

Evaluation of different spectral indices for assessment ecological conditions of *Harike Wetland* (Ramsar Site) using Remote Sensing and Geospatial Technique

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Abstract: This study conducted a geospatial assessment of the Harike Wetland, Punjab, using multispectral (Landsat-8) and hyperspectral (PRISMA) satellite imagery to examine its ecological structure and water dynamics. Six spectral indices - NDVI, NDAVI, NDWI, MNDWI, FAI, and ABDI - were applied to map vegetation, aquatic vegetation, surface water, and algal bloom distribution through threshold-based classification. NDVI and NDAVI effectively captured vegetative cover, whereas NDWI and MNDWI refined water feature detection. Additionally, Z-spectral analysis was performed to compare the reflectance behaviour of algae, agricultural land, open water, and built-up areas, enhancing discrimination based on spectral curvature and shape. This hyperspectral approach improved classification accuracy in spectrally mixed zones. Overall, integrating index-based mapping with spectral profiling demonstrated the combined strength of multispectral and hyperspectral data in wetland monitoring, providing valuable insights for ecological assessment and sustainable management of dynamic wetland ecosystems.

Keywords:

1. Introduction

Harike Wetland, the largest in northern India, lies at the confluence of the Beas and Sutlej rivers and covers about 70% of its area with floating vegetation. It supports flood control, groundwater recharge, and natural pollutant filtration but faces severe degradation from urbanization, agricultural runoff, and industrial waste (Jindal and Sharma, 2011; Moza and Mishra, 2008). Invasive species like water hyacinth, algal blooms, and sedimentation have disrupted its hydrology and ecology (Gopal et al., 1987; Sood et al., 2012; WWF-India, 2013; Dudgeon et al., 2006). This study uses remote sensing and geospatial tools to assess the wetland's ecological condition and support sustainable management of this Ramsar site.

2. Study Area

Punjab, located in northwest India, Harike wetland designated as Ramsar site in 1990, is ecologically, hydrologically, and socio-economically significant. It supports over 200 bird species, including migratory ones such as the Bar-headed Goose and Eurasian Wigeon. Rich in biodiversity, the wetland hosts diverse flora and fauna with abundant floating and submerged aquatic vegetation, making it vital for regional conservation.

