

## MONITORING SOIL SALINITY DYNAMICS IN COASTAL BANGLADESH: A CASE STUDY OF HATIYA SUB-DISTRICT

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### Abstract

This study analyzed soil salinity dynamics in Hatiya Sub-district using Sentinel-2 imagery and Dynamic World land-cover data processed in Google Earth Engine. Cloud-masked seasonal composites, salinity indices and classification were generated in GEE and further refined in ArcGIS Pro. Post-classification comparison between 2018-19 and 2023-24 revealed a decline in low-salinity areas and substantial expansion of moderate salinity zones. The findings highlight accelerating salinity stress and provide essential baseline information for coastal land-management planning.

**Keywords:** Hatiya, Salinity, Coastal area, Sentinel-2, ArcGIS Pro

Bangladesh, situated on the world's largest delta, is highly vulnerable to salinity intrusion due to tidal dynamics, sea-level rise, and upstream freshwater reduction. The intrusion of salinity along the interior coast has been linked to broader issues of food security and population displacement. Studies indicate that significant portions of the coastal regions are already experiencing increased salinity, progressively affecting agricultural practices and crop yields (Khanom, 2016; Islam, 2021). Soils with an electrical conductivity (EC) greater than 4 dS/m are commonly classified as saline, which is essential since such levels can affect plant growth. It has been documented that the yield of many crop plants is significantly reduced when EC levels exceed 4 dS/m, as they encounter osmotic stress and ion toxicity, which hamper their physiological functions (Shrivastava & Kumar, 2015; Zarrougui *et al.*, 2022). So, salinity data are always vital for decision making in crop production in coastal lands. The use of satellite data, particularly from the Sentinel-2 mission, provides an effective and scalable approach for salinity mapping, complementing traditional field-based methods, which can be resource-intensive. Sentinel-2's multi-spectral bands from Dynamic World data enable the calculation of various vegetation indices that are indicative of soil conditions and plant health such as, Normalized Difference Vegetation Index (NDVI) and specific spectral bands responsive to vegetation stress, play a critical role in the early identification of salinity-related issues, allowing for the mapping of salinity "hotspots" that can be targeted for more intensive field surveys (Ghasemian Sorboni *et al.*, 2019; Imran *et al.*, 2021).

