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Wetlands: crucial ecosystem service providers: A contemporary review

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Abstract

Wetlands occupy the transitional interface between aquatic and terrestrial ecosystems, globally distributed from polar tundra to tropical zones, excluding Antarctica. Water is the primary determinant of wetland environments, influencing their diverse flora and fauna. Classified broadly into types such as peatlands, rivers, mangrove forests, and others, wetlands are renowned for their productivity and biodiversity. They deliver a wide range of ecosystem services and economic benefits, including flood control, water filtration, landscape aesthetics, climate moderation, and cultural enrichment through recreational and heritage activities. Supporting diverse biological communities, wetlands harbor significant concentrations of birds, mammals, reptiles, amphibians, fish, insects, and plant genetic resources like rice. Their adaptive capacity to environmental change is critical for human communities and wildlife alike, ensuring health, welfare, and safety benefits. Despite their vital role, wetland ecosystem services remain inadequately quantified due to biophysical measurement limitations, highlighting research gaps. Comparable to rainforests and coral reefs in productivity, wetlands provide essential services at no direct cost, including disease regulation, carbon sequestration, and natural resource provisioning. Protecting wetlands safeguards these invaluable services, underpinning their significance in sustaining ecosystems and human well-being. This review aims to elucidate wetland types, ecosystem services, and current research gaps, emphasizing their indispensable role as natural assets.

Keywords: Ecosystem Services; Wetlands; Wetland Types; Genetic Resources

1. Introduction

Wetlands are characterized as transitional zones between aquatic and terrestrial ecosystems, characterized by shallow water coverage (Upadhay et al., 2020). Covering approximately 6% of the Earth's land surface, wetlands serve as crucial reservoirs of biodiversity, supporting a myriad of species through their complex hydrology and nutrient cycling dynamics (Mitsch et al., 1995; Constanza et al., 1997; Mitsch and Gosselink, 2000; Groot et al., 2012). Recognized as among the most productive and ecologically sensitive ecosystems globally, wetlands play a pivotal role in environmental health (Xu et al., 2020).

The Ramsar Convention defines wetlands as areas where the water depth does not exceed 6 meters at low tide, encompassing diverse types such as peatlands, rivers, lakes, estuaries, marshes, and mangroves (Bowman, 2002; Aber et al., 2012). Emphasizing their significance, the Ramsar Convention's 2013 report states 'The Economics of Ecosystems and Biodiversity for Water and Wetlands' underscores the imperative to shift societal attitudes towards wetlands. This perspective has been echoed by governmental bodies such as India's Ministry of Environment, Forest and Climate Change (MoEFCC), which in a 2017 notification, recognized wetlands as vital ecosystems supporting rich biodiversity and contributing to hydrological cycles.

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Wetlands provide a diverse array of ecosystem services, including flood mitigation, water storage and purification, landscape aesthetic enhancement, microclimate regulation, and cultural and recreational opportunities (Clarkson et al., 2013). These services are categorized as regulating, provisioning, supporting, or cultural, highlighting their multifaceted contributions to human well-being (MEA, 2005).

Despite their immense ecological and economic value, challenges remain in quantifying these services due to methodological limitations in biophysical measurements, indicating areas for further research and development. By safeguarding wetlands, societies can sustainably manage these invaluable natural resources, ensuring continued benefits for both ecosystems and human societies.

2. Materials and methodology

The present study utilized several prominent bibliometric information sources, including Google Scholar, Research Gate, Scopus, Web of Science, PubMed, academia.edu, Shodhganga, Inflibnet, and Scholars Archive@OSU. Keywords such as "ecosystem services," "wetland," "wetland services," "coastal wetlands," and "mangroves" were strategically chosen to compile a comprehensive database of relevant papers for analysis.

A total of 85 scientific articles were selected after meticulous sorting and classification based on various criteria including thematic relevance, academic discipline, geographical origin, and publication year. This process ensured a diverse representation of literature sources, data sets, research articles, and reviews.

The objective of this comprehensive review was to critically analyze trends and insights from existing studies in wetland ecosystem services (WES) research, providing a robust synthesis of current knowledge in the field.

3. Results and discussion

Drawing from published literature and the Ramsar Convention (2018), we compiled a comprehensive overview of eleven major types of wetlands, including peatlands, rivers and deltas, mangrove forests, wetlands in dry regions, high-altitude wetlands, arctic wetlands, coastal wetlands, shallow lakes and ponds, bogs, marshes, swamps, and estuaries (see Table 1). Additionally, building upon the framework provided by the Millennium Ecosystem Assessment (MEA, 2005), we categorized the diverse ecosystem services offered by wetlands into four primary categories and 35 subcategories. These categories include provisioning services (9 subcategories), regulating services (12 subcategories), cultural services (6 subcategories), and supporting services (8 subcategories) (see Table 2). This synthesis aims to provide a structured analysis of the ecological and societal contributions of wetlands, underscoring their multifaceted roles in sustaining biodiversity and human well-being.

