THE FISHWORLD
ISSN: 3049-138X
Vol.2(6) June 2025, 591-596

Wetland Wonders: Unveiling Nature's Secrets with GIS and Remote Sensing

Pallavi Bhalavey[1], Shrishti Sharma[1], Shruthi H U[1], Dr Padmanabha A[1], Harsh Pandey[2], Prabhutva Chaturvedi[1]
[1] College of Fisheries Science, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana-125004, India
[2] ICAR-CICFR, Bhimtal, Uttarakhand-236126, India
DOI:10.5281/Fishworld.15817486

Abstract

Wetlands are among the most biologically diverse and productive ecosystem providing critical ecological services such as water purification, flood control and carbon sequestration. The integration of GIS and satellite remote sensing has revolutionized wetland mapping and management enabling the large scale accurate and real-time monitoring of these vital habitats. Further AI and machine learning enhance the detection and analysis of wetland dynamics and their effective conservational efforts.

Keywords: Wetlands, GIS, Remote Sensing, Mapping, Sustainable management

Introduction

Wetlands are the part of most biologically productive diverse ecosystems of Earth, providing a broad array of essential ecological services. It is essential for maintaining the hydrological cycle, controlling the global climate, protecting diversity and safeguarding welfare. Fish waterfowl and other wildlife depend on wetlands as vital habitats, in fact, at least one-third of all endangered and threatened species depend on them to survive. Wetland ecosystems provide the highest value per hectare of all ecosystem types and their total ecosystem service value represents 47% of the global ecosystem's overall value. It plays an important role in purifying polluted waters, controlling erosion, maintaining stream flows and sequestering carbon, thereby contributing significantly to water quality and climate regulation. Wetlands also serve as natural sponges, absorbing and holding onto extra water during times of high precipitation or flooding suppressing the effect of storms and floods. Beyond their ecological functions, wetlands offer substantial economic and recreational benefits, supporting fisheries, agriculture and tourism and providing opportunities for activities such as fishing, hunting and wildlife observation. The Ramsar Convention emphasizes that wetland support rich biodiversity provide the water and primary productivity that countless species depend on and are among the most productive environment on earth and are also essential for human survival. Despite their recognized importance, they are under severe threat worldwide. Over the past three centuries, 87% of the global wetlands have been lost, majorly due to unsustainable development, agriculture land conversion, urbanization and infrastructure projects. Pollution from untreated wastewater, agricultural runoff, industrial discharges and excessive use of fertilizers and pesticides poses significant risks, leading to water quality degradation, eutrophication and loss of aquatic life.

Evolution of Wetland Mapping

Early Approaches: Field Surveys and Historical Records

The earliest wetland mapping relied on direct field surveys and the interpretation of historical documents and maps. In the United States, much of the initial knowledge about wetlands came from maps and surveyor notes dating back to colonial times, when wetlands were often drained for agriculture and settlement. For example, the Public Land Survey System (PLSS) and other ancillary historical data were used to reconstruct wetland and deepwater habitat extents in the 1850s, though these methods were limited by the accuracy and availability of records (Lawlor *et al.,* 2023).

Advancements: Aerial Photography and Cartography

The integration of aerial imagery with historical survey data allowed for more comprehensive mapping and change detection. Forensic mapping studies have demonstrated how combining PLSS data, historical records and aerial photographs from the 1950s enabled the creation of more accurate wetland maps, improving our understanding of pre-development wetland conditions.

Modern Era: Remote Sensing and Digital Mapping

Remote sensing technologies allow for the classification and quantification of wetlands using spectral data, which is especially helpful for tracking changes over time and across large, inaccessible areas. National-level wetland mapping projects, such as those conducted by India's Space Applications Centre, have utilized remotely sensed data to produce detailed wetland inventories at broad spatial scales

