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REVIEW ARTICLE

Exploring issues and solution in biodiversity management at Ramsar sites

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Abstract

Ramsar Sites are designated wetlands of international importance under the Ramsar Convention, an intergovernmental treaty established in 1971. These sites play a crucial role in conserving biodiversity and providing ecosystem services. The Ramsar Convention encourages countries to designate and manage Ramsar Sites sustainably, aiming to maintain the ecological character of these wetlands. Wetlands are areas that include marsh, fen, peat land, or water, and it is well known that these wetlands are important ecosystems that have a major positive impact on productivity, biodiversity, and the well-being of residents. Though preserved, Ramsar Sites face numerous threats, including habitat loss, pollution, invasive species, and climate change, warranting management, conservation efforts, and international cooperation to safe guarding these valuable wetland ecosystems for future generations. Pollution from agriculture, industry, and urban runoff threatens water quality. Climate change exacerbates these issues, affecting wetland ecosystems and altering migration patterns. Due to the importance of Ramsar sites and to preserve for better livelihood, this paper explores the issues and challenges pertaining to the biodiversity of Ramsar sites in Tamil Nadu for better management through appropriate solutions.

Keywords

biodiversity; conservation; Ramsar site; wetland

Introduction

Biodiversity, or biological diversity, refers to the variety of life on earth, including species diversity, genetic variation, and ecosystems. It is critical in ecosystem services like pollination, water purification, and climate regulation (1). It also contains a vast spectrum of plants, animals, fungi, microorganisms, and diverse ecosystems ranging from oceans to mountain peaks (2). For instance, coral reefs support numerous marine species and provide resources for coastal communities. Biodiversity also enhances resilience to environmental changes and diseases, making it essential for sustainable development and human well-being. Understanding its connections highlights its importance in maintaining ecological balance and supporting life. Biodiversity mapping is necessary to identify the flora and fauna in the region. It involves creating spatial representations that show the distribution, composition, and richness of species, ecosystems, and genetic variation across landscapes or regions. It integrates the abundance, variability, and diversity of life, spanning ecosystems, species, and genetic variation within the species (3). It also contains a vast spectrum of plants, animals, fungi, microorganisms, and diverse ecosystems ranging from oceans to mountain peaks and everything in between. Biodiversity is fundamental in stabilizing ecosystems, regulating the water cycle, and ensuring resilience against climate change. It provides numerous ecosystem services that are essential for human well-being. These services include clean air and water, fertile soil, and climate regulation.

Additionally, biodiversity supports the pollination of crops, pest control, and the provision of food, medicine, and raw materials. Mapping biodiversity is essential for identifying the distribution of flora and fauna, understanding ecosystem functions, and monitoring changes over time. It involves creating spatial representations that show the distribution, composition, and richness of species, ecosystems, and genetic variation across landscapes or regions. It is crucial for conservation, ecological research, land management, and policy-making. It is also essential for conservation, environmental research, land management, and policy-making (4).

From a biodiversity perspective, areas with continuous water sources are highly productive and biologically diverse, *i.e.,* wetlands, river basins, and floodplains. (5). Wetlands lie between vegetative and aquatic systems, with shallow water overlaying the ground and the water table, often at or near the surface (6). Wetlands, as defined by the Ramsar Convention on Wetlands (established in 1971), are "areas of marsh, fen, peatland, or water" and are broadly categorized into three types: inland wetlands, marine or coastal wetlands, and man-made wetlands.(7). It encompasses marine and inland marshes, covering over 12.1 million km^2, with 54 % permanently submerged and 46 % seasonally inundated. A Ramsar site is a wetland recognized for its international importance, protected under the Ramsar Convention—an international treaty dedicated to the conservation and sustainable use of wetlands worldwide. As of 2024, there are over 2,453 Ramsar Sites globally, covering a total area of more than 255 million hectares, with participation from 171 national governments. Coastal marine and inland marshes encompass over 12.1 million km^2, of which 54 % are continuously underwater and 46 % are seasonally inundated. Ramsar Sites are crucial in mitigating these effects by protecting vital wetland ecosystems. These sites provide essential services, such as flood regulation, water purification, and carbon sequestration, essential for climate adaptation and mitigation. (8). Ramsar Sites in Tamil Nadu face several challenges, including habitat degradation, pollution, and lack of awareness that necessitate effective management strategies to ensure long-term conservation and sustainable use.

Current status of Ramsar sites

The convention on wetlands, established in 1960, is the oldest global intergovernmental agreement. It was formulated through dialogues among states and non-governmental organizations in reaction to the escalating loss and deterioration of wetland ecosystems, particularly those vital for migrating waterbirds. The treaty was officially adopted in Ramsar, Iran, in 1971 and came into effect in 1975. (9). Today, the Ramsar sites are the most extensive network of protected areas globally, containing over 2,400 Ramsar sites within the territories of 172 contracting parties worldwide, spanning more than 2.5 million km^2 (10). The world's first site was the Cobourg Peninsula in Australia, which was designated in 1974. Among the largest Sites are Rio Negro in Brazil, covering 120,000 square kilometers, Ngiri-Tumba-Maindombe in the Democratic Republic of Congo and Queen Maud Gulf in Canada, both spanning over 60,000 square kilometres each. Conversely, some Sites are as modest as one hectare in size. Table.1. describes Ramsar sites located in specific regions of countries.

Ramsar sites in India

India is home to diverse wetlands that provide vital ecosystem services, including water supply, flood control, and biodiversity conservation (11) (Fig. 1). Many of these wetlands have been designated as Ramsar Sites, recognized under the Ramsar Convention for their International Importance in conserving wetland biodiversity. India has a total of 75 Ramsar Sites (Table 2). Tamil Nadu has a maximum number of Ramsar sites (14), followed by Uttar Pradesh (12). The mission established by the Convention is: “the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world.” (Convention on Wetlands, Ramsar, 1971).

India has increased its Ramsar sites (Wetlands of International Importance) from 75 to 80 by designating five additional wetlands. The newly recognized sites include Karaivetti Bird Sanctuary and Longwood Shola Reserve Forest in Tamil Nadu, as well as Magadi Kere Conservation Reserve, Ankasamudra Bird Conservation Reserve, and Aghanashini Estuary in Karnataka.

Ramsar sites in Tamil Nadu

In 2023, the Union Ministry of Environment approved two additional Ramsar Sites: Karaivetti Bird Sanctuary and Longwood Shola Reserve Forest. These additions reflect India’s dedication to conserving wetlands of international significance. With this addition, Tamil Nadu now has a total of 16 Ramsar Sites, the highest number in the country (Table 3 and Fig. 2) (The Hindu, February 1, 2024) With this addition, Tamil Nadu now has a total 16 Ramsar Sites, the highest in the country (The Hindu, February 1, 2024).