Table 1 Different types of wetlands.

Sr. No.	Wetland type	Description
1	Peatland	Found worldwide, peatlands are thick, water-logged soil layers composed of decaying plant material. Include moors, mires, peat swamp forests, and permafrost tundra.
2	Rivers and deltas	Rivers originate from high ground and flow downhill into creeks and streams. Deltas form at the river's mouth, where water slows and spreads into wetlands and shallow water.
3	Mangrove forests	Mangroves thrive at the intersection of oceans, freshwater, and land, surviving harsh environmental conditions. Found in tropical and subtropical tidal zones frequently inundated with salt water.
4	Wetland in dry regions	Characterized by seasonal rainfall, these wetlands retain water longer than surrounding landscapes. Include rivers, swamps, lakes, and springs that dry up seasonally
5	High altitude wetland	Store water from rain and glacial melt, recharge groundwater, trap sediments, and recycle nutrients, enhancing water quality and quantity.
6	Arctic wetland	Predominant ecosystem in the Arctic, covering nearly 60% of the region. Store significant amounts of greenhouse gases and support global biodiversity. Include peatlands, rivers, lakes, and shallow bays.

7	Coastal wetland	Found along coastlines where land meets open sea, unaffected by rivers. Include shorelines, beaches, mangroves, and coral reefs.
8	Shallow lakes and ponds	Permanent or semi-permanent water bodies with minimal depth. Include vernal ponds, spring pools, salt lakes, and volcanic crater lakes. Often seasonally flooded.
9	Bogs	Waterlogged peatlands in old lake basins or depressions. Primarily rain-fed, unsuitable for agriculture or development, providing undisturbed habitats for diverse species. |
10	Marshes and swamps	Broad category of palustrine wetlands, comprising marshes, swamps, and fens. Known for high biological diversity.
11	Estuaries	Transition zones where rivers meet the sea, with water transitioning from fresh to salt. Include deltas, tidal mudflats, and salt marshes.

Table 2 Ecosystem Services and Their Types

Sr.No.	Category	Services
1	Provisioning services	Food and fiber Fuel Genetic resources Biochemicals, natural medicines, and pharmaceuticals Freshwater Natural products of economic value Fertile farmland Jobs hub Release of vegetative matte
2	Regulating services	Air quality maintenance Climate regulation Water regulation Erosion control Water purification and waste treatment Regulation of human diseases Biological control Pollination Storm buffer Wind buffer Fish nursery Flood protection Carbon sink
3	Cultural services	Cultural diversity Spiritual and religious value Scientific and educational knowledge Inspiration Aesthetic values Recreation and ecotourism
4	Supporting services	Primary production Nutrient cycling Soil formation Water cycling Provision of habitat Sea level rise mitigation Wildlife nursery

3.1. Provisioning services

Provisioning Ecosystem Services encompass the products obtained from ecosystems that fulfil basic human needs such as food, water, minerals, shelter, and fuel. These services, including food, water, wood, and biochemical and genetic resources, play essential roles in various aspects of human life.

3.1.1. Food and fiber

Coastal wetlands provide crucial food resources. For instance, in mangrove forests, the sap from Nypa palm (*Nypa fruticans*) is tapped for sugar, vinegar, and alcohol production, while its fruits are used both raw and processed (Friess et al., 2021). Species like *Bruguiera* spp., *Sonneratia* spp., and *Avicennia* spp. yield flour for baking, and *Acanthus* spp. leaves are used for tea (FAO, 1966). In salt marshes, *Salicornia* spp. are harvested for culinary use and as the base for vinegar and fermented beverages (Friess et al., 2021). Fiber products include jute, hemp, silk, and other materials derived from wetland ecosystems (MEA, 2005).

3.1.2. Fuel

Certain mangrove species, particularly from the *Rhizophora* genus, are prized for their high calorific value as fuelwood and charcoal sources (Friess et al., 2021). Common reed (*Phragmites australis*) serves as a fuel source through direct burning or processed into fuel pellets or biogas via anaerobic digesters (Köbbing et al., 2013; Wichmann et al., 2017).