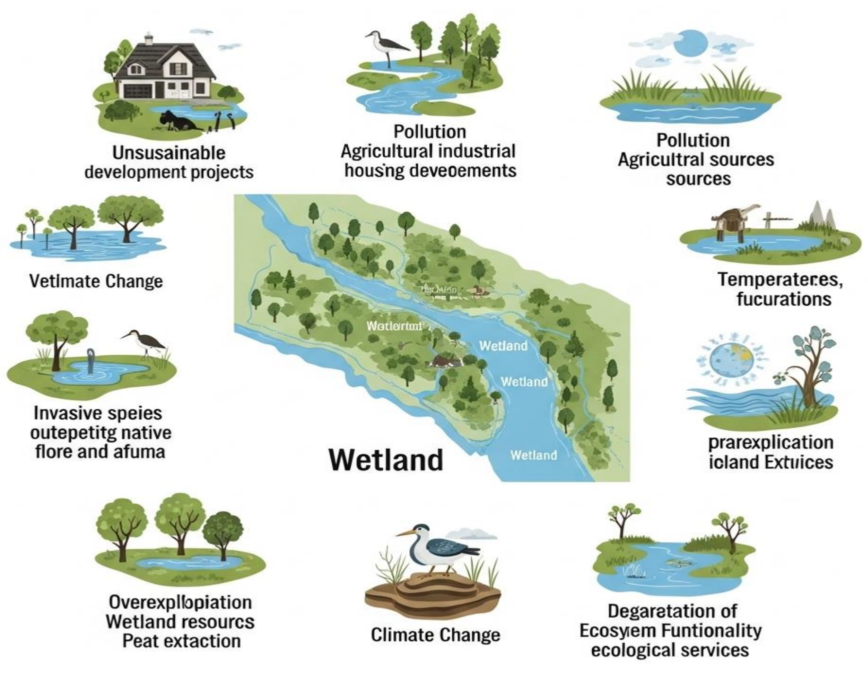


Figure 1. Different threats on wetland ecosystem

Integration with Geographic Information Systems (GIS) and Advanced Analytics

Recent developments have seen the integration of GIS with remote sensing data, allowing for sophisticated spatial analyses and visualization. Machine learning and advanced classification algorithms further enhance the efficiency and accuracy of wetland mapping, supporting national inventories and historical change analyses (Rapinel *et al.,* 2023). Tools like the Wetland Insight Tool (WIT) now provide interactive, multi-decadal visualizations of wetland dynamics, making historical and current wetland data accessible to researchers and policymakers

Remote Sensing Techniques for Wetland Identification:

Technique	Description	References
Optical Remote Sensing	**Satellite Imagery (Landsat, Sentinel, MODIS):** Satellites have Optical sensors such as Landsat, Sentinel-2 and MODIS capture visible and infrared light reflected from the Earth's surface. **Aerial Photography:** High-resolution aerial images provide detailed visual information.	Géant *et al.,* 2023
Radar Remote Sensing	**Synthetic Aperture Radar (SAR):** SAR sensors (e.g., Sentinel-1, ALOS PALSAR) penetrate cloud cover and vegetation canopies, making them useful in regions with frequent cloudiness or dense vegetation.	Géant *et al.,* 2023
Hyperspectral Remote Sensing	**Hyperspectral Sensors:** Capture data in hundreds of Spectral bands that are narrow, enabling identification of subtle differences in vegetation type, soil moisture and water quality.	Huang *et al.,* 2023
Light Detection and Ranging (LiDAR)	**LiDAR:** Airborne LiDAR systems provide high-resolution elevation data, crucial for mapping wetland topography, detecting micro-topographic features and delineating wetland boundaries.	Klemas, 2011
Digital Terrain Models (DTMs)	**DTMs from Satellite or Airborne Data:** DTMs derived from LiDAR or stereo satellite imagery help identify potential wetland areas by modelling hydrological flow and detecting low-lying, water-accumulating regions.	Rapinel *et al.,* 2023
Advanced Analytical Techniques	**Machine Learning and AI:** Techniques such as Random Forest and other statistical classifiers are increasingly used to analyse remote sensing data, integrating multiple data sources (optical, radar, LiDAR, field data) to improve wetland identification accuracy.	Rapinel *et al.,* 2023

Integrating GIS for Wetland Management and Analysis

GIS provides the robust platform for collecting, storing, analysing and visualizing spatial datasets from various sources, such as field surveys, aerial photography and satellite imagery which is essential for understanding wetland dynamics and supporting evidence-based management decisions.