The Karikili Bird Sanctuary

It borders the small village of Karikili, located 8 km north of Vedanthangal, partially extending into Maduranthangam Taluk, Chengalpattu District, Tamil Nadu (Fig. 3). The sanctuary includes two rain-fed, non-perennial irrigation tanks spanning 58.442 hectares, characterized by generally flat terrain with intermittent undulations and gentle slopes. It consists of rich diversity of flora and fauna, including mangroves like *Avicennia* and *Rhizophora*, herbaceous plants, and wetland vegetation. It is a vital habitat for numerous bird species, such as the Painted Stork, Black-headed Ibis, and Little Egret, as well as small mammals like the Indian Fox and various reptiles, especially during the migratory season. Situated at an elevation of 100 meters above mean sea level (MSL), the sanctuary experiences variable rainfall, ranging from 400 mm to nearly 1700 mm annually. This variability

Table 1. Ramsar sites located in specific regions across different countries

S.No.	Continent	Country	Notable Ramsar Site	Total Area (ha)	Reference
1.	**Europe**	United Kingdom	The Wash, Solway Firth, Loch Lomond, Lough Neagh and Lough Beg, Dyfi Estuary.	154,143	(75)
		France	Camargue, Bassin d'Arcachon, Marais Poitevin, Baie de Somme, Etang de Biguglia	225,450	(76)
		Spain	Donana National Park, Ebro Delta , Tablas de Daimiel, Albufera de Valencia, Lagunas de Ruidera, Marismas de Santoña	155,480	(77)
		Germany	Lake Constance, Wadden Sea, Müritz National Park, Oder Delta , Schorfheide-Chorin Biosphere Reserve, Donau-Auen National Park, Lake Neusiedl	5,426,100	(78)
		Netherlands	Wadden Sea, Oostvaarder splassen Nature Reserve, Lake Ijsselmeer, Biesbosch National Park, Deurnsche Peel and Mariapeel, Lauwersmeer	1,594,70	(79)
		Sweeden	Lake ,,Väddöviken, Kristianstads Vattenrike, Ottenby, Lake Stora Le, Vombsjön,	19,750	(80)
		Greece	Lake Mikri Prespa, Lake Orestiada, Lagoon of Gialov, Kopaïs Lake	15,700	(81)
		Italy	Venezia Lagoon, Mincio River, Orbetello Lagoon, Marismas de Coto Doñana, Cabrera Archipelago	4,400	(82)
		Poland	Biebrza Wetlands	5,900,000	(83)
2	**North America**	United States	Everglades National Park	607,000	(84)
		Canada	Queen Maud Gulf in Canada	6,800,000	(85)
		Mexico	Wetland Complex	2,500,000	(86)
3	**Latin America**	Brazil	Pantanal , Rio Negro	500,000	(87)
		Argentina	Laguna Mar Chiquita	350,000	(88)
		chile	Chiloe Archipelago	12,000	(89)
		colombia	Santander Wetlands Complex	1,400	(90)
		peru	Lake Titicaca	83,000	(91)
4	**Asia**	china	Poyang Lake	2,500,000	(92)
		India	Sundarban, Keoladeo National Park	1,002,873	(93)
		Indonesia	Kepulauan Seribu	107,000	(94)
		Iran	Lake Urmia	520,000	(95)
		Bangladesh	Sundarban	601,700	(96)
		Japan	Kushiro Shitsugen Wetland	26,000	(97)
		Nepal	Sundarijal Wetlands, Rara Lake, Koshi Tappu Wildlife Reserve, Barandabhar Forest	20,583	(98)
		Pakistan	Keenjhar Lake, Hingol National Park, Indus Delta, Rann of Kutch,Tarnab Wetland	15,151,600	(99)
5	**Africa**	South Africa	St. Lucia Wetland Park, Wakkerstroom, Barberspan, The Berg River Wetlands	335,700	(100)
		Kenya	Lake Victoria, Lake Nakuru	6,898,800	(101)
		Uganda	Lake Mburo Wetland , Murchison Falls Wetland	40,000	(102)
		Egypt	Lake Burullus, Lake Burullus, Wadi El Rayan Wetlands, Lake Qaraoun, Gulf of Aqaba	443,000	(103)
		Nigeria	Ogun River Estuary, Kainji Lake National Park, Niger Delta Wetlands	2,735,800	(104)
		Madagascar	Tsimanampetsotsa Wetlands, Lake Alaotra, Belo Sur Mer	24,000	(105)
		Ethiopia	Lake Tana	367,300	(106)
6	**Oceania**	Australia	Cobourg Peninsula, Kakadu National Park	2,130,400	(107)
		New zealand	Firth of Thames	25,000	(108)
		Papua	Tonda Wildlife, Varirata National Park	1,003,000	(109)
		New Guinea	Simeulue Island, Lorentz National Park, Mamberamo River Basin, Tonda Wildlife	7,550,000	(110)

Table 2. Ramsar sites in India

S.No	State	Name of wetlands	Total area (ha)	Citation
1	Andhrapradesh	Kolleru lake	1447133	(111)
2	Assam	Deepor beel	764372	(112)
3	Bihar	Kabartal wetland	403209	(113)
4	Goa	Nanda lake	21337	(114)
5	Gujarat	Wadhvana wetland Nalsarovar bird sanctuary Khijadia wildlife sanctuary Thol lake wildlife sanctuary	3474950	(115)
6	Haryana	Suitanpur National park Bhindawas wildlife sanctuary	42478	(116)
7	Himachal pradesh	Pong dam lake Renuka wetland Chandertal wetland	98496	(117)
8	Jammu & Kashmir	Wular lake Hokera wetland Surinsar –mansar lakes Hygam wetland Conservation reserve Shallbugh wetland conservation reserve	391501	(118)
9	Karnataka	Ranganathittu bird sanctuary	643576	(119)
10	Kerala	Asthamudi wetland Sasthamkotta lake Vembanad kol wetland	1609590	(120)
11	Ladakh	Tso kar wetland complex Tsomorin wetland		(121)
12	Madhyapradesh	Sakhya sagar Bhoj wetlands Sirpur wetlands Yashwant sagar	818166	(122)
13	Maharashtra	Lonar lake Thane creek Nandur madhameshwar	1014522	(123)
14	Manipur	Loktak lake	63616	(124)
15	Mizoram	Pala wetland	13968	(125)
16	Odisha	Chilka lake Satkosia gorge Bitarkanika mangroves Tampara lake Hirakund reservoir Anuspa lake	690904	(126)
17	Punjab	Harike lake Kanjili lake Ropar lake Nangal wildlife sanctuary Beas conservation reserve Keshopur – miani community reserve	86283	(127)
18	Rajasthan	Sambhar lake Keoladeo Ghana	782314	(128)
19	Tamil Nadu	Pichavaram mangrove Karilili bird sanctuary Vellodde bird sanctuary Vadavur bird sanctuary Chithrangudi bird sanctuary Vedanthangal bird sanctuary Vembanur wetland complex Point calimere wildlife and bird sanctuary Gulf of mannar Marine Biosphere Reserve Udayamarthandapuram Bird Sanctuary Koonthankulam Bird Sanctuary Pallikaranai Marsh Reserve Forest Kanjirankulam Bird Sanctuary Karivetti Bird Sanctuary Nanjarayan Bird Sanctuary Longwood Shola Reserve Forest	902534	(129)
20	Tripura	Rudrasagar lake	17542	(130)
21	Uttarakhad	Asan conservation reserve	103882	(131)
22	Uttarpradesh	Sur sarovar Haiderpur Sarsai nawar jheel Sandi bird sanctuary Saman bird sanctuary Bakhira wildlife sanctuary Parvati agra bird sanctuary Samaspur bird sanctuary	1242530	
23	West Bengal	Sunderbans wetland East Kolkata wetlands	1107907	(132)