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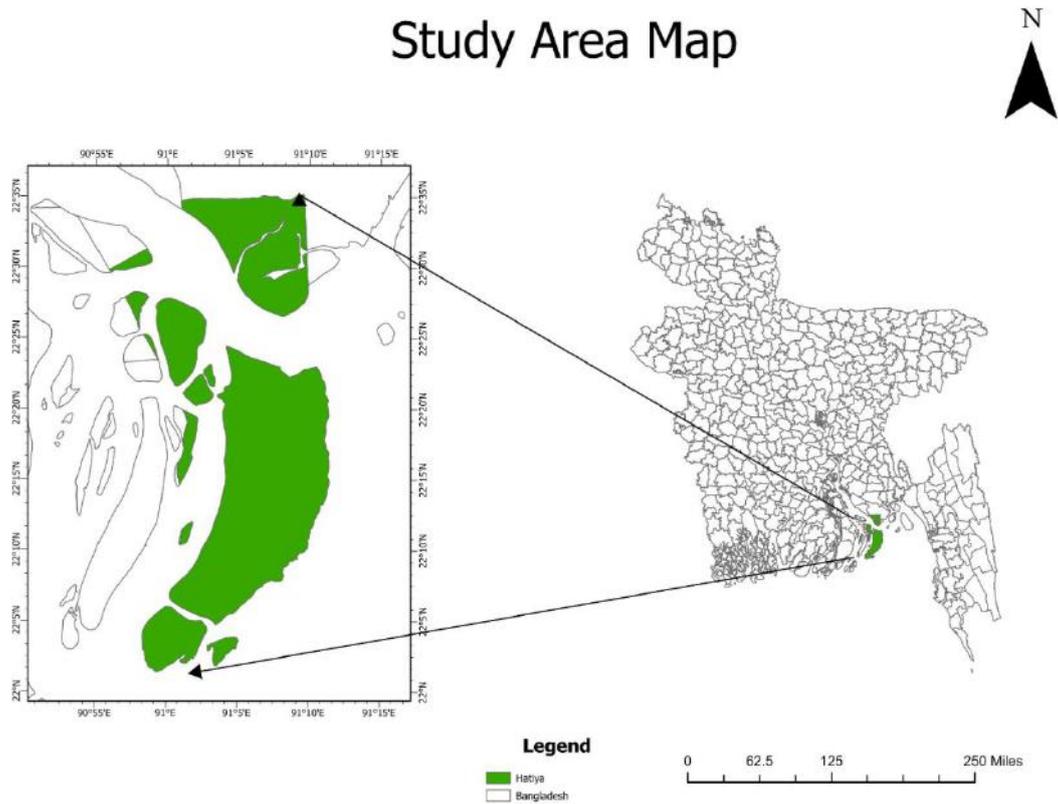
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Several studies have utilized GIS in Bangladesh, particularly in agriculture, soil mapping, and coastal dynamics but research on coastal salinity, specifically focused on Hatiya subdistrict remain limited. Hence, this study aims to assess temporal changes in salinity across Hatiya subdistrict during two dry-season periods, 2018-19 and 2023-24. Using Sentinel-2 satellite imagery and Dynamic World data processed in Google Earth Engine, salinity conditions can be derived through a spectral index and classified into water body, low, moderate, and high salinity zones. The objective of the study is to generate a salinity change detection map, which will indicate shifts from strong decreases to strong increases in salinity levels. This comparison helps identify spatial patterns and trends in salinity that threaten agricultural productivity.

### **Study area**

Hatiya sub-district of Noakhali district (22.6531° N, 90.9981° E) was selected as the study area for this due to its vulnerability to climate change and high exposure to natural disasters such as tidal surges resulting in salinity intrusion (Fig.1).



**Fig. 1. Map of the study area (Hatiya Sub-district, Bangladesh)**

### **Satellite data and processing**

Sentinel-2 Level-2A (surface reflectance) Dynamic World data during dry seasons of 2018-19 and 2023-24 were used in this research (Brown *et al.*, 2022). Pre-processing the data was done in Google Earth Engine, collections were filtered to the Hatiya subdistrict boundary, cloud-screened using Sentinel-2 Scene Classification (SCL) and cloud probability, and composited via the median to reduce residual clouds and glint.

From the imagery data the following were computed:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Where, NIR is the near-infrared band and Red is the red band from the satellite imagery,

The salinity proxy Index (SI) is defined as a remote sensing-based indicator that uses spectral reflectance or vegetation response to estimate the degree of soil or water salinity without direct ground-based electrical conductivity measurements. It can be measured by the following formula:

$$SI = \frac{Red - Green}{Red + Green}$$

Where, red and green band is used (Allbed & Kumar, 2013).

For classification, pixels were assigned as, 0 = Water/No-data; 1 = Low (SI<0); 2 = Moderate (0-0.1); 3 = High (SI>0.1). These thresholds are relative and do not equal ECe; they were intended and normalized for relative spatial comparison and across years.

To analyze the temporal change in salinity, post-classification comparison was performed using salinity class maps from two time periods as given below:

Class 1: Salinity class from 2018/19

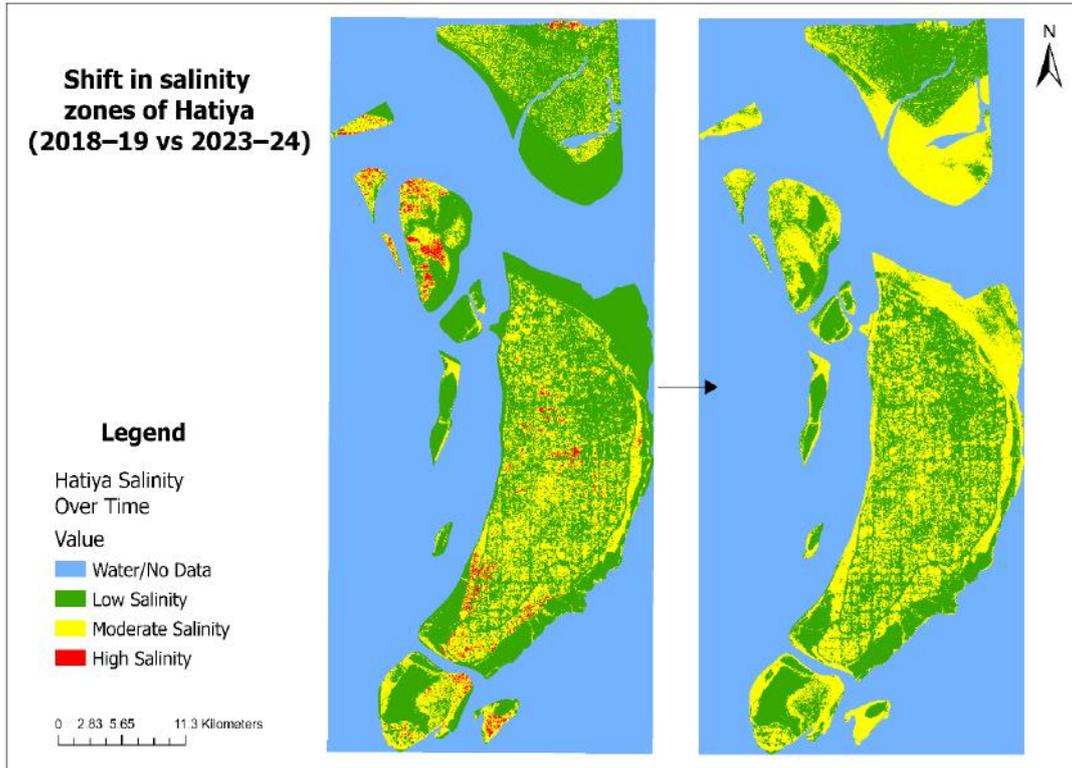
Class 2: Salinity class from 2023/24

$$\Delta Class = Class\ 2023/24 - Class\ 2018/19 = [-2, -1, 0, +1, +2]$$

These values represent the magnitude of change in salinity levels over the study period. Specifically, a value of -2 indicates a strong decrease in salinity, while -1 represents a moderate decrease. A value of 0 signifies no change in salinity between the two periods. Conversely, +1 denotes a moderate increase, and +2 indicates a strong increase in salinity (Dehni & Lounis, 2012).

To get the area statistics, pixel area at 10 m was summed per class to report hectares for each period and net changes (ha and %). Results were exported as CSV tables and GeoTIFF images, with visualizations using custom palettes in Google Earth Engine and further modified in ArcGIS Pro.

The 2018–19 map showed moderately saline zones were distributed primarily in low saline zones (Fig.2). The outskirts had mostly low salinity, while 2023–24 exhibited a visible expansion of moderate class in the peripheral and central zones of Hatiya which previously fell under low saline class (Fig. 2).



