Wetlands: Ecology, Conservation and Management 12

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Wetland Ecosystems: Conservation Strategies, Policy Management and Applications

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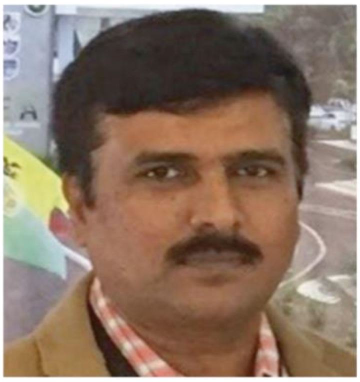

Naga Raju Maddela received his MSc (1996–1998) and PhD (2012) in Microbiology from Sri Krishnadevaraya University, Anantapuramu, India. During his doctoral program in the area of Environmental Microbiology, he investigated the effects of industrial effluents/insecticides on soil microorganisms and their biological activities. He is working as Faculty in Microbiology since 1998, teaching undergraduate and postgraduate students. He worked as Prometeo Investigator (fellowship received from SENESCYT) at Universidad Estatal Amazónica, Ecuador during 2013–15, and has received "Postdoctoral Fellowship" (2016–2018) from Sun Yat-sen University, China. He also received external funding from "China Postdoctoral Science Foundation" in 2017 and internal funding from "Universidad Técnica de Manabí" in 2020. He participated in national/international conferences and presented research data in China, Cuba, Ecuador, India, and Singapore. Currently, he is working as a Full Professor at the Facultad de Ciencias de la Salud, Universidad Técnica de Manabí, Portoviejo, Ecuador. He has been actively publishing scientific articles, books (authored and edited), and chapters since 2007. As of now, he has published 70 articles, 12 books, and 40 book chapters.

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inundation patterns, and the extent of flooding, aiding in flood risk assessment and management (Tahsin et al. 2018).

- **Habitat and Biodiversity Monitoring**: Remote sensing helps in assessing habitat conditions and monitoring biodiversity by mapping habitat types, tracking species distribution, and identifying critical habitats for conservation (Lahoz-Monfort and Magrath 2021).

15.5 Geographic Information Systems (GIS) in Wetland Management

Geographic Information Systems (GIS) are powerful tools for capturing, storing, analyzing, and visualizing spatial and geographic data. GIS integrates hardware, software, and data to manage and analyze spatial information, allowing users to interpret complex relationships and patterns within geographic contexts. In wetland management, GIS is utilized to analyze spatial data related to wetland distribution, land use changes, water quality, and ecological processes. By providing a comprehensive view of spatial data, GIS facilitates informed decision-making and effective management of wetland resources (Sritart and Miyazaki 2022).

15.5.1 GIS Tools and Techniques

GIS tools and techniques encompass a range of functionalities designed to manage and analyze spatial data:

- **Data Layers and Spatial Analysis**: GIS allows for the layering of various types of spatial data, such as land use, vegetation cover, and hydrological features. Spatial analysis techniques, including overlay analysis, buffer analysis, and spatial interpolation, enable the examination of relationships between different data layers. For instance, overlay analysis can be used to assess how changes in land use affect wetland areas, while buffer analysis helps in evaluating the impact of surrounding land uses on wetland health (Gaglio et al. 2017).
- **Remote Sensing Integration**: GIS integrates data from remote sensing technologies, such as satellite imagery and aerial surveys. By combining remote sensing data with GIS, users can enhance wetland mapping, monitor changes over time, and analyze spatial patterns in vegetation and water quality. This integration allows for detailed temporal and spatial analysis, aiding in the assessment of wetland dynamics and health (Waleed et al. 2023).
- **Hydrological Modeling**: GIS tools are used to model hydrological processes and predict the impacts of various factors on wetland hydrology. Techniques such as watershed modeling, flood modeling, and water flow analysis help in understanding water movement, distribution, and availability within wetland

systems. These models can be used to predict the effects of land use changes, climate variability, and water management practices on wetlands (Chun et al. 2020).

- **Decision Support Systems**: GIS supports decision-making through tools that provide spatial analyses and simulations. Decision support systems (DSS) use GIS data to assess different management scenarios, evaluate potential impacts, and deUvelop conservation strategies. These systems facilitate stakeholder engagement and collaborative decision-making by visualizing complex data in an accessible format (John et al. 2020).

15.5.2 Case Studies of GIS in Wetland Conservation

Several case studies demonstrate the effective use of GIS in wetland conservation and management:

- **Everglades Restoration Project, USA**: The Comprehensive Everglades Restoration Plan (CERP) employs GIS to manage and restore the Everglades ecosystem. GIS is used to analyze water flow patterns, monitor vegetation changes, and evaluate the impacts of restoration activities. By integrating spatial data from various sources, CERP aims to restore natural water flows and improve ecosystem health (Dessu et al. 2021).
- **Yangtze River Floodplain, China**: GIS has been utilized to map and assess wetlands in the Yangtze River floodplain. Through integrating remote sensing data and GIS, researchers have monitored changes in wetland extent, vegetation cover, and water quality. The GIS-based analysis has informed conservation strategies and management practices to protect critical wetland habitats (Xiang et al. 2023).
- **Wetland Restoration in the Mississippi Alluvial Valley, USA**: GIS has played a key role in planning and implementing wetland restoration projects in the Mississippi Alluvial Valley. By using GIS to analyze land use changes, hydrological conditions, and habitat quality, managers have developed targeted restoration strategies and evaluated the success of conservation efforts (Murray and Klimas 2013).