Table 3. Details of Ramsar sites in Tamil Nadu (Source: Tamil Nadu Wetland Mission Authority)

S.No.	Name of wetland	District	Area	Declaration year
1.	Karikili Bird Sanctuary	Chengalpattu	2480	2022
2.	Point Calimere	Nagapatinam and Tiruvarur	1210	2022
3.	Pallikaranai Marshland	Chennai	2481	2022
4.	Pichavaram Mangrove	Cuddalore	2482	2022
5.	Vedanthangal Bird Sanctuary	Chengalpattu	2477	2022
6.	Vellode Bird Sanctuary	Erode	2475	2022
7.	Vembannur Wetland complex	Kanyakumari	2474	2022
8.	Gulf of Mannar Marine Biosphere Reserve	Ramanathapram	2472	2022
9.	Chitrangudi Bird Sanctuary	Ramanathapram	2491	2022
10.	Suchindram – Theroor wetland complex	Kanyakumari	2492	2022
11.	Koonthankulam Bird Sanctuary	Tirunelveli	2479	2022
12.	Kanjirankulam Bird Sanctuary	Ramanathapram	2486	2022
13.	Udayamarthandapuram Bird Sanctuary	Tiruvarur	2476	2022
14.	Vaduvur Bird Sanctuary	Tiruvarur	2493	2022
15.	Karaivetti Bird Sanctuary	Ariyalur	4.53	2024
16.	Longwood Shola Reserve Forest	Nilgiris	116	2024

leads to periodic flooding during the monsoon months (October to December). It is situated at an elevation of 100 meters above mean sea level (MSL).

Point Calimere

Situated near the southern extremity of Nagappattinam District, Tamil Nadu, the Point Calimere region is acknowledged for its significant contribution to avian conservation (Fig. 4). The area features diverse flora, including mangroves like *Avicennia* and *Rhizophora*, halophytic plants in salt marshes, and grasses in grasslands. It is a vital habitat for numerous migratory birds, such as the Black-headed Ibis, Greater Flamingo, and Painted Stork. Additionally, it supports mammals like the Indian Fox and Blackbuck, as well as reptiles, including the Olive Ridley Turtle. Overall, Point Calimere plays a significant role in preserving biodiversity, particularly for migratory bird populations. During the monsoon season, water levels gradually diminish. By the end of January, most of the water in the forested and low-lying regions becomes saline due to evaporation and saltwater intrusion. By the end of January, the remaining water evaporates, leaving compacted mud that gradually transforms into fine powdery dust as summer progresses.

The Pallikaranai Marshland

Located at coordinates 12.949371 N latitude and 80.218184 E longitude, it is one of the last remaining natural wetlands in Chennai city (Fig. 5). Locally referred to as 'kazhuveli' in Tamil, signifying a floodplain or waterlogged area, it is bordered on the east by the Buckingham Canal and the Old Mahabalipuram Road, home to the Information Technology (IT) Corridor. Its flora includes wetland vegetation, such as various grasses and sedges, some mangrove species and dominant reeds like *Phragmites*. The marshland is a vital stopover for migratory birds, including the Painted Stork, Black-winged Stilt, Common Teal, and Indian Pond Heron. Additionally, it is home to small mammals like the Indian Fox, reptiles such as the Indian Cobra and monitor lizards, and various frog species. This marshland is crucial for supporting both resident and migratory wildlife. Mixed residential and institutional land uses characterize its southern and western perimeters. To the north lie dense human settlements and public infrastructure like the Mass Rapid Transit System. Covering an area of 250 km^2 in South Chennai, the Pallikaranai Marsh drains through two outlets, Okkiyam Madavu and Kovalam Creek, eventually flowing into the Bay of Bengal. Its topography ensures a consistent storage capacity, establishing a quintessential wetland ecosystem.

The Pichavaram mangrove

Covering 1478 hectares, it is situated between two significant estuaries: the Vellar estuary to the north and the Coleroon estuary to the south in the Cuddalore district (Fig. 6). This area forms the Killai backwater and Pichavaram mangroves. Interconnected by the Vellar and Coleroon river systems, these backwaters offer ample opportunities for water sports such as rowing, kayaking, and canoeing. What makes the Pichavaram forest unique is the sight of mangrove trees rooted in just a few feet of water, creating a striking waterscape ideal for backwater cruises. Key flora includes mangrove species like *Avicennia marina* (Grey Mangrove), *Rhizophora apiculata* (Red Mangrove), and *Bruguiera gymnorhiza* (Black Mangrove), along with other vegetation such as *Casuarina equisetifolia* and Phragmites karka. The area is home to various fauna, including migratory and resident birds like the Spot-billed Duck and Painted Stork and mammals like the Fishing Cat. Reptiles such as the Saltwater Crocodile and diverse fish species, including Barramundi,