Using a combination of wetlands indicators, including hydrology, vegetation, soil types and topographic position, GIS makes it easier to identify and demarcate wetlands areas. These wetlands indicators can be combined or superimposed to find regions with a high likelihood of having wetland (i.e. potential wetlands). By using GIS and RS, it is easier to identify wetlands with high level of moisture than those have dried land. In addition to cloud shadow, multispectral remote sensing imagery with a dark tone frequently denotes areas with high soil moisture or water, which are likely to have wetlands.

Hydrology

A popular metric for identifying and defining water-like features and regions with high moisture content in soil is the normalized Difference Water Index (NDWI) (McFeeters 1996). The following formula is used to determine the NDWI:

$$NDWI=(GREEN-NIR)/(GREEN+NIR)$$

Here GREEN and NIR depicts the values of reflectance observed in green and infrared portion of electromagnetic radiations.

Hydrophytic vegetation

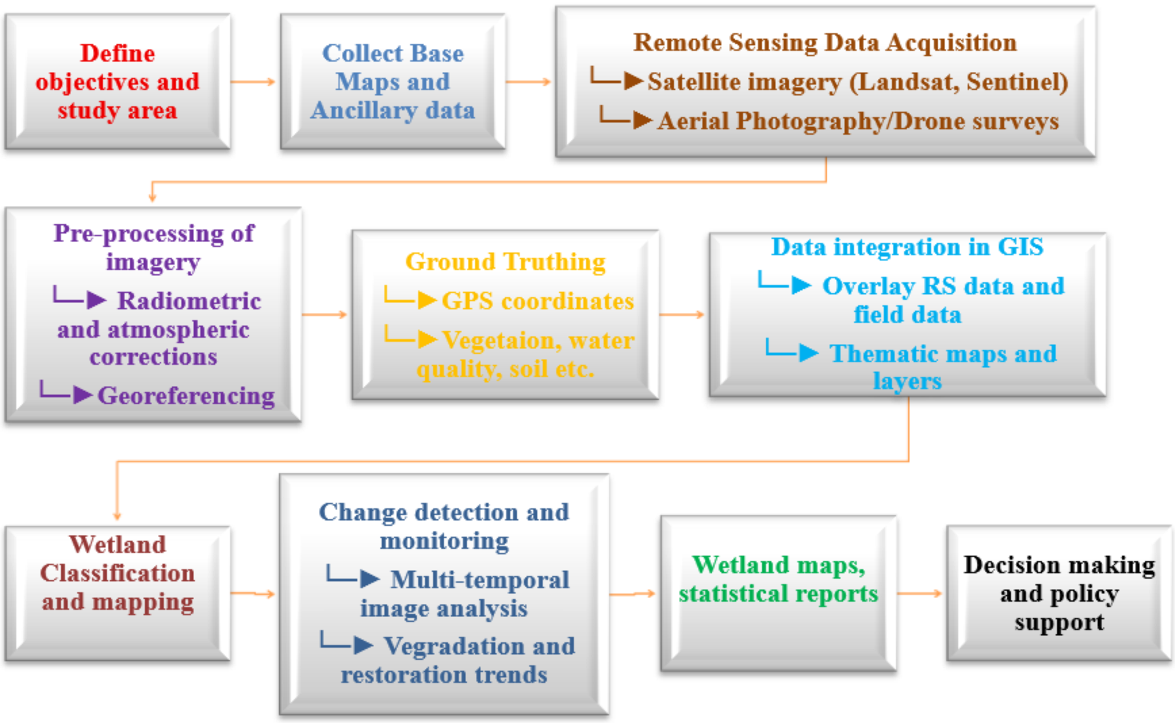
Normalized Difference Vegetation Index (NDVI) which uses the multispectral remote sensed data to recognize the green vegetation and can be calculated by using a formula suggested by (Tucker 1979):

$$NDVI=(NIR-RED)/(NIR+RED)$$

Here, RED and NIR represent the spectral reflectance values found in the near-infrared and red region of electromagnetic spectrum.

Hydric soil and topographic vegetation

GIS-based maps use morphological indicators and field-verified data to delineate hydric soils, and for topographic vegetation, GIS overlays soil maps with elevation and slope



data to analyses how landscape position affects drainage and vegetation patterns.