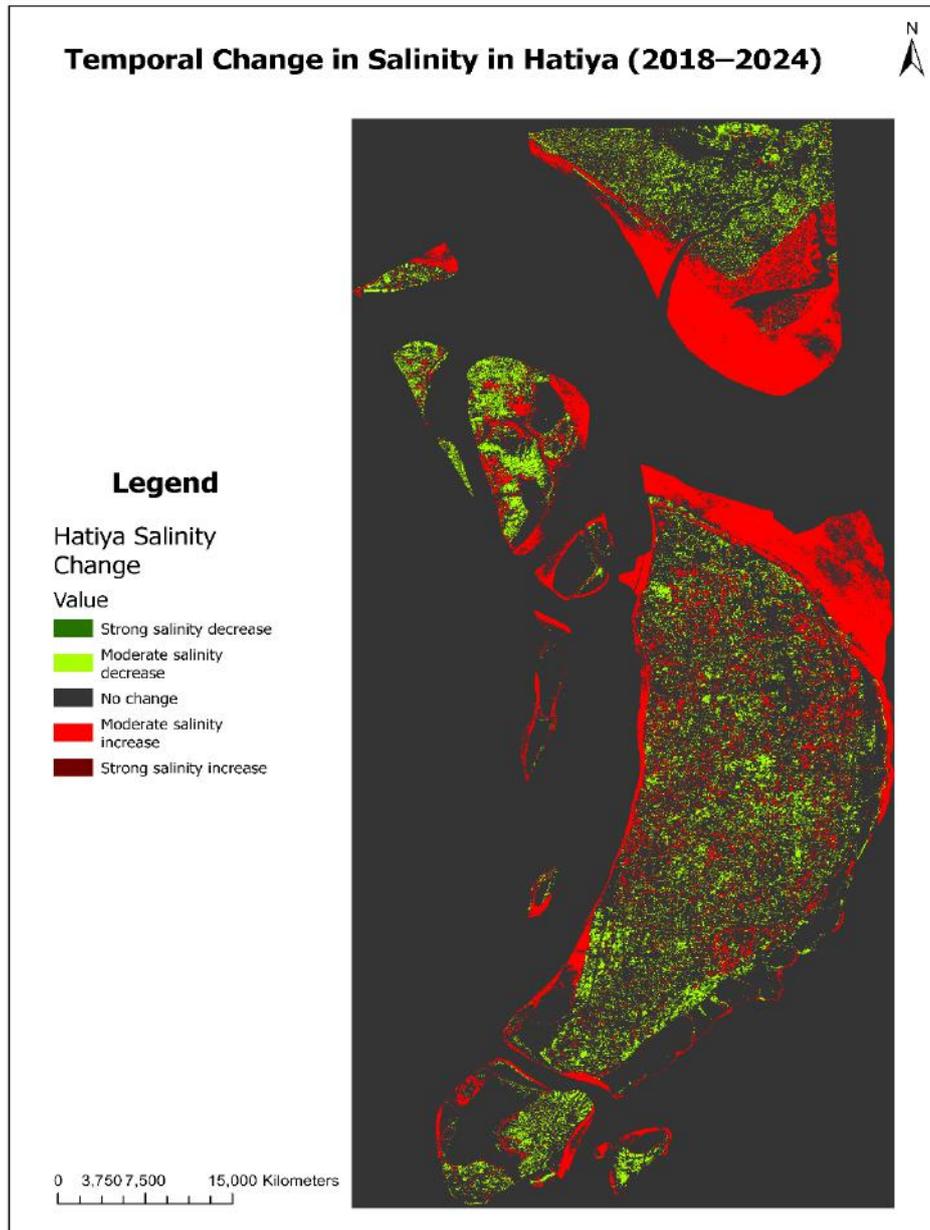
**Fig.2.** Comparison of soil salinity maps of 2018-19 (on the left) and 2023-24 (on the right)

The area change table clearly state temporal changes per class in hectares for both periods and net change. There was significant decline in low saline area as the percent change was -21.63% from 2018-19 to 2023-24 (Table.1). Meanwhile, moderate saline area increased over time having a 52.54% change till 2024. Conversely, high saline zones drastically reduced, with a change of 99.64%.

**Table.1.** Changes in saline area over time in Hatiya (2018-19 to 2023-24)

Salinity Class	Area in 2018-19 (ha)	Area in 2023-24 (ha)	Change (ha)	Change (%)
Low	43183.57	33841.1	-9342.48	-21.6343
Moderate	21242.11	32401.73	11159.62	52.53539
High	1816.885	6.594454	-1810.29	-99.637

There's a clear shift from low to moderate salinity, indicating worsening salinity conditions overall (Fig. 3). It is clear from the Fig. 3 that even though moderate salinity decrease in particular regions of Hatiya is evident, the increase clearly outweighs the mere decline.