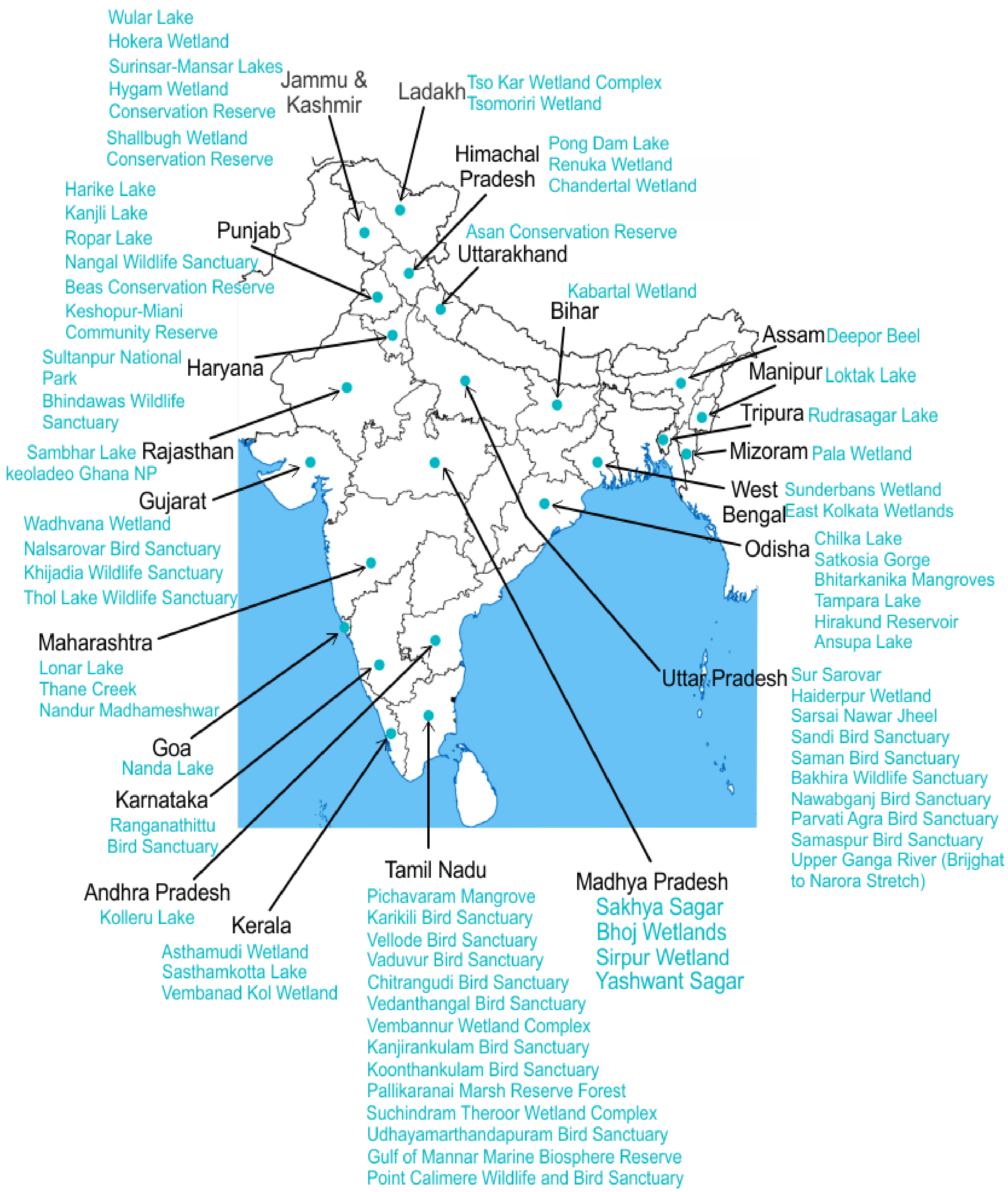

Fig.1. Location of Ramsar sites in India (Source: Tamil Nadu Wetland Mission Authority).

thrive in this unique ecosystem. Pichavaram is vital for biodiversity conservation and supports a wide range of species.

Vedanthangal Bird Sanctuary

The sanctuary, one of the oldest avian protected areas in the nation and Tamil Nadu, is in Maduranthagam Taluk of Chengalpattu District (formerly Kancheepuram). It includes a small irrigation tank spanning 40 hectares within Vedanthangal village and the surrounding 5 km radius around the lake (Fig. 7). Key flora includes wetland vegetation such as grasses and sedges, along with Tamarind trees (*Tamarindus indica*) and Neem trees (*Azadirachta indica*), which provide essential habitats. The sanctuary is home to diverse bird species, including the Painted Stork, Black-headed Ibis, Little Egret, Common Teal, and Grey Heron. Small mammals like the Indian Fox, reptiles such as the Indian Cobra, and various fish species also thrive in the area. Internationally recognized as an Important Bird and Biodiversity Area (IBA) under the code IN284, Vedanthangal meets Criteria A1 (species of global conservation concern) and A4iii (significant congregations of birds). It is categorized within the Coromandel Coast Biotic Province, known for its rich coastal wetlands and diverse bird species.