Innovations: AI, Machine Learning and Cloud Platforms

Recent advancements in machine learning (ML), artificial intelligence (AI), and cloud platforms have significantly advanced the field of wetland mapping using GIS and RS technologies. Convolutional neural networks (CNNs) which is a type of deep learning model, have shown exceptional accuracy in wetland classification by integrating high-resolution aerial imagery, multispectral satellite data and LiDAR-derived terrain information.

Machine learning algorithms such a Gradient Tree and Boost Random Forest have proven especially effective for identifying small and ephemeral wetlands, which are aften missed in conventional mapping efforts (Bu *et al*., 2025). These models utilize critical predictors like the NDWI and image texture metrics to distinguish wetlands from other land covers. The integration of cloud platforms, such as AWS and Google Earth Engine, has enabled large-scale parallel processing of vast geospatial datasets, drastically reducing the computational resources and time required for wetland mapping. These technological advancements not only improve the accuracy and efficiency of wetland mapping but also support conservation planning, regulatory compliance and restoration monitoring by providing up-to-date, high resolution spatial data. As AI and cloud technologies continues to evolve, their integration into GIS and remote sensing is anticipated to further improve the scalability, adaptability and real-time capabilities of wetland monitoring and management.

Cha

Figure 2. Flow-chart for Mapping and Monitoring of Wetlands using GIS and RS

- In arid and semi-arid regions, mapping these wetlands with the highest level of precision remains difficult because of their intricate edaphic and tiny hydrological gradients.
- The detection and monitoring of these wetlands are limited by the spatial resolution of these openly accessible multispectral sensors.
- Wetlands lack a single, unifying land-cover feature are highly dynamic and have constantly shifting energy signatures.
- Additionally, steep environmental gradient within and surrounding wetlands produce slender ecotones that are typically below the remote sensors' resolving ability.

Conclusion

In wetland conservation, geospatial technologies such as GIS and Remote Sensing have become essential tools. These technologies facilitate informed decision-making for sustainable management by enabling accurate mapping, real-time monitoring and efficient evaluation of wetland ecosystems. They support prompt restoration efforts and offer vital insights into wetland degradation by identifying changes in vegetation cover, hydrology and land use. Furthermore, the comprehension of human-wetland interactions is improved by the incorporation of ecological and socioeconomic parameters with geospatial data. The strategic use of geospatial tools is essential for preserving ecosystem services, biodiversity and guaranteeing the resilience of wetland habitats as anthropogenic pressure and climate change increase. Thus, to optimize the potential of geospatial technologies in protecting our priceless wetland ecosystems, sustained investment in capacity-building, data infrastructure and interdisciplinary research is necessary.

References

Bu, F., Dai, Z., Mei, X., Chu, A., Cheng, J., & Lan, L. (2025). Machine learning-based mapping wetland dynamics of the largest freshwater lake in China. *Global Ecology and Conservation*, *59*, e03585.

Géant, C. B., Gustave, M. N., & Schmitz, S. (2023). Mapping small inland wetlands in the South-Kivu province by integrating optical and SAR data with statistical models for accurate distribution assessment. *Scientific Reports*, *13*(1), 17626.

Huang, Y., Peng, J., Chen, N., Sun, W., Du, Q., Ren, K., & Huang, K. (2023). Cross-scene wetland mapping on hyperspectral remote sensing images using adversarial domain adaptation network. *ISPRS Journal of Photogrammetry and Remote Sensing*, *203*, 37-54.

Klemas, V. (2011). Remote sensing of wetlands: case studies comparing practical techniques. *Journal of Coastal Research*, *27*(3), 418-427.

Lawlor, S., Rains, K., Landry, S., & Rains, M. (2023). Forensic wetland and deepwater habitat mapping for setting pre-development conditions. *Wetland Science and Practice*.

McFeeters, S.K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, 17, 1425 1432

Rapinel, S., Panhelleux, L., Gayet, G., Vanacker, R., Lemercier, B., Laroche, B., ... & Hubert-Moy, L. (2023). National wetland mapping using remote-sensing-derived environmental variables, archive field data and artificial intelligence. *Heliyon*, *9*(2).

Tucker, C.J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment, 8, 127-150