15.6 Conservation Tools and Strategies for Wetlands

15.6.1 Policy and Regulatory Frameworks

Policy and regulatory frameworks are essential for effectively conserving and managing wetlands. These frameworks provide the legal and institutional structures necessary to protect wetlands and ensure sustainable use. Key aspects include:

- **International Agreements and Conventions**: International agreements such as the Ramsar Convention on Wetlands are crucial for global wetland conservation. The Ramsar Convention promotes the conservation of wetlands of international importance and encourages member countries to develop national policies for wetland protection and sustainable use (Gell et al. 2023).
- **National Legislation**: Many countries have specific laws and regulations governing wetland conservation. For example, the Clean Water Act in the United States regulates the discharge of pollutants into waters and protects wetlands through permitting processes and water quality standards (Andreen 2024). Similarly, the European Union's Water Framework Directive sets out water quality and wetland conservation objectives across member states (Munné et al. 2015).
- **Local Regulations and Zoning**: At the local level, zoning regulations and land-use planning can influence wetland conservation. Municipalities often implement zoning laws to control development near wetlands and ensure that land use is compatible with conservation goals. Local regulations can include restrictions on construction, requirements for buffer zones, and guidelines for sustainable land use (Petrakovska et al. 2020).

These frameworks help to establish guidelines and enforcement mechanisms that support wetland conservation and sustainable management.

15.6.2 Community Involvement and Stakeholder Engagement

Community involvement and stakeholder engagement are vital for the success of wetland conservation efforts. Effective conservation strategies often include:

- **Public Awareness and Education**: Raising awareness about the importance of wetlands and the benefits they provide is crucial for garnering public support. Educational programs and outreach activities can help inform communities about wetland functions, conservation needs, and ways to participate in protection efforts (Gell et al. 2023).
- **Local Participation in Decision-Making**: Engaging local communities in decision-making processes ensures that conservation strategies are relevant and consider local knowledge and needs. Participatory approaches can involve community consultations, workshops, and collaborative planning, allowing stakeholders to contribute to the development and implementation of conservation plans (Kusters et al. 2018).
- **Partnerships and Collaborations**: Forming partnerships between government agencies, non-governmental organizations (NGOs), businesses, and local communities can enhance conservation efforts. Collaborative initiatives can leverage resources, share expertise, and coordinate actions to address conservation challenges more effectively (Abdulsalam et al. 2024).

Active engagement of stakeholders helps to build consensus, enhance the effectiveness of conservation measures, and promote sustainable management of wetland resources.

15.6.3 Best Practices in Wetland Conservation

Adopting best practices in wetland conservation ensures that conservation efforts are effective, sustainable, and aligned with ecological goals. Key practices include:

- **Restoration and Rehabilitation**: Restoration involves reestablishing the natural functions and structure of degraded wetlands. This can include actions such as removing invasive species, replanting native vegetation, and restoring hydrological regimes. Successful restoration projects require careful planning, monitoring, and adaptive management (Musa et al. 2024).
- **Sustainable Management**: Implementing sustainable management practices involves balancing ecological, economic, and social objectives. This can include sustainable use of wetland resources, such as controlled fishing or ecotourism, and managing land use around wetlands to reduce impacts and support conservation goals (Lawal et al. 2023).
- **Monitoring and Evaluation**: Regular monitoring and evaluation are essential for assessing the effectiveness of conservation measures and making informed decisions. This includes tracking changes in wetland conditions, evaluating the success of restoration efforts, and adapting management practices based on monitoring data (Geneletti, 2004).
- **Adaptive Management**: Adaptive management is an iterative process that incorporates feedback and learning to improve conservation strategies. By continually assessing outcomes and adjusting approaches based on new information, adaptive management helps to address uncertainties and enhance the resilience of wetland ecosystems (Livinus et al. 2024).

15.7 Case Studies and Applications

15.7.1 Successful Wetland Restoration Projects

Wetland restoration projects aim to revive and enhance the ecological functions of degraded wetlands. Successful projects demonstrate effective strategies for restoring wetland health and resilience:

- **Florida Everglades Restoration (USA)**: The Comprehensive Everglades Restoration Plan (CERP) is one of the most extensive wetland restoration projects globally. Initiated in 2000, CERP aims to restore the natural flow of water across the Everglades, address habitat loss, and improve water quality. Key activities include removing barriers to water flow, restoring natural wetlands, and managing water levels to support diverse plant and animal species. CERP has made significant progress in improving water flow and enhancing habitat conditions, though challenges remain in fully achieving restoration goals (Davis and Ogden 1994).

- **The Danube Delta Restoration (Romania/Ukraine)**: The Danube Delta is a UNESCO World Heritage Site and one of Europe's most biodiverse wetlands. Restoration efforts have focused on reconnecting the delta's natural water channels, enhancing floodplain connectivity, and improving water quality. These efforts have led to the recovery of critical habitats for fish and bird species, improved ecological functions, and increased biodiversity. The project highlights the importance of cross-border cooperation and integrated management for successful restoration (Bojinski et al. 2014).
- **The Loess Plateau Watershed Rehabilitation Project (China)**: Although not exclusively a wetland restoration project, this initiative has significantly impacted wetland ecosystems by addressing land degradation and improving watershed health. The project has implemented soil conservation measures, reforestation, and wetland restoration to reduce erosion, enhance water retention, and support local livelihoods. The success of this project demonstrates the potential benefits of integrating wetland restoration with broader landscape management efforts (Shaojun et al. 2004).

15.7.2 Innovative Technologies in Action

Innovative technologies are increasingly being applied to enhance wetland management and restoration:

- **LiDAR Technology**: Light Detection and Ranging (LiDAR) technology is used to create high-resolution digital elevation models and assess vegetation structure in wetlands. LiDAR data helps in mapping wetland topography, monitoring changes in vegetation cover, and evaluating hydrological patterns. For instance, LiDAR has been used in the Mississippi Alluvial Valley to assess floodplain elevations and support restoration planning (van der Most and Hudson 2018).
- **Remote Sensing for Water Quality Monitoring**: Advanced remote sensing technologies, such as hyperspectral and thermal imaging, are used to monitor water quality parameters, including temperature, chlorophyll-a concentration, and turbidity. These technologies provide real-time data on water conditions, enabling timely responses to pollution events and improved management of wetland water quality (Chasmer et al. 2020).
- **Automated Monitoring Systems**: Automated systems equipped with sensors and telemetry units are deployed to continuously monitor wetland conditions. These systems can measure parameters such as water level, flow rate, and soil

moisture in real-time. Automated systems facilitate efficient data collection, reduce the need for manual sampling, and provide continuous insights into wetland dynamics (Lunetta et al. 2022).

