. The comparative application of both methods provides a richer picture of both the long-term trend and the accelerating recent trajectory of land loss.

2. Study Area

Ghoramara Island is a tidal island located in the Sagar block of South 24 Parganas district, West Bengal, India. It lies at the confluence of the Hooghly and Muriganga rivers before they drain into the Bay of Bengal. The island is classified as part of the active delta region of the Sundarban, which is characterized by dynamic sediment transport, high tidal ranges (up to 5 metres), and frequent cyclonic storms.

The island's geology is dominated by unconsolidated alluvial and deltaic sediments, making it highly susceptible to erosion. The combination of soft sediment, low elevation (mostly less than 1 metre above mean sea level), strong tidal currents, and the relative sea-level rise of approximately 3.14 mm per year recorded in the region [5] creates conditions of extreme vulnerability. Satellite imagery-based studies have documented the erosion of the island's periphery, the

disappearance of previously inhabited villages, and the submergence of agricultural tracts.

The island supports — or has supported — paddy cultivation, fishing, and small-scale agriculture. The population, estimated at around 40, 000 in the 1970s, has declined dramatically as residents have been forced to relocate to nearby Sagar Island and the mainland due to the loss of habitable land. Ghoramara [6] thus serves as a living example of climate-induced displacement and a sentinel site for the impacts of sea-level rise on low-lying deltaic islands.

3. Data

The land area data used in this study were compiled from published remote sensing studies, satellite imagery analyses, and government survey reports. A total of 14 observations spanning the period from 1970 to 2020 were available. The data points are unevenly spaced in time, with gaps ranging from 1 year (e.g., 1989 to 1990, 2000 to 2001) to 10 years (e.g., 1979 to 1989, 1990 to 2000). This irregular spacing is a natural consequence of the availability of satellite imagery and survey data and is acknowledged as a limitation of the dataset.

The observed land area values are presented in Table 1. The data show a clear and consistent downward trend over the five-decade study period, with the total area declining from 9.09 km² in 1970 to 2.88 km² in 2020, representing a loss of approximately 68.3% of the 1970 land area within 50 years.

Table 1: Observed area of Ghoramara Island with computed SMA and EMA values

Year	Observed Area (km ²)	SMA (window=3)	EMA (span=3)
1970	9.09	—	9.09
1972	8.59	—	8.84
1975	8.51	8.73	8.68
1979	7.83	8.31	8.25
1989	6.36	7.57	7.31
1990	5.99	6.73	6.65
2000	5.47	5.94	6.06
2001	5.11	5.52	5.58
2005	4.87	5.15	5.23
2010	4.81	4.93	5.02
2012	4.43	4.70	4.72
2015	4.23	4.49	4.48
2019	3.59	4.08	4.03
2020	2.88	3.57	3.46

Note: '—' indicates SMA not computed (insufficient prior observations).

4. Methodology

4.1 Simple Moving Average (SMA)

The Simple Moving Average is a widely used smoothing technique in time-series analysis. For a time series $\{A_1, A_2, \dots, A_n\}$, the SMA at time t with window size k is defined as:

$$\text{SMA}(t) = (1/k) \times \sum A_i \text{ for } i = t-k+1 \text{ to } t$$

In this formula, k denotes the window size, and A_i is the observed land area at the i -th data point. The SMA assigns equal weight to each observation within the window. In the present study, a window size of $k = 3$ was chosen. Since the dataset contains only 14 observations, a window of $k = 3$ is appropriate: it provides sufficient smoothing to reduce observation-to-observation variability while retaining enough data points in the smoothed series (12 valid values) for meaningful interpretation. It is important to note that since the data are unevenly spaced in time, the moving average is computed over observation indices rather than calendar years. This is an acknowledged limitation, and the SMA values

should be interpreted as trend estimates over successive groups of three observations rather than fixed time intervals.

4.2 Exponential Moving Average (EMA)

The Exponential Moving Average differs from the SMA [7] in that it assigns exponentially decreasing weights to older observations, making it more responsive to recent changes in the time series. The EMA is computed recursively as:

$$\text{EMA}(t) = \alpha \times A(t) + (1 - \alpha) \times \text{EMA}(t-1)$$

where $\alpha = 2 / (\text{span} + 1)$ is the smoothing factor, and span is an analogue of the window size. For span = 3, we have $\alpha = 0.5$, meaning each new observation is weighted equally with the accumulated history. The first EMA value is initialized to the first observation (A_1). In this study, a span of 3 was used, consistent with the SMA window size, to allow a direct comparison between the two methods. The EMA is computed for all 14 data points. Since all data points are included (unlike SMA, which loses the first $k-1$ points), the EMA

provides a more complete picture of the trend, particularly at the beginning of the series.