3.1.3. Genetic resources

Wetlands serve as vital genetic reservoirs, preserving a wealth of biodiversity that plays a crucial role in global food security, agriculture, and medicine. These ecosystems support a diverse array of plant species, including essential crops such as rice, which is a staple food for over half of the global population (Upadhay et al., 2020). Wetlands provide the ideal growing conditions for rice, and their genetic diversity is key to improving crop resilience to pests, diseases, and changing environmental conditions. This biodiversity enables selective breeding programs to develop new rice varieties that are more adaptable to climatic stresses, ensuring food security in the face of climate change.

Moreover, the genetic resources found in wetlands are not limited to crops. Wetlands are home to numerous plant species that offer potential medicinal benefits, contributing to drug discovery and pharmaceutical research. According to the Millennium Ecosystem Assessment (MEA, 2005), many wetland plants have unique biochemical properties that could lead to the development of new medicines, including treatments for diseases such as cancer and malaria. Wetlands' genetic diversity thus supports a wide range of applications, from agriculture to biotechnology, making their conservation a priority for sustainable development.

In addition to their agricultural and medicinal value, wetlands contribute to the overall stability and resilience of ecosystems. By maintaining a diverse gene pool, they enable ecosystems to adapt to environmental changes and stresses, preserving the ecological functions necessary for water purification, flood control, and carbon sequestration (MEA, 2005). As wetlands face increasing threats from human activities and climate change, protecting their genetic resources is essential for sustaining ecosystem services that benefit both human health and livelihoods

3.1.4. Biochemicals, natural medicines, and pharmaceuticals

Chemicals derived from coastal wetland organisms are widely used in traditional and modern medicine across Asia, Africa, Latin America, and the Caribbean. These substances treat ailments such as asthma, skin diseases, diabetes, and various infections (Friess et al., 2021). Mangrove vegetation, for example, provides bioactive compounds for treating conditions like leprosy and smallpox (Bandaranayake, 1998; Ito et al., 2000).

3.1.5. Fresh water

Wetlands are primary sources of freshwater for numerous communities worldwide. They enhance water quality by naturally filtering pollutants and recycling nutrients, making this resource suitable for drinking, agriculture, and sustaining aquatic ecosystems (Turcices et al., 2023). Wetlands are critical sources of freshwater, providing essential ecosystem services to both human communities and the environment. These ecosystems play a pivotal role in maintaining water quality by acting as natural filtration systems, where pollutants, sediments, and excess nutrients are trapped and broken down by wetland plants and microorganisms. Through this process, wetlands improve water purity, making it suitable for drinking, agriculture, and supporting aquatic ecosystems (Zedler & Kercher, 2005). Wetlands also help regulate water flow, reducing the impact of floods and droughts by storing water during periods of excess rainfall and gradually releasing it during dry spells. This buffering capacity is particularly valuable for sustaining agricultural activities in water-scarce regions.

For communities that depend on wetlands for their freshwater supply, these ecosystems are essential to both livelihoods and health. In regions where wetlands are abundant, such as Southeast Asia and parts of Africa, they provide water for irrigation, fishing, and daily consumption, directly supporting the local economy (MEA, 2005). In addition to human use, wetlands play a crucial role in maintaining the health of freshwater ecosystems by regulating nutrient cycles and supporting biodiversity. Aquatic organisms rely on the clean, nutrient-balanced water that wetlands provide, ensuring the survival of species critical to the ecological balance of rivers, lakes, and other water bodies (Junk et al., 2013).

However, the degradation and loss of wetlands due to human activities, such as urbanization, agriculture, and pollution, pose a significant threat to these freshwater resources. The destruction of wetlands not only reduces their capacity to filter water and regulate water flow but also jeopardizes the ecosystems and communities that depend on them. Conservation and restoration efforts are critical to preserving wetlands' ability to provide fresh water and sustain both human and natural systems (Gardner & Finlayson, 2018).

3.1.6. Natural products of economic value

Wetlands yield a variety of economic products, including fish, shellfish, berries, timber, and wild rice, as well as biochemicals from soils and plants (Balwan & Kour, 2021). Commercial fisheries and shellfish industries depend heavily on wetland ecosystems for their economic and recreational value (Maltby et al., 2011).

3.1.7. Fertile farmland

Wetlands globally support agriculture due to their nutrient-rich soils. Rice, a staple for half the world's population, thrives in wetland environments (Sarkar et al., 2021). Wetlands also support the cultivation of commercially important fish species and aquatic plants (Ramchandra et al., 2018).

3.1.8. Job hubs

Wetlands provide employment opportunities across various sectors, including trade, hospitality, and commercial fishing. Wetland restoration projects also create significant job opportunities (MEA, 2005). Coastal regions in the United States alone generate employment for millions of people (Balwan & Kour, 2021).