15.7.3 Lessons Learned from Various Regions

Case studies from different regions offer valuable lessons for wetland management and restoration:

- **Adaptive Management**: The experience from the Everglades Restoration Project underscores the importance of adaptive management in addressing uncertainties and evolving conditions. Continuous monitoring, evaluation, and flexibility in management strategies are essential for achieving long-term restoration goals (Davis and Ogden 1994).
- **Stakeholder Engagement**: Successful projects, such as the Danube Delta Restoration, highlight the need for active stakeholder engagement and cross-border cooperation. Engaging local communities, governments, and NGOs in planning and implementation ensures that restoration efforts are well-supported and aligned with local needs (Bojinski et al. 2014).
- **Integration with Broader Goals**: The Loess Plateau project demonstrates the benefits of integrating wetland restoration with broader environmental and socio-economic goals. Combining wetland restoration with land management, soil conservation, and livelihood improvements can enhance the overall effectiveness and sustainability of conservation efforts (Jiang et al. 2019).

15.8 Future Directions and Emerging Trends

15.8.1 Advances in Monitoring Technologies

Monitoring technologies are continuously evolving, offering new tools and methods for tracking and managing wetland ecosystems:

- **Satellite and Aerial Remote Sensing**: Advances in satellite and aerial remote sensing technologies are improving the resolution and accuracy of wetland monitoring. Newer satellites, such as the Sentinel-2 mission, provide high-resolution multispectral imagery that allows for detailed vegetation analysis and water quality assessment. More so, the development of hyperspectral sensors enhances the ability to detect subtle changes in wetland ecosystems, such as variations in plant health and nutrient concentrations (Chasmer et al. 2020).
- **Drones and UAVs**: Unmanned Aerial Vehicles (UAVs) or drones are increasingly used for wetland monitoring due to their ability to capture high-resolution

imagery and provide real-time data. Advances in drone technology, including improved flight stability and longer battery life, enable detailed assessments of wetland conditions, vegetation structure, and hydrological changes (Messina and Modica 2020).
- **Smart Sensors and IoT**: The integration of smart sensors and Internet of Things (IoT) technologies is revolutionizing wetland monitoring. These sensors can measure various environmental parameters such as water quality, soil moisture, and atmospheric conditions. IoT networks facilitate the collection of real-time data from remote and inaccessible locations, enabling more responsive management and conservation efforts (Salam 2024).

15.8.2 Integrating New Data Sources

The integration of diverse data sources enhances the understanding and management of wetlands:

- **Big Data and Analytics**: The use of big data and advanced analytics is transforming wetland management. By integrating large volumes of data from remote sensing, in-situ measurements, and historical records, researchers can perform complex analyses to identify trends, predict changes, and assess the impact of various factors on wetland ecosystems (Saheed et al. 2023). Big data analytics can provide insights into patterns of wetland degradation, restoration effectiveness, and ecological interactions.
- **Citizen Science**: Citizen science initiatives are increasingly contributing to wetland monitoring and conservation. Platforms that engage the public in data collection and observation allow for the gathering of large datasets from diverse locations. These contributions can enhance the monitoring of wetland species, track changes in wetland conditions, and increase public awareness and involvement in conservation efforts (Silvertown 2009).
- **Cross-Disciplinary Integration**: Combining data from different disciplines, such as hydrology, ecology, and climatology, provides a more comprehensive understanding of wetland systems. Cross-disciplinary approaches enable the integration of various data types and models, facilitating more accurate predictions and better-informed management strategies (Dandois and Ellis 2010).

15.8.3 Predictions for the Future of Wetland Conservation

The future of wetland conservation will likely be shaped by several emerging trends and predictions:

- **Increased Use of AI and Machine Learning**: Artificial Intelligence (AI) and machine learning are expected to play a significant role in wetland conservation.

These technologies can automate data analysis, improve the accuracy of ecological models, and identify patterns and anomalies in large datasets. AI-driven tools will enhance decision-making processes and facilitate more efficient conservation planning (Raihan 2023).

- **Climate Change Adaptation**: As climate change continues to impact wetland ecosystems, adaptation strategies will become increasingly important. Future conservation efforts will need to focus on enhancing the resilience of wetlands to climate-induced stresses, such as altered hydrological patterns and increased temperatures. Strategies may include developing climate-resilient restoration techniques, managing migration corridors for species, and integrating climate projections into conservation planning (Lahoz-Monfort and Magrath 2021).
- **Emphasis on Ecosystem Services**: There will be a growing emphasis on recognizing and valuing the ecosystem services provided by wetlands. Future conservation efforts will likely incorporate economic valuation of ecosystem services, such as flood regulation, water purification, and carbon sequestration, into decision-making processes. This approach will help to justify investments in wetland conservation and restoration by highlighting the tangible benefits provided by these ecosystems (Goyette et al. 2021).

15.9 Conclusion

This chapter has examined the diverse methods for monitoring and assessing water treatment in wetlands, emphasizing the importance of technological innovations, remote sensing, GIS, and conservation tools. Wetlands play a crucial role in maintaining biodiversity, regulating water quality, and providing essential ecosystem services through natural processes like nutrient cycling and water filtration. Advances in monitoring technologies, including remote sensing, GIS, and in-situ sensors, are transforming how wetlands are observed and managed by offering detailed spatial and temporal data. Remote sensing technologies such as satellite imagery and UAVs provide valuable insights into wetland conditions, while GIS tools support spatial data analysis and hydrological modeling. Effective wetland conservation requires strong policy frameworks, community engagement, and best practices. To enhance conservation efforts, it is recommended that practitioners integrate various technologies and data sources, engage stakeholders, adopt adaptive management practices, and promote supportive policies. Embracing emerging technologies like AI and machine learning will also play a key role. The conservation and management of wetland ecosystems are vital for sustaining their ecological functions and services. Addressing environmental challenges and integrating innovative approaches will be crucial for the future of wetland conservation, with collaborative efforts from practitioners, policymakers, and communities being essential for long-term success.