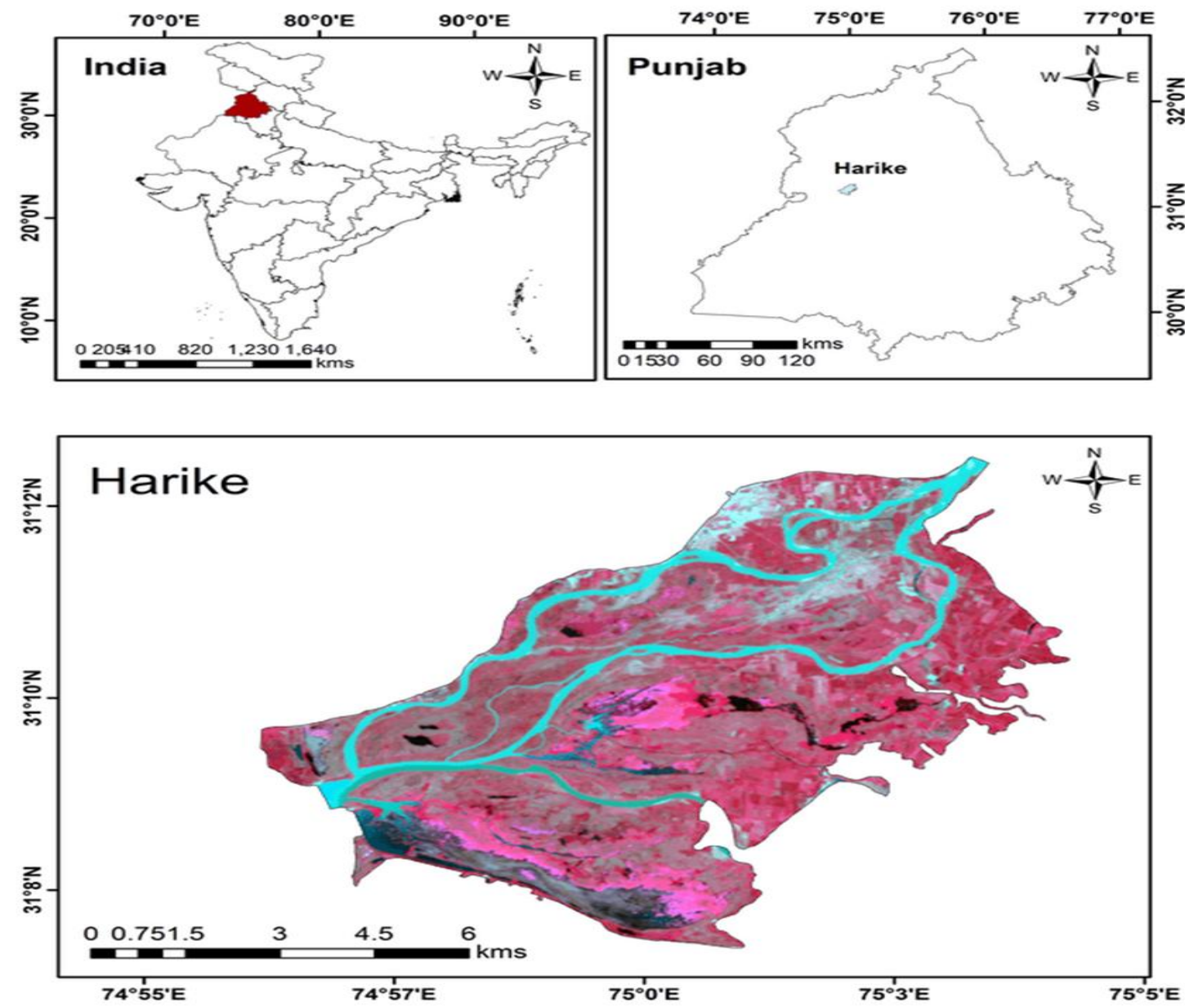
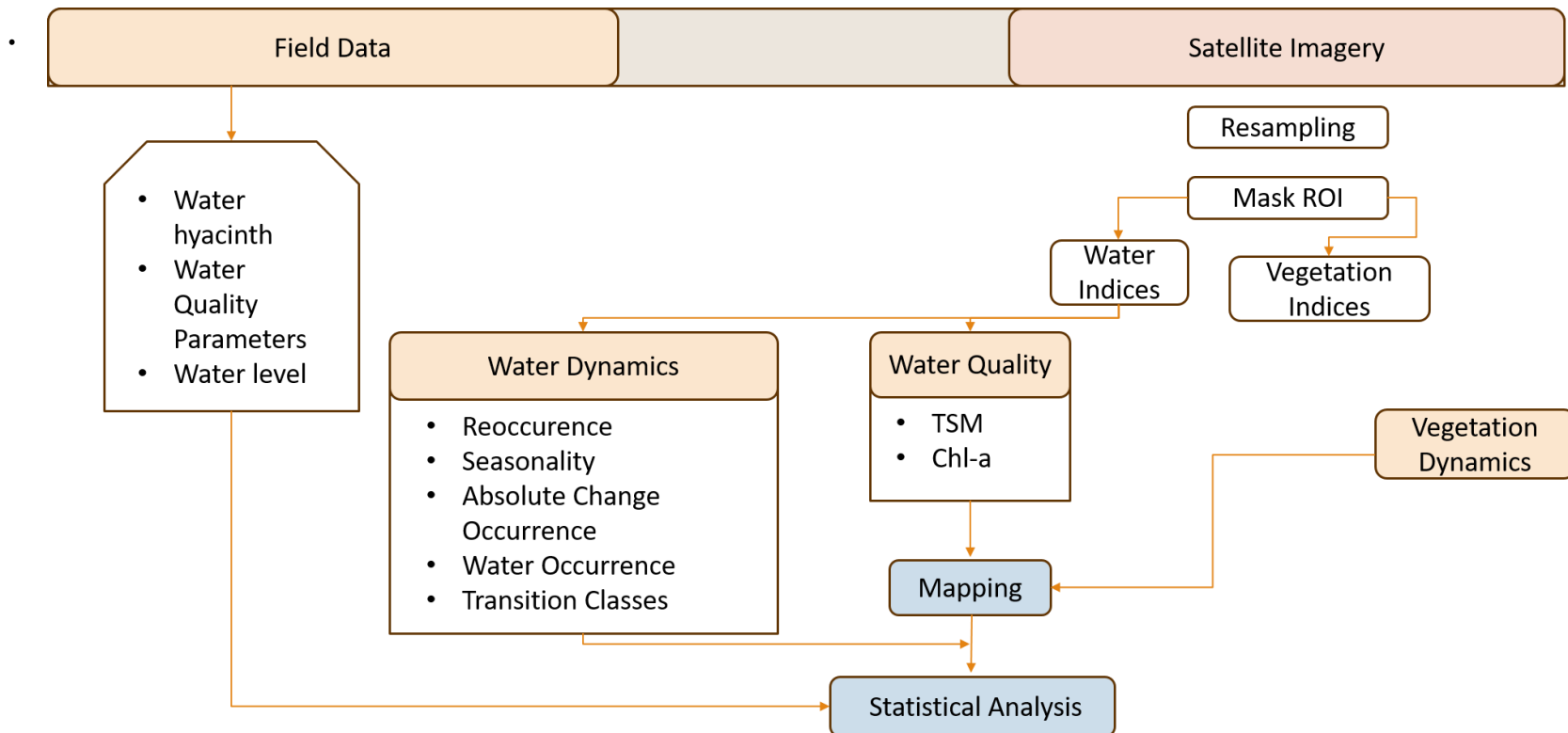