The Vellode Bird Sanctuary

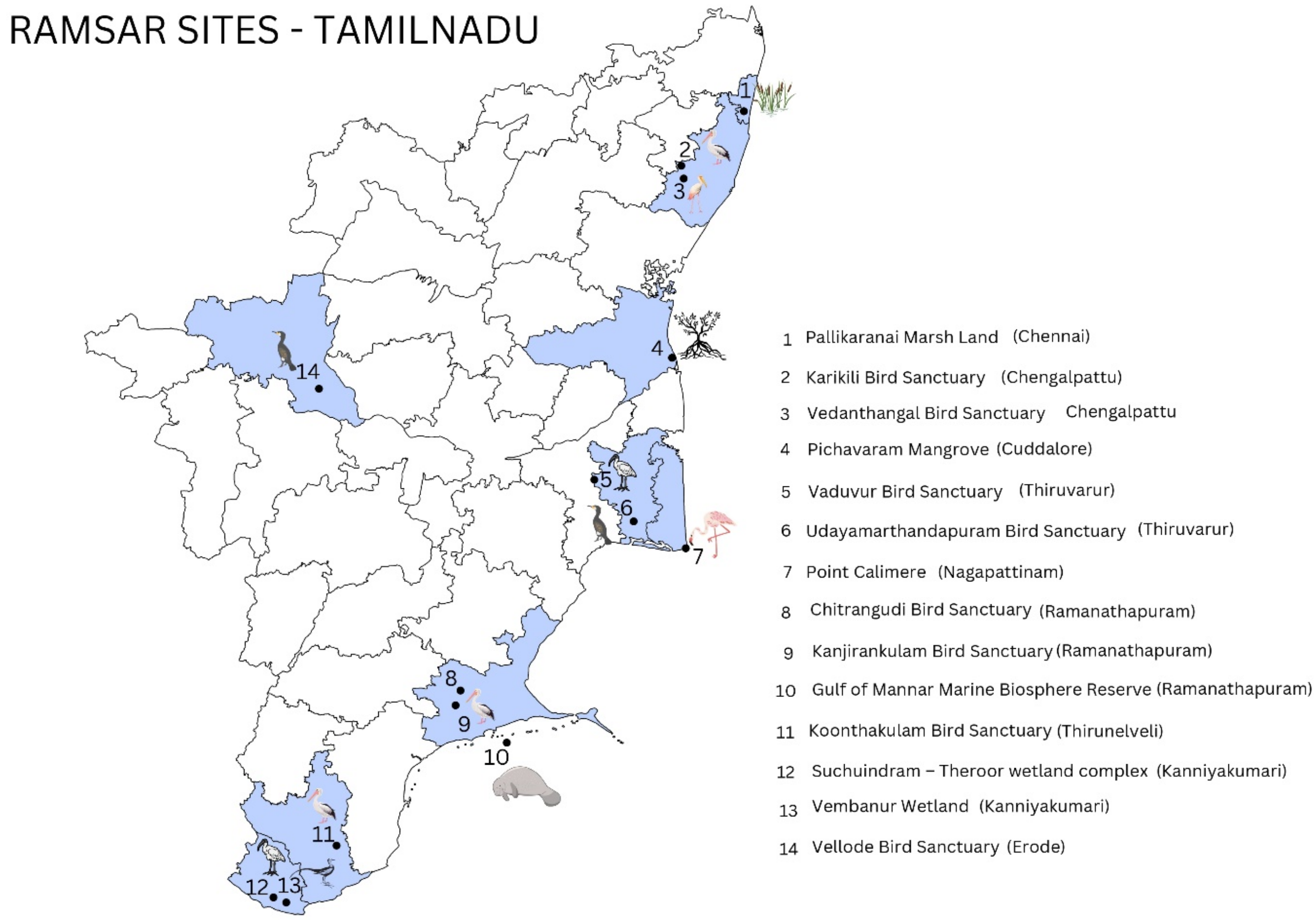

Fig.2. Location of Ramsar sites in Tamil Nadu (Source: Tamil Nadu Wetland Mission Authority).

It is in Vadamugam Vellode Village within the Perundurai Taluk, Erode District, Tamil Nadu, India (Fig. 8). Situated about 12 km from Erode along the Chinnamalai main road, it spans approximately 77 hectares. It showcases diverse flora like water hyacinth and lotus and supporting fauna such as painted storks, jungle cats, and various reptiles, all of which are crucial for local ecosystems. The sanctuary experiences temperatures ranging from a maximum of 38°C in summer to a minimum of 19°C in winter, creating a seasonal environment for the birds that visit the area. Rainfall occurs predominantly during the Northeast monsoon season (September to December), replenishing the sanctuary's water bodies and supporting migratory bird species.

The Vembanur wetland

Situated near Vembanur, a small hamlet in Rajakkamangalam Block, Kanniyakumari District, is an artificial inland tank covering approximately 20 hectares (Fig. 9). This wetland is designated as an important bird and biodiversity area due to its critical role in supporting diverse bird species, including migratory populations. It also provides essential habitats such as marshes and reed beds, supports threatened species, and offers vital ecological services like water purification and flood control. Additionally, the wetland sustains local livelihoods through fishing and ecotourism, emphasizing the importance of conservation efforts to protect this rich ecosystem. It is known for its rich biodiversity, supporting diverse flora such as Water Hyacinth and Lotus, and fauna including migratory birds like the Lesser Flamingo, small mammals like Otters, and various freshwater fish, all contributing to essential ecological services and

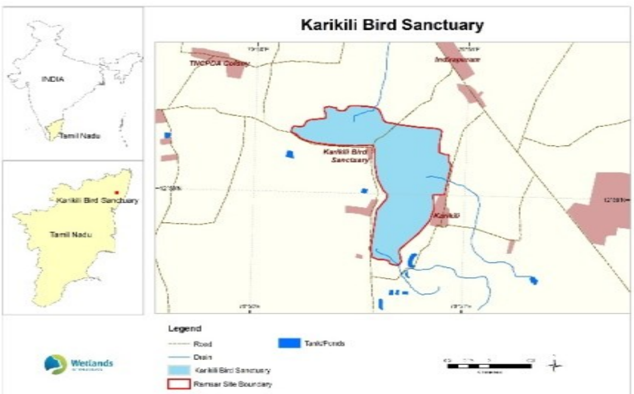

Fig .3. Map of Karikili Bird Sanctuary (Source: Tamil Nadu Wetland Mission Authority).

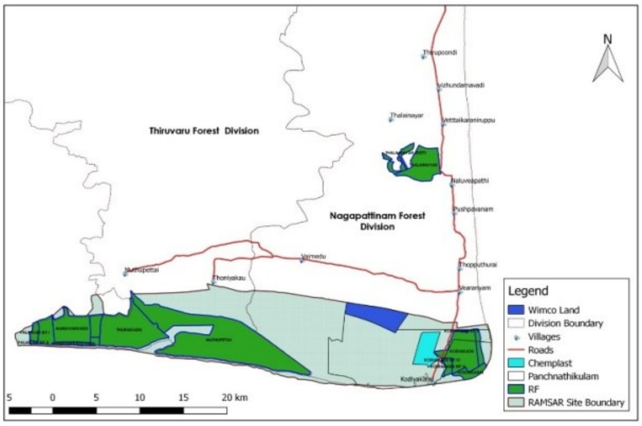

Fig.4. Map of Point Calimere. (Source: Tamil Nadu Wetland Mission Authority).

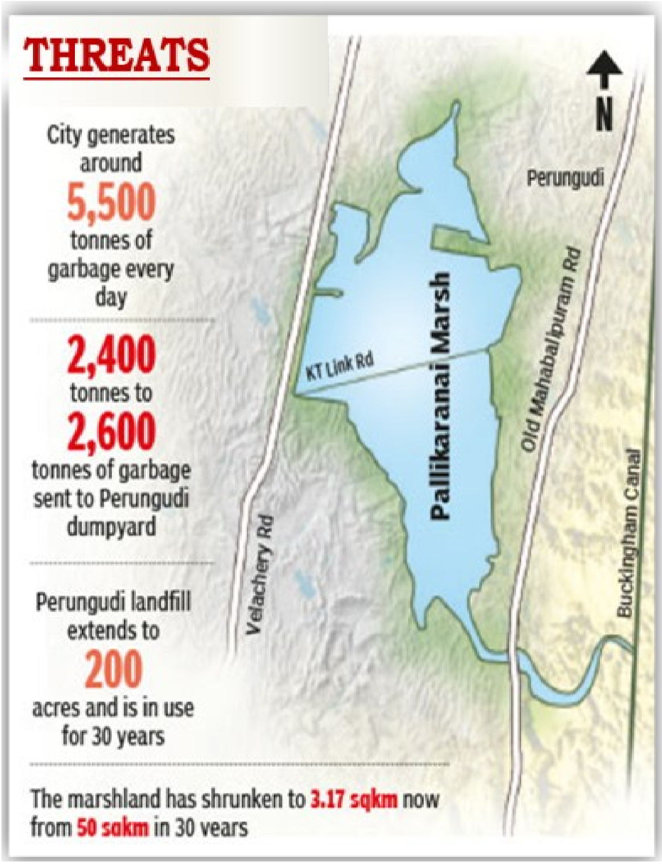

Fig.5. Map of Pallikaranai Marshland. (Source: Tamil Nadu Wetland Mission Authority).