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Chapter 16
Application of Remote Sensing in Wetland Monitoring

Adejoke Blessing Aransiola, Alaaya Abdulrasheed Abdulwaheed, Mamud Baba, Imeime Innocent Uyo, Temitope Oyadokun, and Mohammed Oludare Idrees

Abstract Wetlands are a valuable resource that are natural which offer the ecology several advantages. For this reason, wetlands need to be well defined. So far, a number of review papers have been published for Remote Sensing (RS) based wetland mapping. This review will give an insight to the reader on the usage of remote sensing (RS) in the monitoring of wetlands. Nevertheless, there is a pressing need to classify and analysis wetlands. Several RS techniques for classifying wetlands are examined, along with the benefits and drawbacks of each. Wetlands are amazing ecosystems with a wealth of ecological, commercial, and social advantages. These methods involve the classification of wetlands using aerial, multispectral, synthetic aperture radar (SAR), and various other data sets. This study also investigates object-based and pixel-based wetland classification techniques. The most significant findings from the literature indicate that the optimal optical bands for mapping wetlands are the red edge and near-infrared bands.

Keywords Multi-spectral satellites · Coarse spatial resolution data · Mapping · Photography

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16.1 Introduction

Wetland is a terrain that transitions between terrestrial and aquatic systems and has shallow water covering it or a water table that is typically at or near the surface (Mitsch and Gosselink 1993). Wetlands are extremely advantageous to the environment and serve as essential habitats for a number of rare kinds of plants and animals. They provide a variety of advantages, including recreational opportunities, soil and water conservation, protection from natural dangers, and water purification (Ji et al. 2015). Melton et al. (2013) estimate that wetlands occupy at least seven million square kilometers of the planet. However, due to intensive irrigation techniques, exploitation, and other factors, wetlands are vulnerable to an accelerated degradation (Millennium Ecosystem Assessment 2005). Numerous stakeholders have created various wetland inventories for this reason after realizing the importance of wetlands and the great potential of remote sensing (RS) for mapping these priceless natural resources. Wetland inventories are a valuable tool for assessing the efficacy of wetland policies. They are simply maps that show the location and distribution of wetlands across geographic regions. Nevertheless, creating categorization schemes (Fig. 16.1) to specify the kinds of wetland classes that need to be mapped is a prerequisite for creating wetland inventories. As a result, a variety of classification method which may be broadly categorized into field-based and RS methods—were developed for the purpose of implementing categorization schemes. In contrast to field-based techniques, remote sensing (RS) is an affordable instrument that can obtain regular measurements from far locations and deliver data in

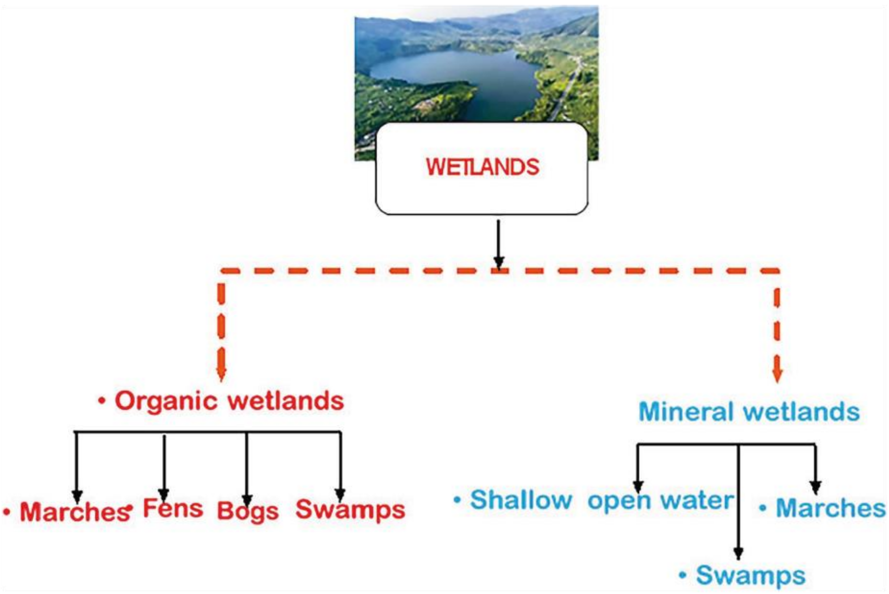

Fig. 16.1 The 2017 Alberta Wetland Policy and the Wetland Classification System (WCS)

real time. Satellite remote sensing (RS) has proven to be the most successful and economical approach for this goal, considering the present requirement for current information and the extensive coverage of wetland maps (Ozesmi and Bauer 2002). Wetland classification remains a difficult task from the perspective of RS, even with numerous advancements in RS technology (Corcoran et al. 2012). The fact that each of the wetland classes has a number of unique traits, but also some ecological parallels with other non-wetland classes and each other, is a major contributing factor to this issue. As a result, spectral and/or backscattering information in RS images is similar across different wetlands (Amani et al. 2017). Furthermore, wetlands differ greatly throughout time and place. Notwithstanding these challenges, RS approaches are preferred, particularly in light of the fact that fieldwork (a tedious, somewhat expensive, and time-consuming task) is the prospective alternative. Consequently, a great deal of research has been done in an effort to create novel and efficient RS techniques for the goal of mapping wetlands with the least amount of in situ data. Many review papers have been published regarding the classification of wetlands and the several issues that come with it. For example, SAR sensors were briefly discussed in Ozesmi and Bauer's (2002) comprehensive assessment of various sensors used for wetland mapping and monitoring. This review paper also examined various approaches to the classification of wetlands, such as aerial photo interpretation and supervised and unsupervised classification techniques. The reader will gain a great deal of understanding from this review of the advantages and restrictions of using SAR sensors to detect wetlands. Additionally, it gives consumers advice on selecting the proper sensor configuration. In a different study, Adam et al. (2010) examined the spectral properties of different types of vegetation found in wetlands and reviewed the classification of wetland using multispectral and hyperspectral RS sensors. Similar to this, Dronova (2015) conducted a comprehensive and helpful analysis of the literature on object-based wetland classification and investigated the benefits and drawbacks of object-oriented mapping of wetlands, as well as the factors that influence its correctness. Lastly, Brisco (2015) looked into surface water and wetland mapping and monitoring using SAR RS techniques. Every review that was previously discussed examined wetland classification from a particular angle. Consequently, a more comprehensive literature study is required, one that includes an overview of the significance of wetlands, the rationale behind the necessity of mapping and monitoring wetlands, and a varied explanation of the numerous approaches to wetlands classification and monitoring through the use of RS. This review gives an insight of the application of RS in wetland monitoring and also the likely future guidelines in wetland ecosystem monitoring.