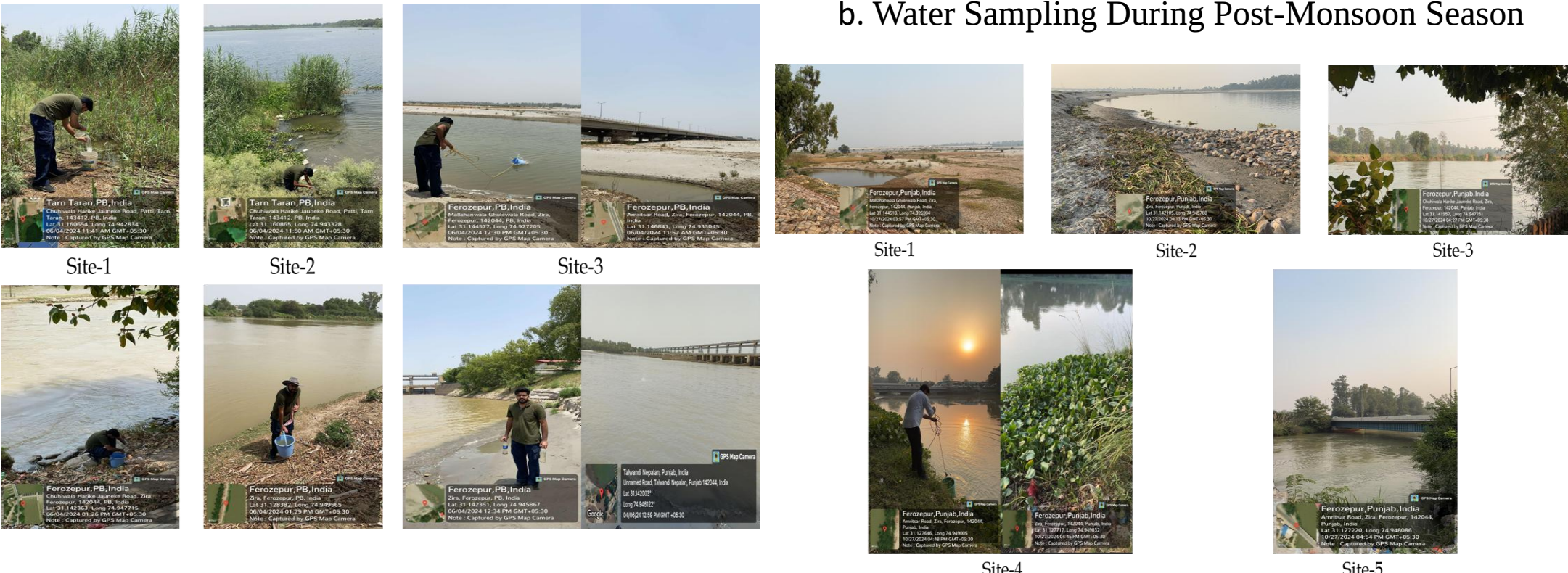