3.1.9. Release of vegetative matter

Wetlands release substantial vegetative matter into their surroundings (MEA, 2005). This organic matter, carried into waterways, enriches ecosystems, stabilizes habitats, and sustains aquatic life (Davis et al., 2006; Kröger et al., 2007).

3.2. Regulating services

Regulating Ecosystem Services encompass processes that maintain favourable environmental conditions for life. These services, such as air quality maintenance, climate regulation, water regulation, erosion control, and water purification, are essential for ecosystem health and human well-being.

3.2.1. Air quality maintenance

Wetlands contribute to air quality by emitting and absorbing various chemicals (Friess et al., 2021). Often referred to as the "kidneys of the planet," wetlands filter pollutants and purify the air, benefiting local and global environments (MEA, 2005; Giri et al., 2007).

3.2.2. Climate regulation

Wetlands influence climate patterns locally and globally. They contribute to local climate by affecting temperature and precipitation, while globally, they sequester and store significant amounts of carbon dioxide (Charles & Duke, 2009; Tallis et al., 2011). Wetlands play a pivotal role in regulating climate patterns both locally and globally. At a local level, wetlands influence temperature and precipitation by modulating humidity through water retention and evapotranspiration processes. This natural ability to store and release water gradually helps create localized microclimates that regulate regional weather patterns, including temperature stability and rainfall distribution (Finlayson et al., 2017). Wetlands also act as a buffer against extreme temperatures by absorbing solar energy and releasing moisture into the atmosphere, which reduces heat in surrounding areas and contributes to more consistent climate patterns.

Globally, wetlands are essential in mitigating climate change through their capacity to sequester and store large amounts of carbon dioxide (CO_2). Wetland ecosystems, particularly peatlands, mangroves, and freshwater marshes, act as significant carbon sinks, storing carbon in both plant biomass and soil. This reduces the concentration of greenhouse gases in the atmosphere, which is critical for limiting global warming (Salimi et al., 2021). According to Erwin (2009), wetland restoration can enhance these carbon sequestration capabilities, providing a cost-effective and natural solution for mitigating climate change.

However, these ecosystems face increasing threats from climate change and human activity. As wetlands are drained, degraded, or altered, their ability to sequester carbon is diminished, and in some cases, wetlands may even become net carbon emitters, exacerbating climate issues (Xiong et al., 2023). The loss of wetlands also reduces their local climate-regulating functions, such as controlling floods and maintaining regional precipitation levels. Finlayson et al. (2017) stress the need for targeted policy measures and adaptive management to protect these vital ecosystems from further degradation under changing climate conditions.

Wetlands, therefore, serve a dual purpose in climate regulation: locally, by stabilizing temperatures and influencing precipitation patterns, and globally, by sequestering carbon dioxide. Protecting and restoring these ecosystems is critical for ensuring their continued contribution to climate mitigation and adaptation efforts.

3.2.3. Water regulation

Wetlands act as natural reservoirs, regulating water flow, and groundwater recharge. They enhance soil structure, influence water infiltration and retention, and mitigate floods, benefiting agriculture and ecosystem stability (Ferreira et al., 2020).

3.2.4. Erosion control

Wetlands play a crucial role in shoreline protection against erosion caused by storms and natural forces (UNEP, 2017; MoEFCC, 2017). Wetland vegetation stabilizes soil, absorbs wave energy, and slows water flow, reducing erosion in coastal and inland areas (Friess et al., 2021).

3.2.5. Water purification

Wetlands act as natural filters, intercepting pollutants and organic waste from surface water runoff. They improve water quality, reduce sedimentation, and support aquatic life by removing excess nutrients (Hammer and Bastian, 2020; Muduli et al., 2023).

3.2.6. Regulation of human diseases

Changes in ecosystems can directly impact the prevalence of human pathogens such as cholera and influence the abundance of disease vectors like mosquitoes. *Ecteinascidin* 743, derived from the mangrove ascidian *Ecteinascidia turbinata*, is employed as an anti-cancer treatment for soft tissue sarcoma. Extracts from *Salicornia herbacea* exhibit potential antibacterial and anti-diabetic properties, used in managing diabetes. Similarly, extracts from *Suaeda fruticosa* show a range of antioxidant, anti-inflammatory, and anti-cancer properties (Friess et al., 2021).

3.2.7. Biological control

Changes in ecosystems affect the prevalence of crop and livestock pests and diseases (MEA, 2005). Wetlands provide habitats for animals that control pests and diseases; for instance, some frogs and fish reduce disease vector populations by consuming mosquitoes or larvae. Wetlands also support predators that regulate agricultural pests, such as ibis preying on grasshoppers (Hämback et al., 2023).