16.2 Remote sensing in Wetland Monitoring

Land surveys of vegetation, soil and water are the approaches on which the traditional mapping and classification techniques are based on in other to check different wetland characteristics. Though laborious, costly and having some limitation when considering accuracy (for example hydrological regime and wetland connections), a framework for understanding the characteristics of wetland and the management of the resources of wetland can be provided effectively using this approach (Huang et al. 2002).

More severe on a large scale are these limitations for mapping wetland. For some years now, Earth Observation (EO) technologies data has alleviated the problem to a significant ratio by gathering EO time series data for different applications in the environment. Repeatable and consistent observation, wide spatial coverage and high spatial and temporal resolution data ability in particular reduced need for wide field campaigns (Hemati et al. 2023).

16.2.1 Remote Sensing (RS) in Wetland Studies and Their Categories

The spectral, spatial and temporal dynamics of wetland ecosystems essential component which are hydrology, vegetation, and geomorphology, can be best taken with the use of data and technology of remote sensing. According to Schmidt and Skidmore 2003, a major basis of earth surface's cover constitution spatial information is RS. Abundant Earth information are captured by different sensors and can be useful for scientists that have interest in spatial information monitoring in a timely manner (Park et al. 2003).

In many researches involving wetland areas, RS technology has been used during the past five decades for purposes such as: (1) Climate warming in wetland environments and carbon cycle (Holden 2005); (2) wetland regions mapping or land use/cover changes (Giri et al. 2011); (3) peatland fires release of carbon (Rappold et al. 2011); and (4) wetlands hydrology procedures (Slater and Reeve 2002). The various remote sensing categories include.

16.2.1.1 Studying Wetland with Aerial Photographs

This permits the speedy gathering of a huge sum of data and a exceptional impression of an area. The foremost remote sensing technology used in analyzing events on ground surface is the Aerial photography. Satellite remote sensing progress during the 1970s and 1980s has pushed the analyses of aerial-imagery to a new state (Kuenzer et al. 2011).

Wetland plant and land cover identification and classification are of a big challenge due to phenological vegetation variations, the complication of the landscapes of wetland and the impact of biological and physical variables, such as levels of water, density and content of salt (Cline et al. 2011). Aerial photography procedures have been broadly used in studies of wetland because of their outstanding benefits when considering spatial resolution, time and cost, particularly when satellite remote sensing methods were in an initial stage. Since the challenges of data procurement in large zones by aircraft, aerial photography is usually been used for small areas mapping of wetland. After the launching of the satellites, particularly Landsat TM, aerial photography was chiefly used in the valuation of the procedures involved in biomass classification gotten from remote sensing approaches with lower-resolution (Guo et al. 2017).

16.2.1.2 Optical Remote Sensing for Wetland Classification

Multi-spectral (MS) satellites, such as Landsat optical remote sensing data are widely used for the classification of wetland, which result in precise classification maps (Mahdianpari et al. 2018). This is due to the fact that most sensitivity of classes of wetland are in the visible bands and Near-Infrared (NIR) and derived indexes of vegetation such as Normalized Difference Vegetation Index (NDVI) from MS data, which makes them distinct from another. Nevertheless, cloud cover and /night conditions hinder the ability of optical remote sensing sensors. Thus, commonly unusable in geographic areas with high cloud cover are such data (Mahdianpari et al. 2021). As a result, Synthetic Aperture Radar (SAR) has been an attractive substitute, considering its capacity of collecting data in all conditions of weather. Also, the penetration of radar makes it advantageous for studies of vegetation in wetland. The signal of SAR is also sensitive to the surface dielectric and roughness properties thus making it likely to recover data about the size, shape, moisture content and orientation of the target (Mahdianpari et al. 2018).

16.2.1.3 Studying Wetland with LiDAR Data

Light Detection and Ranging (LiDAR) is a remote sensing technology used in monitoring the surface of the Earth. It makes use of a pulsed laser to measure the distance between the target object and the sensor. Three-dimensional data about the ground and its surface can be generated by LiDAR and is therefore useful in deriving the Digital Elevation Model (DEM) (Guo et al. 2017). LiDAR data have been effectively used in elevation mapping of the forest environments using the advantage of acquiring an accurate DEM. The first signal returned is reflected from the canopy while the last signal returned is from the surface of the ground for full waveform LiDAR (Hladik and Alber 2012). Disasters such as flood, storm surges and saltwater intrusion along coastal regions are caused by sea level rise, an important factor for salt marshes stability. Because of the benefits LiDAR data have in deriving accurate elevations of the ground, sea level rise and related research are also key research themes using LiDAR data (Guo et al. 2017).

16.2.1.4 Studying Wetland with Radar (Radio Detection and Ranging) Data

Since the 1970s, Space borne optical data have been extensively used for studying the environment and vegetation. Landsat and Terra/Aqua launching took optical sensors usage to a new level. Though, the principal optical data weakness is the haze and clouds presence. In some regions, because of the cycle of the monsoon, rain and clouds last for a long time; this period is sometimes also significant for the growth of plant. As a result of the thick vegetation cover that leads to signal saturation within wetlands, optical images usually fail to monitor vegetation types (Morandeira et al. 2016). A radar being a sensor that is active transmits, receives and processes the signals of microwave radio. The ability of the radar data to infiltrate clouds is a strong advantage over optical data in the acquisition of ground information. Because of the strength of infiltrating canopy of vegetation and obtaining information of the ground all without the restriction of clouds, radar data, such as RadarSAT, European Remote Sensing (ERS-1), Phased Array L-band Synthetic Aperture Radar (PALSAR), AIRSAR, TerraSAR-X and Japanese Earth Resources Satellite 1 (JERS-1) are uniquely fit to monitor and identify changes in flooding, soil moisture, and above-ground biomass in wetlands (Kasischke et al. 2009).