Figure 1: The location of study area overlaying a False Color Composite (FCC)

3. Materials and Methodology



3.1. Field Data Collection:



a. Water Sampling During Pre-Monsoon Season

Figure 2: Ground truth data for (a) During Pre-Monsoon (b) During Post-Monsoon

4. Results and Discussion:

Z-Spectral Profile Interpretation

Z-spectral analysis of PRISMA hyperspectral imagery revealed distinct spectral signatures for major land cover types in Harike Wetland. Vegetation showed a sharp red-edge rise and strong NIR peak (700–900 nm), indicating active photosynthesis, while algae exhibited moderate green-red reflectance with suppressed NIR due to water absorption. Water bodies maintained low reflectance across all bands with a slight blue-green bump (~500 nm) and deep NIR dip, whereas built-up areas displayed relatively uniform reflectance with a mild increase in the SWIR region from materials like concrete and asphalt.

(i) Index-Based Spatial Analysis

Six spectral indices - NDVI, NDAVI, NDWI, MNDWI, FAI, and ABDI - were applied to enhance detection of vegetation, water, and algal features in Harike Wetland (Figure 4 a,b,c,d,e,f). NDVI delineated terrestrial vegetation, while NDAVI sensitively captured aquatic vegetation and algal zones. NDWI and MNDWI effectively identified open water, with MNDWI improving detection in turbid areas. Together, these indices provided a comprehensive view of the wetland's ecological structure, and the resulting maps revealed clear spatial variation across vegetation, water, and algal cover.

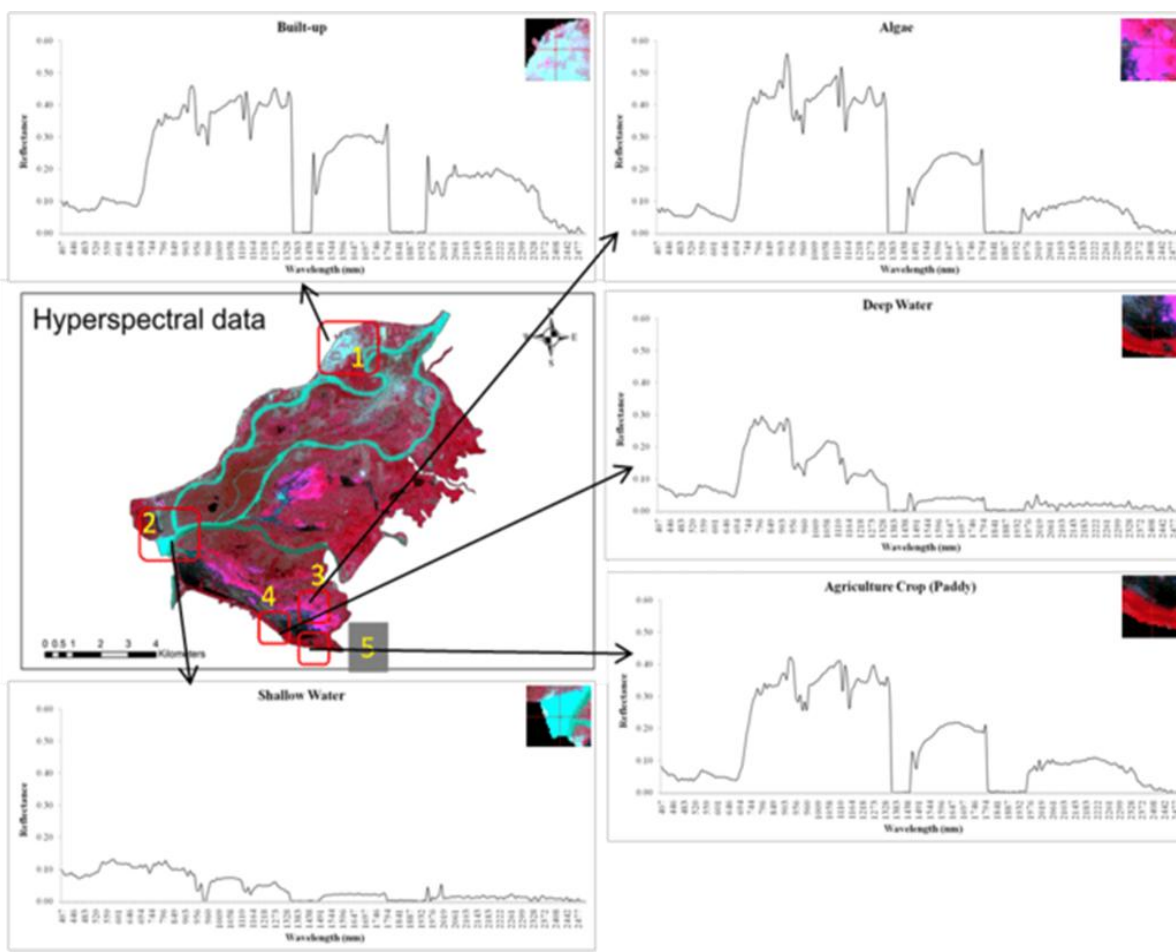


Figure 3: Z-Spectral Profile Interpretation.