4.3 Comparative Framework

The two methods are applied in parallel and their outputs compared to extract complementary insights. The SMA captures the broad, long-term trend by treating recent and past observations equally within the window. The EMA captures the current momentum of area loss by upweighting recent observations. A divergence between SMA and EMA at the end of the series — specifically, EMA falling below SMA — indicates that the rate of area loss is accelerating beyond the long-term average. This divergence is a key diagnostic of the study.

5. Results and Discussion

5.1 Observed Trend

The raw data (Table 1, Figure 1 top-left) reveal a monotonically decreasing trend in the land area of Ghoramara Island over the entire study period. The area declined from 9.09 km² in 1970 to 2.88 km² in 2020, a total reduction of 6.21 km² (68.3%) over 50 years. The rate of decline was not uniform, however. During the decade 1979-1989, the area dropped by 1.47 km² (approximately 0.147 km²/year), reflecting a period of intensified erosion. The period 2019-2020 shows a particularly sharp single-year drop of 0.71 km², which may reflect the impact of a specific cyclonic or tidal event in addition to the background erosion trend.

5.2 SMA Analysis

The SMA series (Figure 1, top-right) smooths out the observation-to-observation variability and confirms the long-term downward trend. The SMA^[8] values decline steadily from 8.73 km² (centered on 1975) to 3.57 km² (centered on 2020). The SMA curve closely tracks the observed data throughout most of the series but lags slightly at the end, where it does not fully capture the sharp decline observed in

2020. This lag is an inherent property of the SMA: because it weights all observations equally, it is slower to respond to sudden changes at the end of the series.

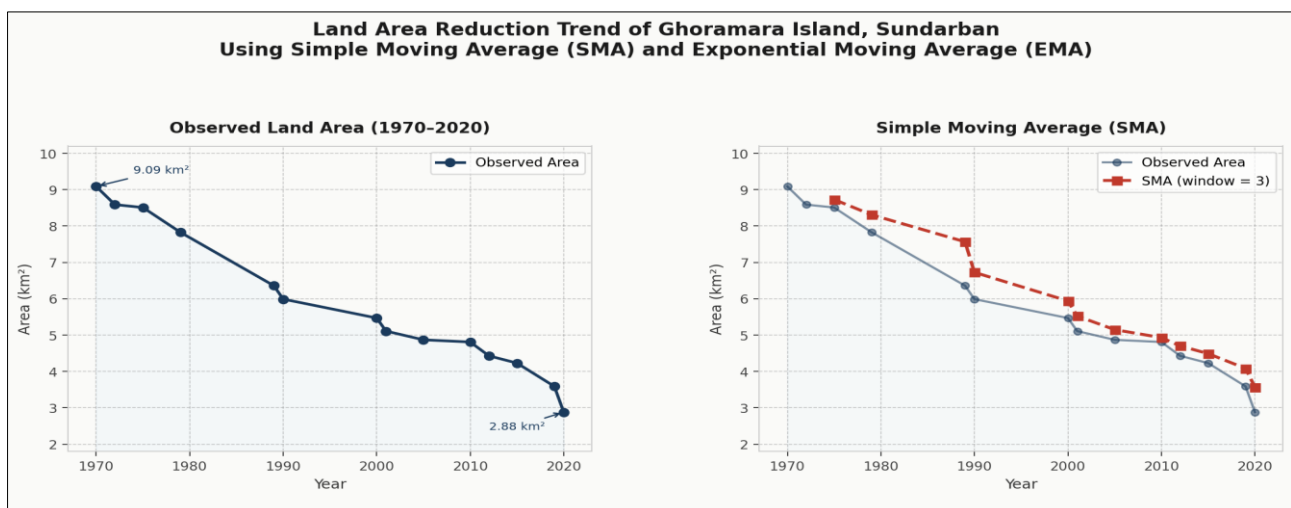
5.3 EMA Analysis

The EMA series (Figure 1, bottom-left) provides a more nuanced picture of the trend. Due to the exponential weighting scheme ($\alpha = 0.5$), the EMA responds more quickly to recent observations. The EMA values follow a similar downward trajectory to the SMA but diverge noticeably in the final years of the study. By 2020, the EMA has fallen to 3.46 km², compared to 3.57 km² for the SMA. This difference, while numerically modest, is significant in that it indicates the EMA recognizes the acceleration of recent erosion that the SMA tends to understate. The EMA also has the advantage of being defined for all 14 data points, including the earliest observations, unlike the SMA which is undefined for the first two points.