Multi-sensors were used to by White (2013) in capturing the variation in the community's vegetation of spring wetland and Australian Great Artesian Basin surface expressions. The imagery of airborne hyperspectral was carefully chosen as a reference data to differentiate spring plant communities and surrounding substrate in detail. Rapinel et al. 2015a used the combination of multispectral and multi-seasonal imagery and Light Detection and Ranging (LiDAR) data to map precisely the wetland habitats distribution in northeastern Brittany near the Mont-Saint-Michel Bay, France.

16.3 Resolution of RS for Wetland Monitoring

16.3.1 Studying Wetland with Medium Spatial Resolution Data

Spatial resolution data within the range of 4-30 m (referred to as Medium spatial resolution) in remote sensing are used for studying wetland. They mostly include LandSat TM/Enhanced Thematic Mapper plus (ETM+), Systeme Probatoire D'Observation De La Terre (SPOT 1–4), China & Brazil Earth Resources Satellite (CBERS), Advance Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Advanced Visible and Near Infrared Radiometer type 2(AVNIR-2) and Advanced Land Observation Satellite (ALOS) (Guo et al. 2017).

16.3.2 Studying Wetland with Coarse Spatial Resolution Data

Studying Wetland with Coarse spatial resolution data comprises Moderate Resolution Imaging Spectroradiometer (MODIS) and AVHRR data. MODIS instrument offers almost daily coverage of the Earth's surface repeatedly with a swath width of nearly 2330 km and 36 spectral bands. Seven bands are precisely designed for land remote sensing with 250 m (bands 1to 2) and 500 m (bands 3 to 7) spatial resolutions (Pflugmacher et al. 2007).

16.3.3 Studying Wetland with High Spatial Resolution Optical Data

Guo et al. 2017 described image of high spatial resolution as images with <4 m spatial resolution, which primarily include SPOT-5, Quickbird, IKONOS, GeoEye and WorldView data. Compared with images of medium-resolution and hyperspectral, high spatial resolution images have more information on texture and geometry on the surface features which can be used to recognize features of the ground easily in wetland areas.

16.3.4 Studying Wetland with Hyperspectral Data

Imaging spectrometers are used to obtain Hyperspectral data which provide continuous and complete spectral information with a huge number of narrow bands (less than 10 nm) which fall within 0.38–2.5 μm range. This significantly increases the comprehensive information on vegetation and has been widely used in wetland research as a result of complex composition of the vegetation. Satellite, hyperspectral data and airspace and have been excellently used for mapping wetland, research of plant leaf chemistry, identification of wetland species, wetland analysis of soil property, and other themes (Guo et al. 2017).

16.4 Synthetic Aperture Radar (SAR) for Wetland Monitoring

SAR provides the physical and geometric structure of vegetation, spot the inundation levels of vegetation, track the periodic and annual differences within wetland location while optical data provides the molecular and chemical structure of vegetation. As such, the amalgamation can improve accuracy, increase information content, improve the mapping of the wetland boundaries and enhance temporal coverage

(Hosseiny et al. 2021). The European Space Agency (ESA) launched Copernicus program, brought about the massive advancement for wetland mapping. Precisely, the 12 SAR Sentinel-1 and 10 optical Sentinel-2 (multi-spectral instrument, MSI) sensors availability is remarkable, as it offers an extraordinary opportunity to gather data of high spatial resolution for mapping wetland.

Majority of wetland research used SAR in classifying and mapping wetlands (Bartsch et al. 2009). The algorithms for classification are mostly divided into a group of two: unsupervised and supervised (Melendez-Pastor et al. 2010). K-means ISODATA are instances of unsupervised classification methods, while support vector machine (SVM) (Bourgeau-Chavez et al. 2016), maximum likelihood classification (MLC) (Betbeder et al. 2015), and object-based random forest (RF) (Zhang et al. 2019) are supervised procedures.

Unsupervised classification procedures are frequently in use for classifying types of land cover with the use of optical imagery (Li et al. 2016). While studying wetland, supervised classification procedures are preferred given the high similarity between different classes of wetland. The machine learning techniques availability has allowed large-volume earth observation data analyzes (Tamiminia et al. 2020). Non-restriction of the data input to a distribution that is normal is one of the advantages of machine learning classifiers (Bhat and Huang 2021).

Convolutional neural network (CNN) are one more instance of supervised classification procedure for Deep learning approach. Its classifiers can make use of the spatial spectral information gotten directly from an image as training (Meng et al. 2019). Also, due to rising trend in wetlands lost, applying diverse methods to detect and interpret changes in wetland's dynamic ecosystems is essential (Yuan et al. 2015).

The SAR signal illuminated surface is being altered by changes in wetlands and so therefore change the intensity of the image or mechanism of backscattering. The intensity-based change detection method final result is calculated by differencing before and after phenomena image pixels (Bouvet and Le Toan 2011). This backscattering mechanism change can be considered as a pointer to change in the surface type (Kwoun and Lu 2009).

The estimation of soil moisture is one more way of applying SAR imagery (Fig. 16.2) in monitoring wetlands (Kasischke et al. 2009). SAR is sensitive to dielectric properties signal of the target and so, content of water of a target can be retrieved using SAR data. Three common inversion methods exist for estimation of soil moisture in wetland complexes: empirical, semi-empirical and physically based models (Millard and Richardson 2018). Synthetic aperture radar (SAR) has appeared as a capable tool for fast and precise wetland extent and type monitoring. SAR gives an exceptional potential for wetland monitoring in the acquisition of information on the roughness and moisture content of the surface, (Adeli et al. 2020).