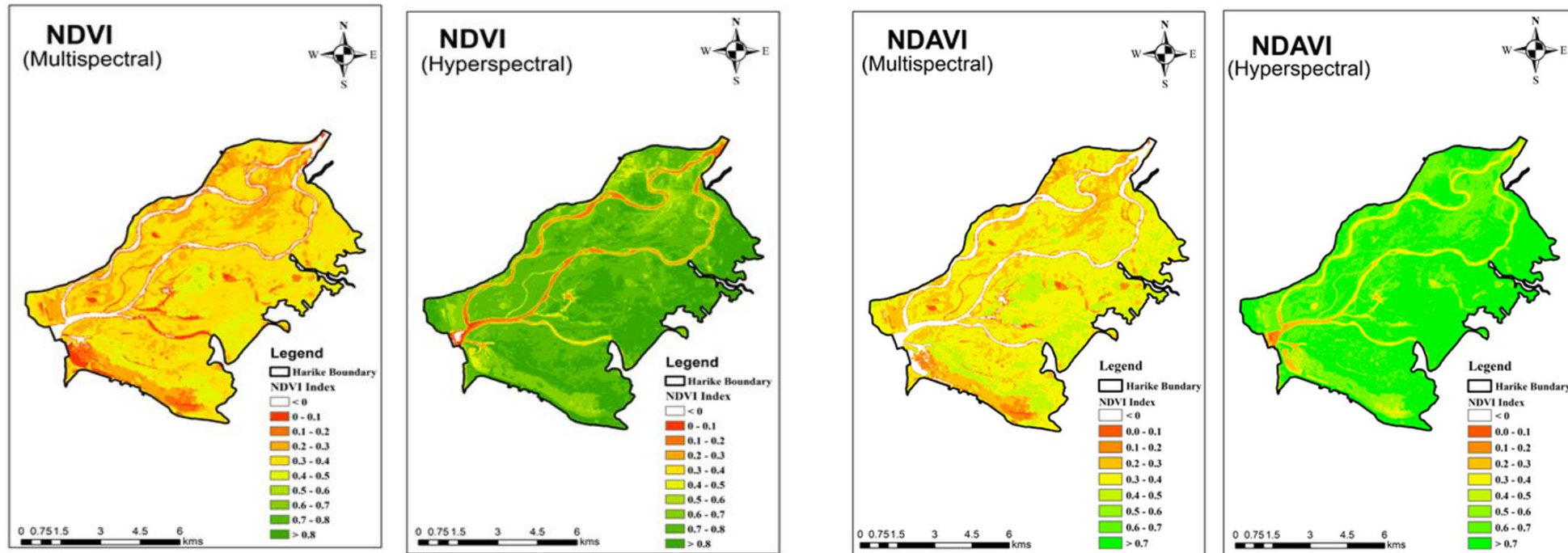


Figure 4a: Satellite derived vegetation index.