**Fig. 3. Temporal change in salinity in Hatiya (2018-2024)**

The gradual increase in zones with moderately salinity is an evident indication of impact of climate change on coastal areas and soil degradation due to calamities and not taking soil health under serious consideration. Lots of studies corroborate with this result how seasonal changes, particularly between wet and dry seasons, influence salinity dynamics. This was supported by Wang *et al.*, 2025 as they reported that farmer practices during the wet season can exacerbate salinization due to irrigation, which is compounded by natural rainfall patterns. The decreasing levels of high saline zones can be linked to changes in precipitation patterns. Hossain & Li, 2024 indicate that as much as 53% of the coastal region is currently subject to varying degrees of salinization, which aligns with the claim of diminishing high saline areas contrasted against an increase in moderate salinity levels.

As saline area increases by natural causes, crop production decreases; subsequently, this results in more areas coming under saline influence due to lack of agricultural activities. Similar findings were reported by Dasgupta *et al.*, 2018; Jahan *et al.*, 2023 as they stated crops like rice and others face reduced productivity during the dry season due to increased salinity levels.

The temporal change graph suggests an expansion of salinity stress, even if severe cases have reduced. Several studies establish the efficacy of the Salinity Index in relation to soil salinity mapping using remote sensing techniques. Asfaw *et al.*, 2018 highlight the significant correlation between SI and EC, demonstrating its effectiveness in identifying salt-affected areas when compared to individual spectral bands. The work of Golabkesh *et al.*, 2021 further substantiates this claim, revealing that SI exhibited high interpretation coefficients in predicting soil salinity and he found similar trends of salinity change over time. Such findings underscore the importance of SI as a reliable measure in salinity assessments.

Now, selecting SI as research method can be brought under question as other advanced indices for salinity measurement like Short-Wave Infrared (SWIR) are there. But this approach rapidly spots where salinity conditions likely worsened, guiding where to send field teams for EC sampling, rather than replacing ground truth. Recent studies emphasize Sentinel-2's spatial resolution advantages over traditional platforms. For instance, Yan *et al.*, 2022 highlight that the higher spatial resolution of Sentinel-2 (10 m) allows for finer distinctions among salinity levels, facilitating the rapid calculation of salinity indices.

The red–green index is simple and reproducible, but SWIR-based salinity indices often perform better. Researchers like Nguyen *et al.*, 2020 and many more have recommended the Vegetation Soil Salinity Index (VSSI) and Normalized Difference Salinity Index (NDSI) as they yield better predictive outcomes compared to conventional indices like NDVI and SI.

Salinity mapping is most reliable on bare soil and masking dense vegetation can reduce confounding. The findings of AbdelRahman *et al.*, 2022 indicate that the spectral characteristics associated with saline soils can be obscured by vegetation effects, which may be mitigated through the strategic exclusion based on NDVI thresholds.

The results from this study can serve as a milestone for initiating rapid salinity mitigation measures in Hatiya subdistrict and for commencing further advanced studies.

This study demonstrated how satellite-based monitoring using Sentinel-2 imagery, Dynamic World data, and geospatial analysis in Google Earth Engine and ArcGIS Pro can effectively give insights on soil salinity dynamics in coastal environments. The results revealed a marked decline in low saline zones and a substantial expansion of moderately saline areas between 2018-19 and 2023-24, indicating a gradual but concerning intensification of salinity stress in Hatiya. The analysis revealed the dynamic nature of salinity patterns in the region and how climate and land use changes affecting it. Such spatial and temporal insights are crucial for identifying vulnerable areas, guiding resource allocation, and supporting sustainable land and water management strategies.

### **Data and Code Availability**

Sentinel-2 L2A imagery from Dynamic World data (Google Earth Engine). AOI: Hatiya boundary (feature collection asset). Processing scripts and export parameters are available upon request.

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