Wetland classification and mapping using SAR data have been one of the most explored application to date (Mohammadimanesh et al. 2019), yet the backscattering similarity of wetland classes presents challenges. Spatiotemporal change detection is another application of SAR wetland monitoring. Of a great benefit is this because the dynamic nature of wetlands needs methods that can monitor changes

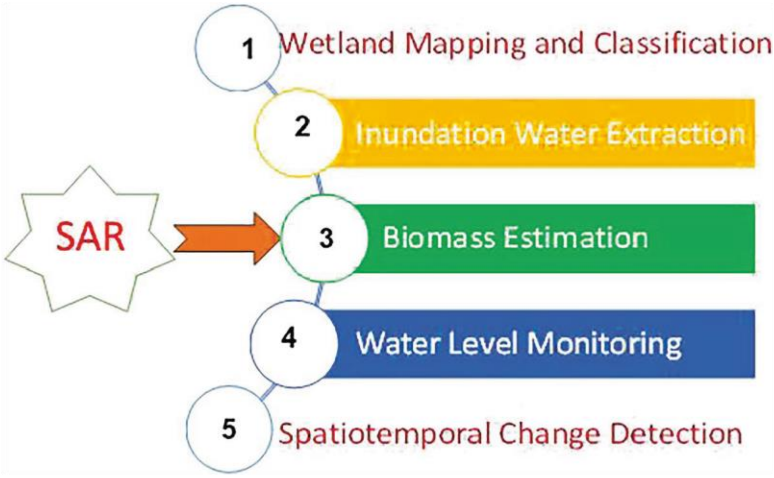

Fig. 16.2 SAR and its application

(Zakharova et al. 2014). Monitoring of water level using Interferometric SAR (InSAR) methods is another, less developed technique of monitoring wetland (Kim et al. 2009). Finally, due to the great influence of wetlands in methane emission and consequently the carbon cycle, estimation of biomass in wetlands using SAR data are also becoming progressively vital (Lee and Fatoyinbo 2015).

16.5 Mapping of Wetland

The anthropogenic activities and climate change have been a threat to the wetlands globally (Aransiola et al. 2024). The changes caused are seen in shrinkage of the wetland area or land cover or vegetation cover. When these changes are understood, it could help in assessing wetland ecosystems and provision of information for department in charge of environmental protection. These trends and sudden change of wetland, dynamic analysis and wetland protection could be understood by long-term change detection studies. On a regional scale, because of the availability of free data and also benefit of spatial and temporal resolution, Landsat is used for research themes in wetland areas mapping, vegetation classification and change detection (Guo et al. 2017). Rapinel et al. (2015b) discovered that with higher accuracy, the images of Landsat 8 OLI can be used in mapping plant communities in coastal marshlands. Also, its data have been used in mapping of flood or building flood models in wetland flood research. Robinove (1978) in Queensland, Australia, initiated the usage of Landsat images in floods mapping. He projected that the areas appearing dark in the Landsat images are wet soil but not flooded regions. Overton (2005), based on Geographic Information System (GIS), Remote sensing, and a hydrological model built an inundation model. The images of Landsat TM were used in monitoring flood inundation extent. It was stated that the model detects flood inundation of a large area and at a lower cost.

16.5.1 Habitat/Biodiversity

Wildlife tends to habituate in Wetlands. Depending on the types of species, some endangered birds are constrained to specific wetland habitats. Waterfowls are highly threatened by degradation and habitat loss as a result of anthropogenic activities such as water conservation engineering and reclamation of wetland and climate change such as frequent drought which could cause wetland area shrinkage (Jiang et al. 2014). Landsat data, as a medium-resolution sensor, have been considered to be a good technique in habitat study of wildlife in wetlands at a large area, due to time scales >30 years.

16.6 Wetland Classification

Lush and complex vegetation structure are the major characteristics of wetland and this pose to be a challenge for mapping using traditional optical sensors. Due to the benefit with respect to the band number and continuous reflectance values for the vegetation of the ground, Hyperspectral sensors have been broadly used for classifying wetland. Wetland types, remote sensors used for wetland mapping and their various applications are displayed in Fig. 16.3.

An efficient and effective tool for water body areas detection and inundation of flood extent on a large area is satellite remote sensing. MODIS, due to high temporal resolution and large coverage, has substantial benefit for wetland extent mapping and dynamics at a coarse spatial resolution. In Namibia North-Central, the distribution of surface water was recognized by (Mizuochi et al. 2014) with the use of modified normalized difference water index (MNDWI) of MODIS and normalized difference polarization index (NDPI) of the multi-frequency Advanced Microwave Scanning Radiometer Earth Observing System (AMSR-E). Also, Kaptué et al. (2013), monitored the surface water spatiotemporal variations from 2003 to 2011 in the Soudan-Sahel region of Africa and observed that MODIS could efficiently characterize open water bodies larger than 50 ha. It was concluded that it could also be used in monitoring the surface water seasonal changes of semiarid regions.