Fig. 6. Map of Pichavaram Bird Sanctuary. (Source: Tamil Nadu Wetland Mission Authority).

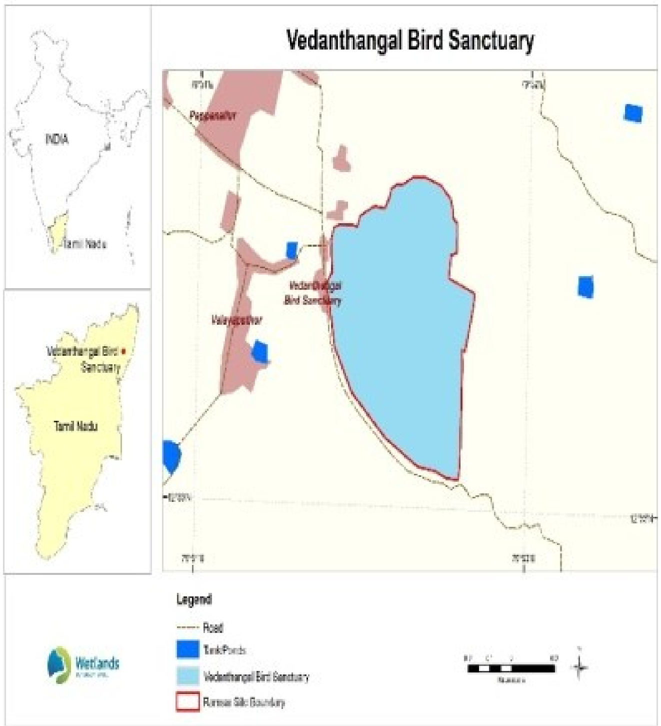

Fig .7. Vedanthangal Bird Sanctuary. (Source: Tamil Nadu Wetland Mission Authority).

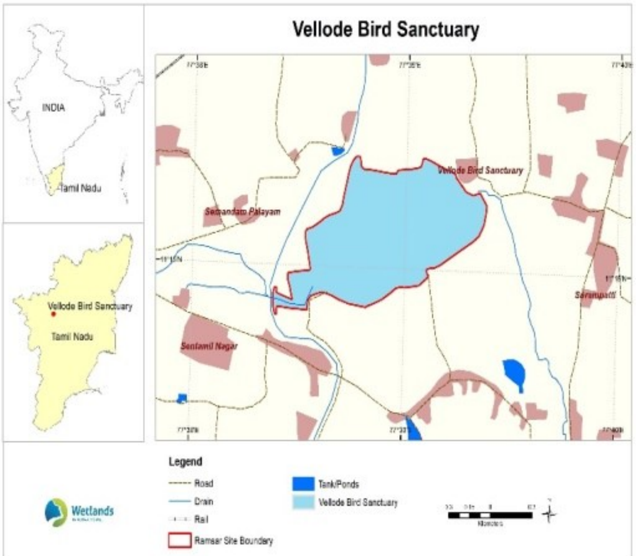

Fig .8. Map of Vellode Bird Sanctuary. (Source: Tamil Nadu Wetland Mission Authority).

biodiversity conservation. Historical records suggest that the tank was constructed during the reign of Pandyan king Veeranarayana, making it a significant feature of local agricultural and water management systems. The tank and Therrakal canal were designed to draw water from the River Pazhayar for irrigation, which also supports the wetland's ecological function. The river Pazhayar and the Vembanur wetland serve as catchment areas for the entire valley's drainage, providing irrigation to Nanchilwadu and supporting wetland biodiversity and water retention.

The Gulf of Mannar

This biosphere reserve stretches across Toothukudi and Ramanathapuram districts, encompassing the southeastern coast of India (Fig. 10). It represents a distinctive marine ecosystem abundant in biodiversity. Also characterized by diverse coral reefs, essential mangrove species, and seagrasses that stabilize the seabed, all supporting a rich array of marine life, including numerous fish species, migratory and resident birds, marine mammals like Spinner Dolphins, and nesting turtles such as the Olive Ridley and Green Turtle, highlighting its critical role in biodiversity conservation and the necessity of its protection for sustaining these ecosystems. Established on 18th February 1989 through a joint declaration by the Government of India and Tamil Nadu, the GoMBR was recognized by UNESCO's Man and Biosphere (MAB) Programme for its ecological significance.

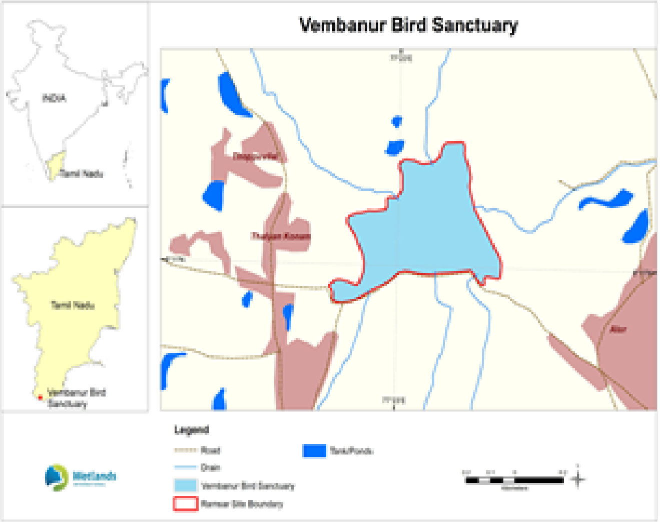

Fig .9. Map of Vembanur wetland. (Source: Tamil Nadu Wetland Mission Authority).

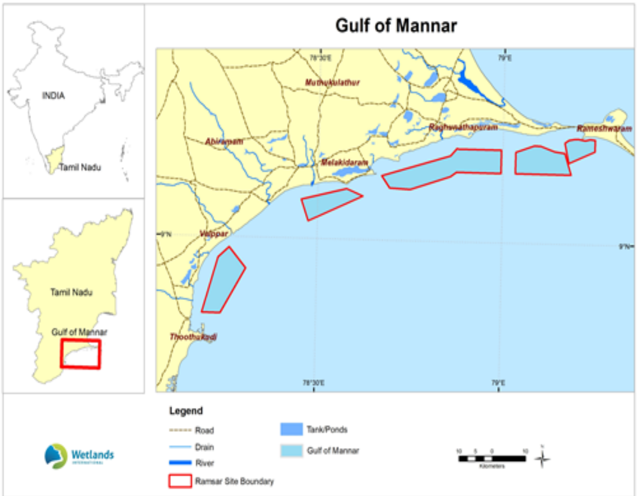

Fig.10. Map of the Gulf of Mannar. (Source: Tamil Nadu Wetland Mission Authority).