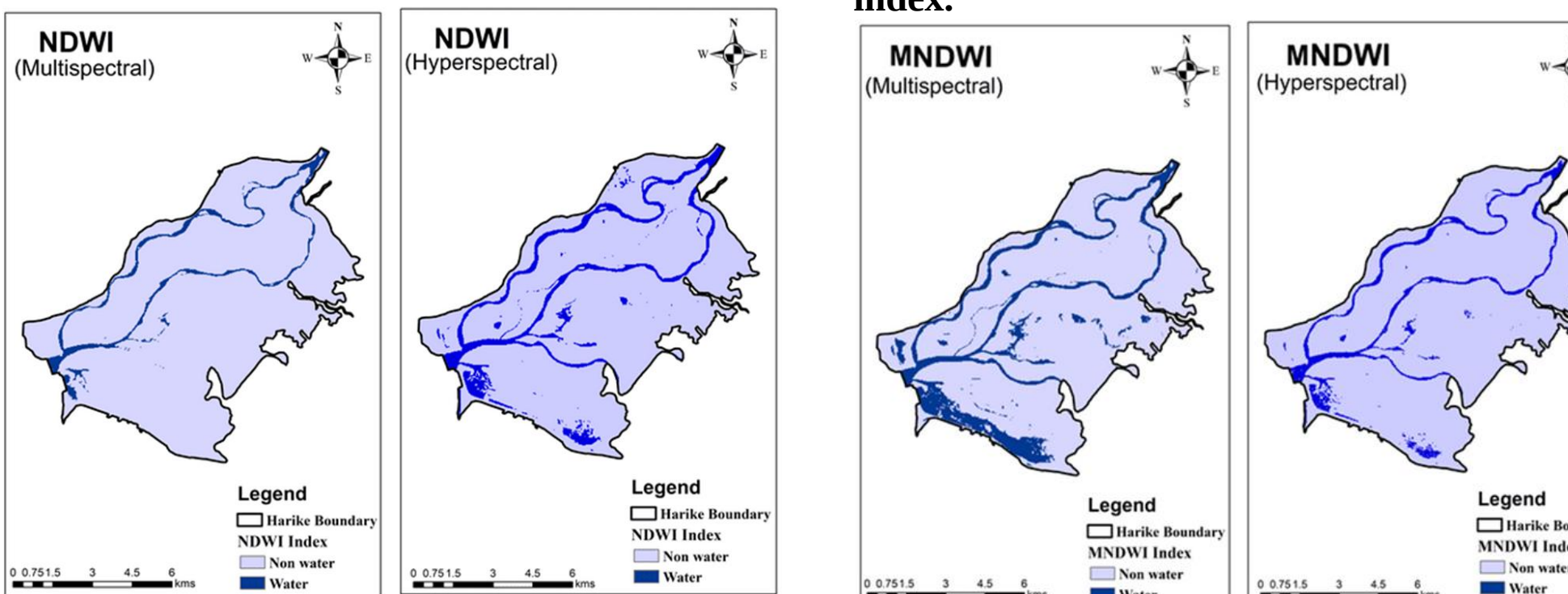


Figure 4c: Satellite derived water index

b. Water Sampling During Post-Monsoon Season

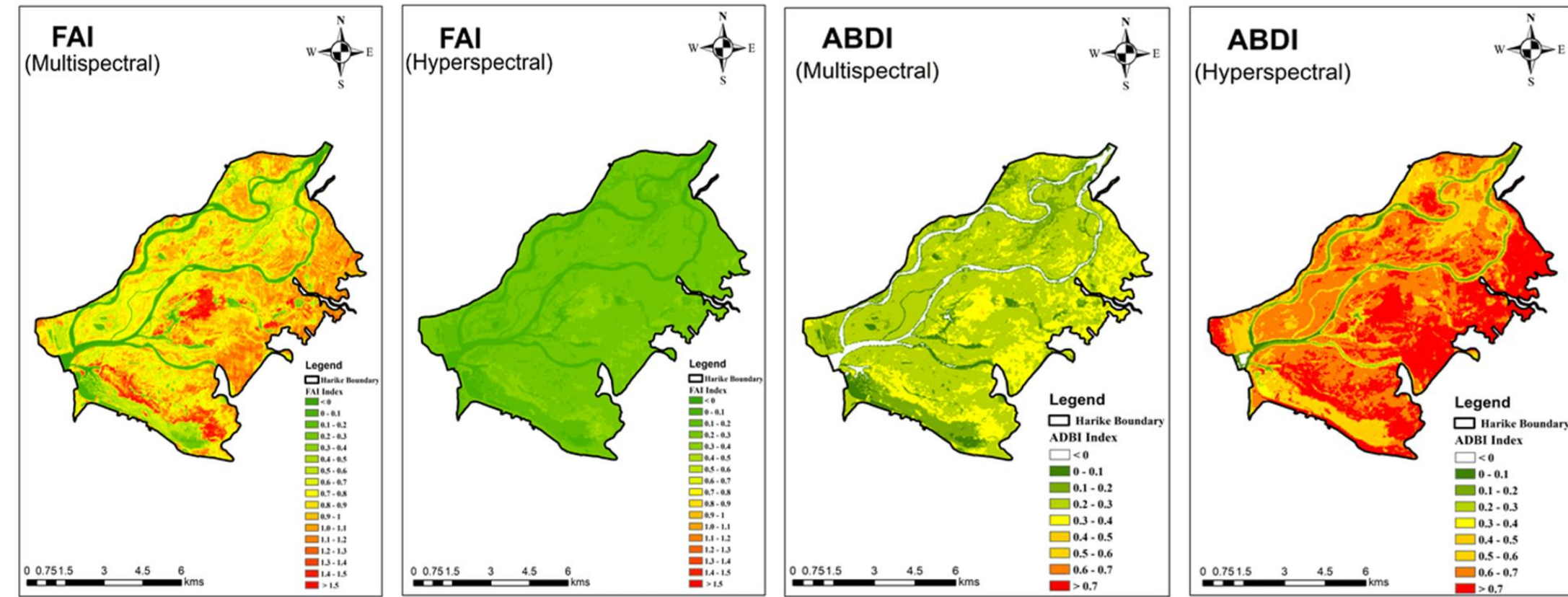


Figure 4e: Satellite derived floating algal index.