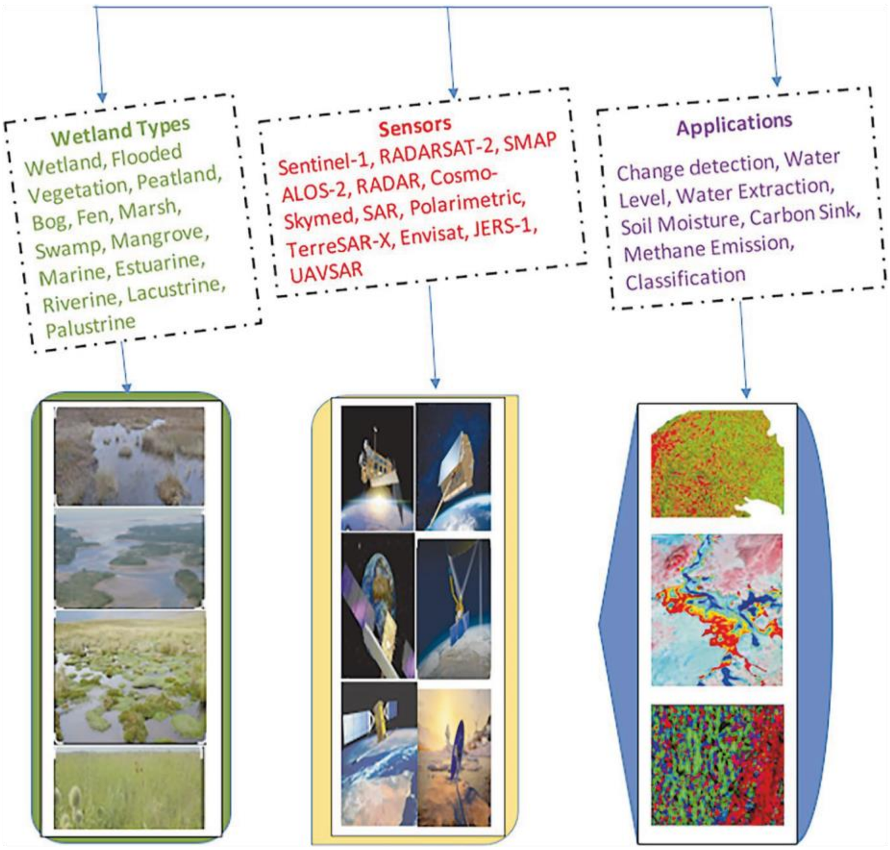

Fig. 16.3 Wetland, sensors and application

16.7 Future Perspective of GIS and Wetland Preservation

Geographic Information Systems (GIS) is an essential tool use for mapping, managing and monitoring environmental resources. GIS tools enhance robust spatial data manipulation, analysis, and management capabilities, which are essential for understanding and reducing the effects of climate change and the negative anthropogenic activity on wetlands. This article seeks to present the future of GIS technique on wetland preservation, with the aim of strengthen wetland conservation through data acquisition, decision support making procedures and data processing approach.

Wetland mapping capabilities have been greatly improved over the past decades with the aid of GIS tools in conjunction with remote sensing. At the early period, wetland mapping were manually based, where aerial photographs in conjunction with ground field survey data are used for mapping and characterization of wetland areas. This technique is time consuming and labor-intensive. Since the first multispectral satellite data were made accessible to the general public in the early 1970s, wetland mapping and monitoring in developing nations has advanced tremendously. It has become more promising due to the advancements in GIS and remote sensing technologies, which offer accurate and sufficient information on its ecosystem.

The utilization of active remote sensing technologies is becoming more increasing, LiDAR (Light Detection and Ranging) and satellite altimetry (LaRocque et al. 2020). These technologies enable the comprehensive collection of topographical and subsurface water potential data, particularly in the areas of mapping wetland boundaries and assessing their groundwater quality. Wetland areas that could not be mapped efficiently by traditional mapping approaches, can now be located with high-resolution digital elevation models (DEMs) created using LiDAR that can display seconds fluctuations in the landscape (Rouxinol 2023). Furthermore, changes in vegetation health and soil moisture content can be detected by multispectral and hyperspectral imaging, providing trustworthy data on the biological condition of wetlands (Casamaitjana et al. 2020: Younis and Iqbal 2015).

The preservation of Wetland ecosystem is now more achievable through GIS technique. However, before it can reach its full potential, there's need to address some critical challenges. Especially, in the direction of data characteristics. The quality of dataset used for spatial analyses has great influence on the results outcome. The higher the data resolution, the better the result (Amanda 2023). The accessibility of this data is also a challenge, most open source multispectral image data are of low quality. Overcoming these obstacles will require accessibility of high resolution data and it manipulation process. Also, Training and capacity building for staff is a prerequisite requirements that should be taken into account. Data analysis, and spatial data modeling are professional skills needed to use GIS effectively (Graybill 2024). To guarantee that GIS tools are utilized to their maximum potential, it is imperative to offer resources and training stakeholders involve in the wetland conservation. Collaboration between governmental, non-governmental organization, and academic institutions will go a long way in initiating positive drive, and encourage more innovative ideas in the preservation of wetlands.

An expert in GIS tools has the potential to facilitate well-informed Decision-Support System (DSS) in the protection and preservation of wetland. Through its interface, a tool that enables the simulation and visualization of numerous data sources can help stakeholders comprehend the difficulties the environment faces. An expert in (GIS) can also, quickly evaluate possible conservation difficulties and determine the best course of action. Lin et al. (2006) state that the application of DSS can help to rank the importance of wetland regions in terms of biodiversity, flood danger, and pressure from land development when it comes to their need for protection. A comprehensive and accurate foundation for decision-making is provided by GIS-based DSS, which can make wetland preservation efforts more dependable and efficient.

Wetland preservation has swiftly been made flexible by the constantly improving its analytical capabilities of GIS. Assessing data with deep machine learning algorithms and artificial intelligence (AI) is a newly emerging field. Large dataset processing capacities and trend patterns analysis are capabilities of machine learning algorithms as human analysis may not be able to match. Machine learning enables various applications such as classifying land cover, tracking changes in land surface dynamics, recognizing wetland change dynamics, and forecasting the impact of environmental factors on wetland ecosystems. With the help of deep learning algorithms, wetland dynamics may now be recreated and the findings will be more accurate, GIS-based modeling techniques make this possible (Ahmed et al. 2021). Hydrological models, water management strategies, and aquifer characterization can all be used to forecast subsurface water storage and flow as well as storage in wetlands.

In conclusion, equality and inclusion must be the driving principles behind the use of GIS in wetland preservation in order to guarantee that all parties involved such as organizations, residents, and stakeholders benefit equally from the conservation efforts. This is accomplished by acknowledging the rights of Indigenous peoples and include them in the process of making decisions. GIS can be used to create an inclusive and active approach to wetland protection, leading to more equitable and long-lasting effects.

In summary, GIS can provide better tools for monitoring, understanding, and protecting these vital ecosystems through enhanced data collection, enhanced decision support system and automated analytical techniques processes. As we move forward, the use of inclusive, collaborative methodologies and the simulation of GIS with new spatial technologies will be necessary to realize the full potential of GIS in wetland preservation.

16.8 Conclusion

Wetland is an important ecosystem that harbors diversity of organisms and contribute to stability of ecosystem if maintained. Remote sensing has proven to be a good tool or technology in monitoring the preservation of ecosystem and helps in predicting the outcome of the wetland deterioration.

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