Chitrangudi Bird Sanctuary

This place is located 5 km from Mudukulathur and 25 km from Paramakudi in Ramanathapuram and was declared a Bird Sanctuary and protected area in 1989 (Fig. 11). The Sanctuary is enclosed by 15 m (49 ft) high embankments surrounding a community irrigation tank. The total embankment stretches for 4.01 km (2.492 miles) and encloses an area of 260 hectares. It is renowned for its rich avian biodiversity, supporting key flora such as water hyacinth and lotus, and fauna including migratory species like the lesser flamingo, resident birds like the painted stork, and a variety of mammals, reptiles, and fish, all of which underscore its critical role in conserving wildlife and their habitats. Bottom of FormThe Fluvial landforms around the Chitrangudi wetland include floodplains from Vaigai, Varshalei, Pambar, Kottakkarai, and Gundar rivers. In contrast, marine landforms feature sand mounds (Teri dunes) and barrier dunes along the coast.

The Suchindrum Theroor Wetland

This is a constituent of the Suchindrum-Theroor Manakudi Conservation Reserve, covering an area of 94.229 hectares. Commonly referred to as Suchindrum Eri & Theroor Kulam, it is situated in Kanniyakumari district, Tamil Nadu (Fig. 12). It is known for its rich biodiversity, featuring key flora such as Water Hyacinth, Lotus, and various grasses, alongside limited mangrove species like *Avicennia* and *Rhizophora*. It supports diverse fauna, including migratory birds like the Lesser Flamingo and Black-tailed Godwit, resident species such as the painted stork and little egret, and small mammals like jungle cats. Additionally, it is home to various reptiles and freshwater fish, making it vital for ecological balance and biodiversity conservation in the region. The Theroor tank receives water from the Thovalai channel, while the Pazhaiyar river channel feeds the Suchindram tank. Positioned at an intermittent point of the Kodaiyar River drainage system, the wetland complex serves as a collection point for water. This water is released from the Perunchanidam, Pechipparai, and Kodaiyar dams and flows into the channel, draining numerous ponds.

Koonthankulam Bird Sanctuary

It is also known as Kunthankulam and is a significant artificial wetland in Tamil Nadu (Fig. 13). Encompassing an area of 72 hectares, this wetland is situated near Koonthankulam village in Nanguneri Taluk of Tirunelveli district. It supports a rich diversity of flora and fauna, including key species such as various aquatic plants, migratory and resident birds, Spot-billed Duck (*Anas poecilorhyncha*), Painted Stork (*Mycteria leucocephala*), Common Coot (*Fulica atra*) small mammals, and reptiles, highlighting its significance for biodiversity conservation. Designated as a bird sanctuary in 1994, it falls

Fig.11. Map of Chitrangudi Bird Sanctuary. (Source: Tamil Nadu Wetland Mission Authority).

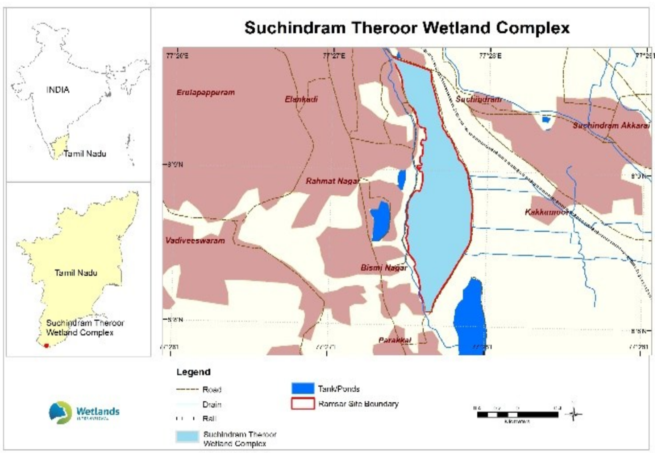

Fig.12. Map of Map of Suchindrum Theroor wetland. (Source: Tamil Nadu Wetland Mission Authority).

under the purview of the Tamil Nadu Water Resources Department (PWD) and the Tamil Nadu Forest Department, Tirunelveli district. Constructed several centuries ago, the inland tank is interconnected by canals drawing water from rivers originating in the Western Ghats. These rivers and tanks hold immense social and cultural significance and play a pivotal role in supporting agriculture by irrigating. The interaction between the rivers and tanks surrounding Koonthankulam Bird Sanctuary is vital for both local agriculture and conservation, as these water bodies sustain wetland ecosystems, support biodiversity, engage communities in stewardship, promote ecotourism, and enhance water quality, illustrating the potential for harmonious coexistence between sustainable resource management and ecological preservation.

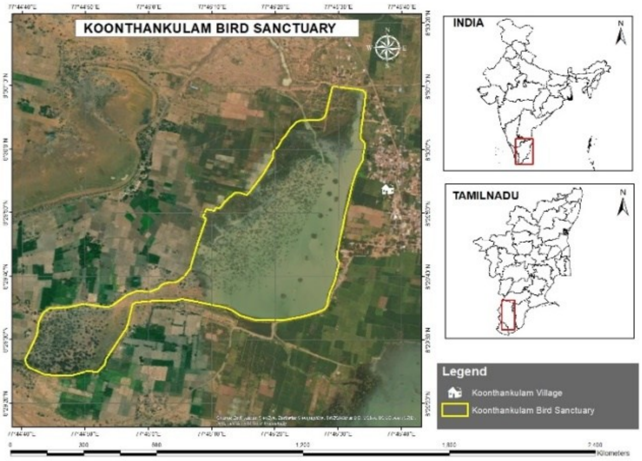

Fig.13. Map of Koonthankulam Bird Sanctuary. (Source: Tamil Nadu Wetland Mission Authority).

The Kanjirankulam Bird Sanctuary

It is a designated protected area near Mudukulathur in Ramanathapuram District, Tamil Nadu, India, established in 1989 (Fig. 14). It is located within the village of Kanjirankulam in southern Tamil Nadu. The sanctuary spans an estimated area divided between Keela (lower) Kanjirankulam, covering 66 hectares, and Mela (upper) Kanjirankulam, spanning 30.231 hectares. It is a vital wetland ecosystem that supports a diverse array of flora and fauna, including key aquatic plants, *Prosopis juliflora* and *Acacia nilotica*, Nelumbo *nucifera,* and a variety of migratory and resident birds, Spot-billed Duck (Anas *poecilorhyncha*), Painted Stork (Mycteria *leucocephala*), Black-winged Stilt small mammals, and reptiles, underscoring its significance for biodiversity conservation.