Figure 4f: Satellite derived floating algal bloom detection index.

(ii) Surface Water Dynamics

Water Occurrence Map shows frequency of water detection - *Always Water* (Blue/Violet) indicates permanent bodies, while *Sometimes Water* (Yellow/Green) marks seasonal or flood-driven areas. **Absolute Change Map** depicts net shifts in water extent - Blue/Purple for increase (expansion or retention) and Orange/Red for decrease. **Water Recurrence Map** shows consistency of water over years - high (Purple/Blue) for stable, low (Yellow/Orange) for irregular presence. **Seasonality Map** displays intra-annual variation - high (Red/Yellow) for seasonal, low (Blue/Purple) for perennial water. **Transition Class Map** identifies changes: *Permanent*, *New/Lost Permanent*, *Seasonal*, *New/Lost Seasonal*, *Seasonal Permanent*, and *Ephemeral* (irregular after extreme events).

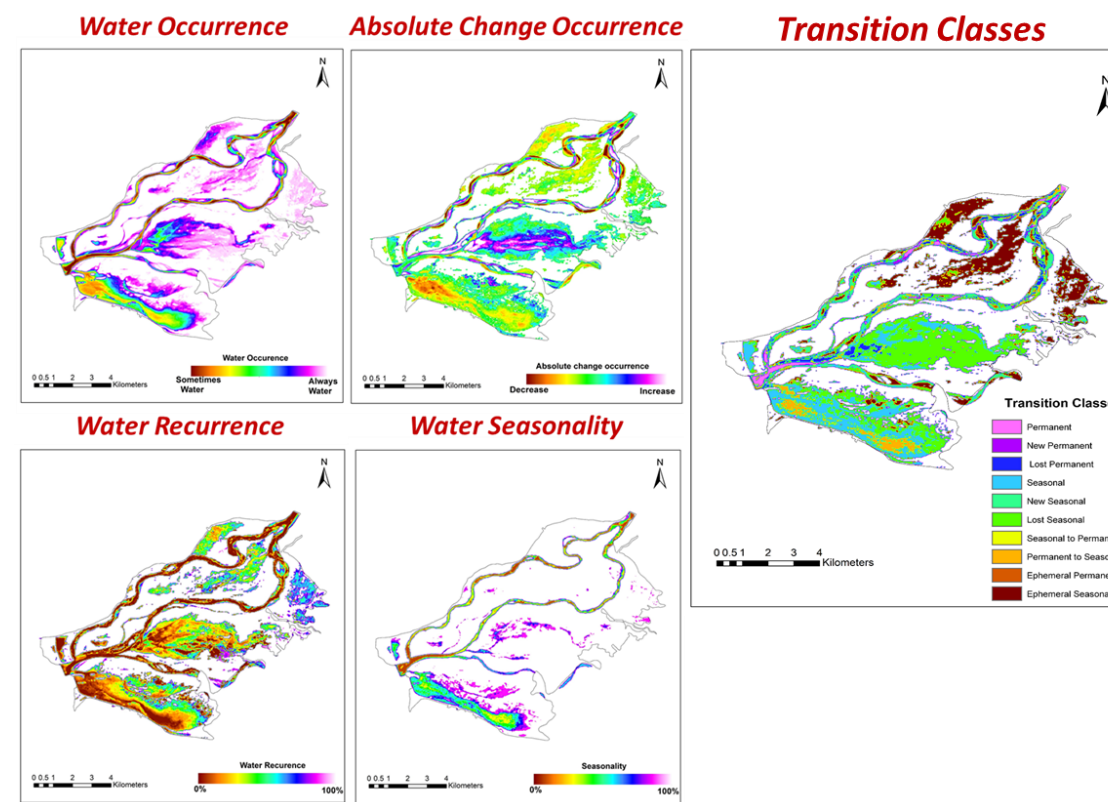


Figure 5: Satellite derived water dynamics.