5.4 Comparative Interpretation

The combined plot (Figure 1, bottom-right) reveals the most important finding of this study: in the later part of the time series (2015-2020), the EMA falls below the SMA. This divergence is a diagnostic indicator that the recent rate of area loss is faster than the long-term average captured by the SMA. In the context of Ghoramara Island, this finding is environmentally significant: it suggests that the erosion process is not merely continuing at a steady rate but is, in fact, accelerating in the most recent period.

This acceleration is consistent with broader observations of increasing cyclone intensity in the Bay of Bengal which accelerates global sea-level rise^[8, 9] and the progressive loss of protective mangrove cover that would otherwise buffer wave and tidal energy. The moving average analysis thus provides a mathematically^[10] grounded confirmation of what qualitative and remote-sensing studies have suggested.



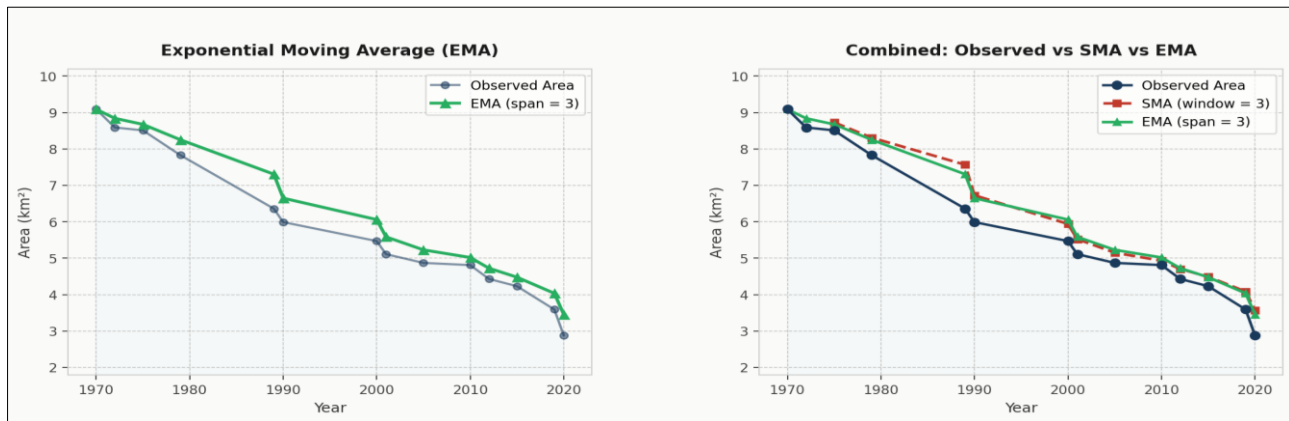


Fig 1: Land area reduction trend of Ghoramara Island using SMA and EMA (1970-2020). Top-left: observed data; Top-right: SMA overlay; Bottom-left: EMA overlay; Bottom-right: combined comparison

6. Conclusion

This study has applied Simple Moving Average and Exponential Moving Average analyses to the historical land area data of Ghoramara Island in the Sundarban delta. The key findings are as follows:

1. Ghoramara Island has lost approximately 68.3% of its 1970 land area (9.09 km² to 2.88 km²) over the fifty-year study period.
2. Both SMA and EMA confirm a monotonically decreasing trend in land area, providing quantitative support for findings from remote sensing studies.
3. The divergence of EMA below SMA in the 2015-2020 period indicates an acceleration of the erosion process in recent years, which is of particular concern for the island's remaining population and ecosystem.
4. The methodology is simple, transparent, and reproducible, and can be extended to other vulnerable coastal islands and deltaic landmasses globally.

The results of this study underscore the urgent need for coordinated governmental and scientific action to address the climate-driven disappearance of Ghoramara Island. Immediate measures needed include planned relocation assistance for the remaining population, construction of embankments and coastal protection structures, and large-scale mangrove restoration. The moving average framework presented here can serve as a monitoring tool, enabling periodic updates of the trend analysis as new satellite imagery and area measurements become available.

Future work may extend this analysis by incorporating interpolation to annual data to allow time-aware moving averages by fitting formal regression models to quantify the rate of area loss, and by integrating sea-level rise projections to forecast the island's expected lifespan under different climate scenarios.

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