3.2.8. Pollination

Wetland ecosystems support pollination by providing habitats for various pollinators. The availability of natural habitats significantly influences ecosystem services, particularly for native bee species with diverse habitat requirements (Verhulst et al., 2004). Wetland margins, rich in undisturbed habitats, support nesting for native bees and attract hover fly species. Specific wetland plant species, like nude yellow loosestrife (*Lycimachia ciliata* L.) and the loosestrife bee (*Macropis nuda*), are essential pollen and nectar sources for certain pollinators (Vickruck et al., 2019).

3.2.9. Storm buffer

Coastal wetland ecosystems play a crucial role in mitigating damage from hurricanes and large waves (Ramchandra et al., 2005). Mangrove forests and salt marshes protect shorelines by reducing wave energy through reflection and dissipation (Costanza et al., 2021). Studies suggest that every 3 miles of healthy wetlands can reduce storm surge heights significantly, showcasing their protective value (Balwan & Kour, 2021).

3.2.10. Wind buffer

Wetlands mitigate the impacts of storms, tsunamis, cyclones, and strong winds by acting as natural protective buffers (Gupta & Nair, 2012). Managed ecosystems provide essential protection against natural hazards, enhancing resilience in landscapes prone to landslides, floods, wildfires, storm surges, and strong winds (Rieux et al., 2009).

3.2.11. Fish nurseries

Transient and resident fish and invertebrate communities utilize wetlands for food, shelter, and refuge, crucial for commercial fisheries (Keddy, 2010; Junk et al., 2011). Complex root and stem structures within wetlands provide shelter for juvenile fish, protecting them from larger predators and supporting high densities of juveniles. Coastal wetlands, such as mangrove forests, are particularly noted for their nursery functions for tropical reef fish (Friess et al., 2021).

3.2.12. Flood protection

Wetlands play a critical role in flood mitigation by absorbing and storing floodwaters (Penatti et al., 2015). Acting as natural sponges, wetlands slow down and release surface water, rain, snowmelt, and groundwater gradually, reducing flood heights and erosion (Syrbe and Walz, 2012). They are especially valuable in urban areas, where they counteract increased surface water runoff from built environments, thereby controlling floods and preserving crop lands (Ramchandra et al., 2005).

3.2.13. Carbon sink

Wetland soils store carbon over extended periods, making them significant contributors to climate change mitigation (Balwan & Kour, 2021). This carbon sequestration capability is crucial for regulating greenhouse gases and influencing global carbon cycles (Mitsch and Gosselink, 2015). Wetlands' role in carbon sequestration underscores their importance in both atmospheric and terrestrial ecosystem interactions (Finlayson et al., 2018).

4. Conclusion

Wetlands, among the most productive and diverse ecosystems on Earth, play a crucial role in the natural environment, offering a wide array of services. The Ramsar Convention on Wetlands, following the Millennium Ecosystem Assessment, underscored the concept of ecosystem services, defining wetland ecosystem services as the benefits derived by people from wetlands and integrating them as a central concept of the Convention. These services are broadly classified into four categories proposed by the Millennium Ecosystem Assessment: provisioning services (e.g., food, fiber, freshwater, fertile farmland), regulating services (e.g., climate regulation, water purification, flood protection, disease regulation), cultural services (aesthetic, spiritual, educational, recreational), and supporting services (nutrient cycling, soil formation, primary production).

Wetlands provide a diverse range of services that are invaluable to human well-being, stemming from ecosystem processes and functions. Over the past two decades, there has been a notable increase in research studies valuing wetlands. However, certain gaps and limitations persist in current literature, particularly in the availability of data and information that directly link ecosystem characteristics to the final services they provide. Our paper highlights the importance of various ecosystem services provided by wetlands while identifying these gaps and shortcomings.

Future perspectives

Looking ahead, addressing these gaps and enhancing the monitoring of wetland ecosystem characteristics and services are crucial. By compiling and analyzing comprehensive data on wetland ecosystems and their services, stakeholders and policymakers can make informed decisions aimed at effectively conserving and restoring wetlands. This integrated approach will be essential for ensuring the sustainable management and preservation of wetland ecosystems, thereby maximizing their contributions to human societies and the broader environment in the face of ongoing environmental challenges.

Authors' contributions

VK conceived the concept and KS supported the idea. Sonia collected all the literature and composed all the information and wrote the article. KS and VK extensively edited the article and give valuable suggestions.

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