(iii) Optically Active Water Quality Parameters:

Regular monitoring of optically active water quality parameters using physics-based inversion methods enables accurate assessment across diverse water bodies. Analytical models generally perform better than empirical ones. Derived chlorophyll-a and total suspended matter (TSM) concentrations ranged from 0-36 mg/m³ and 0-156 mg/m³, respectively, with chl-a peaking in the pre-monsoon and TSM in the post-monsoon season. These spatial and temporal variations are mainly influenced by rainfall, runoff, and climatic factors, making water quality monitoring vital for evaluating river productivity and eutrophication levels.

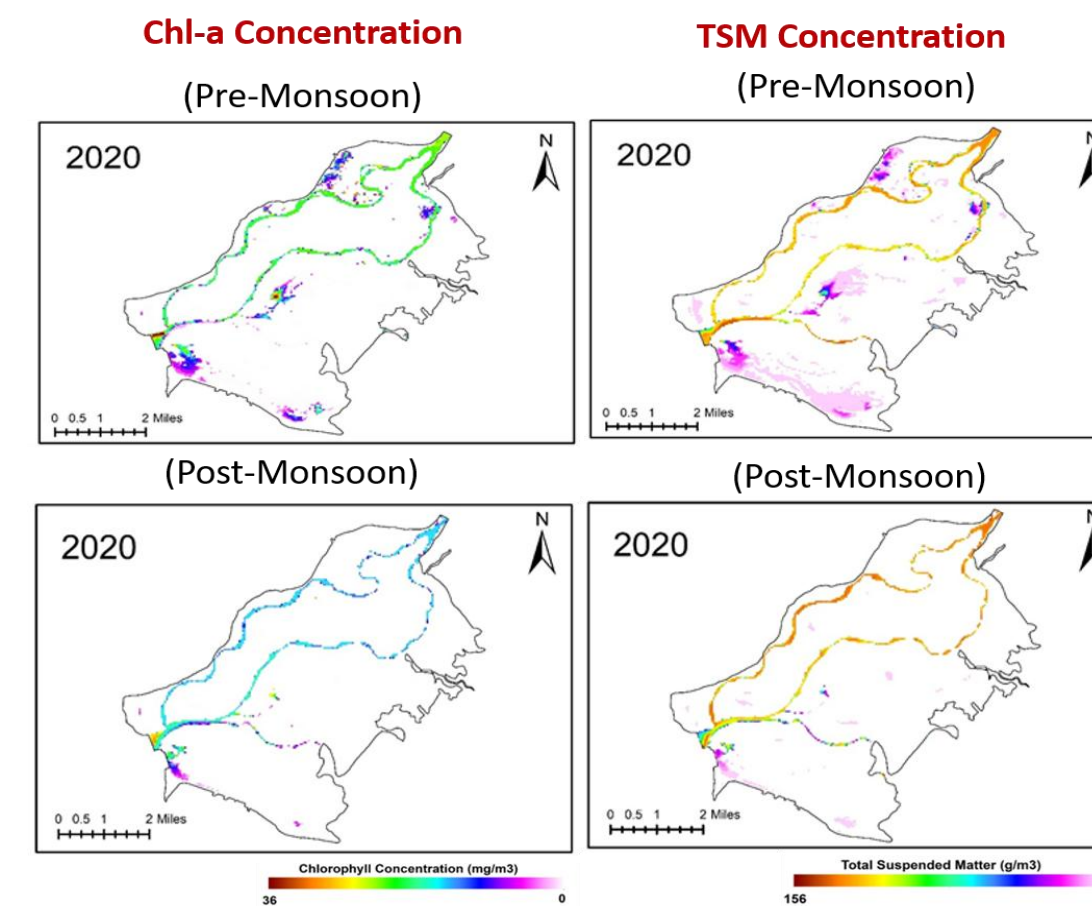


Figure 5: Satellite derived water quality parameters.

5. Conclusion: Wetlands are vital ecosystems that maintain ecological balance and support biodiversity. This study used multispectral (Landsat-8) and hyperspectral (PRISMA) satellite data to assess the ecological structure and water dynamics of the Harike Wetland, Punjab. Six indices—NDVI, NDAVI, NDWI, MNDWI, FAI, and ABDI—were applied to map vegetation, aquatic vegetation, surface water, and algal blooms. NDVI and NDAVI effectively represented vegetative cover, while NDWI and MNDWI improved water detection. Z-spectral analysis further distinguished algae, open water, agricultural, and built-up areas by enhancing subtle spectral variations. The integration of spectral indices with hyperspectral profiling proved effective for accurate wetland monitoring, offering valuable insights for conservation, ecological assessment, and sustainable management of Punjab's wetland ecosystems.

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