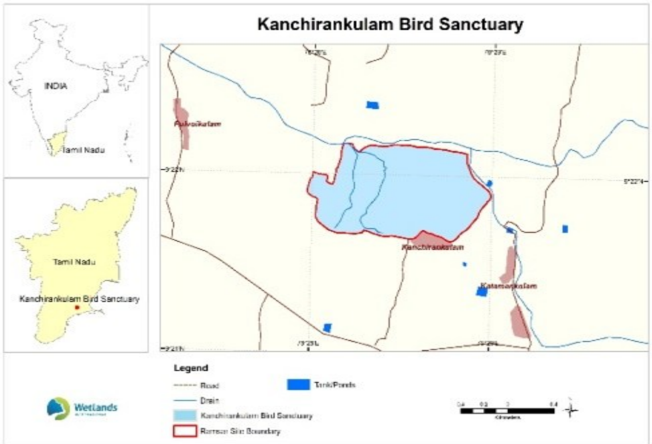

Fig.14. Map of Kanjirankulam Bird Sanctuary. (Source: Tamil Nadu Wetland Mission Authority).

Udayamarthandapuram

Udayamarthandapuram is a significant bird sanctuary in Tamil Nadu, located within the administrative jurisdiction of Thiruthuraipoondi taluk, Muthupet Block, Tiruvarur district (Fig. 15). Established in 1998, the sanctuary covers approximately 44 hectares and is near the confluence of the Baminiyar and Kannanaar Rivers. It is a vital wetland habitat that supports a rich diversity of flora and fauna, including key aquatic plants, numerous migratory and resident birds, small mammals, and various reptiles, highlighting its significance for biodiversity conservation.

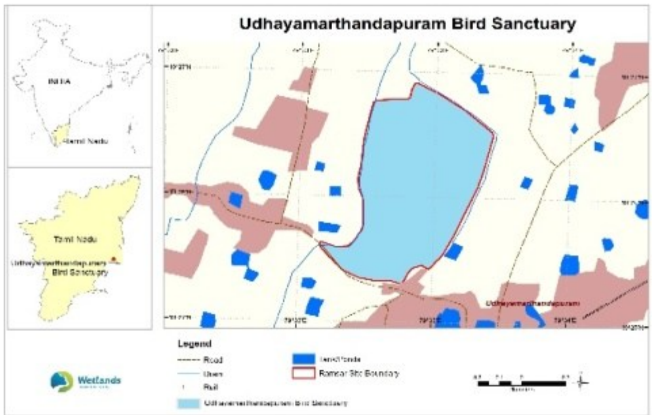

Fig.15. Map of Udayamarthandapuram. (Source: Tamil Nadu Wetland Mission Authority).

The Vaduvur bird sanctuary

A large human-made irrigation tank, spanning roughly 113 hectares, is situated in Needamangalam taluk, Thiruvarur district (Fig. 16). It lies partly within the Cauvery delta, relying on water releases from the Mettur dam to sustain its ecosystem. It is a vital wetland ecosystem that supports a rich diversity of flora, species such as *Typha angustifolia* and *Phragmites australis* and fauna, Spot-billed Duck (*Anas poecilorhyncha*) Painted Stork (*Mycteria leucocephala*) Black-winged Stilt (*Himantopus himantopus*) Common Coot (*Fulica atra*) including key aquatic plants, a variety of migratory and resident birds, small mammals, and reptiles, underscoring its importance for biodiversity conservation. Encircled by a substantial bund to the south and a shorter one to the north, the natural elevation acts as a barrier, retaining water up to a depth of 2.5 meters. With four outlets and discharge canals, potable groundwater is accessible at depths ranging from 20 to 50 meters.

The Karaivetti bird sanctuary:

It is situated in the Ariyalur district and covers roughly 454 hectares (Fig. 17). Positioned within the central Asian Flyway, this sanctuary is a crucial breeding and foraging habitat for resident and migratory birds. It is a vital wetland ecosystem that supports a rich diversity of flora species such as Typha a*ngustifolia* and Phragmites *australis* and fauna, Spot-Billed Duck (*Anas poecilorhyncha)*, Painted Stork *(Mycteria leucocephala)*, Black-winged Stilt *(Himantopus Himantopus).*

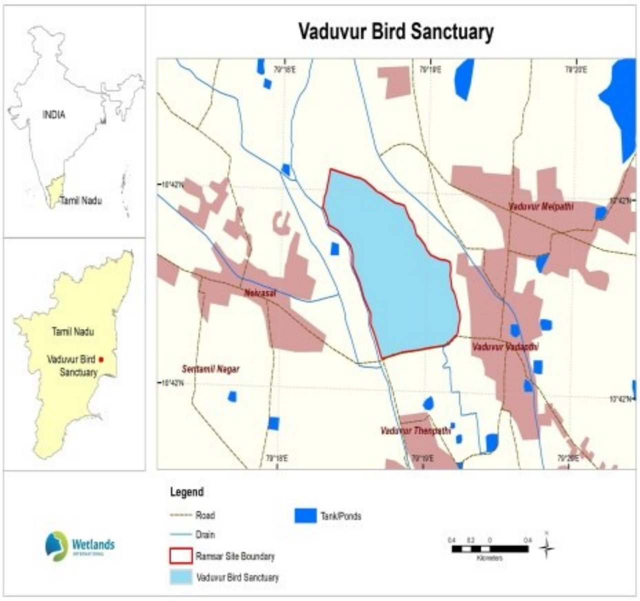

Fig.16. Map of Vaduvurbirdsanctuary. (Source: Tamil Nadu Wetland Mission Authority).

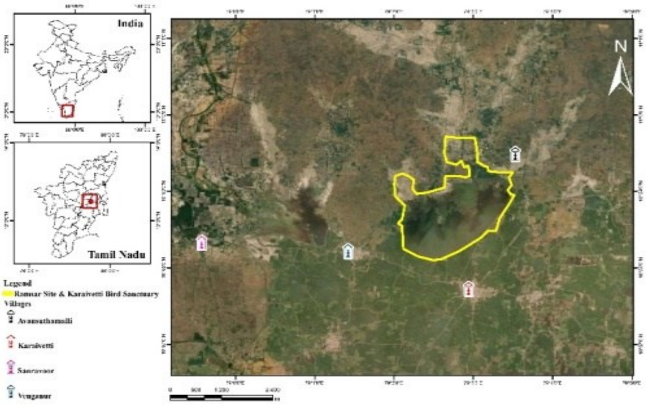

Fig.17. Map of Karaivettibirdsanctuary(Source: Tamil Nadu Wetland Mission Authority)

Recognized as a Ramsar site with site number 2537, the Karaivetti Bird Sanctuary holds significance as one of the Important Bird Areas (IBAs) of Tamil Nadu (Code No. IN – TN - 13, Criteria: A1, A4i, A4iii). The site accommodates a diverse flora and fauna, providing a home for more than 500 species.

Longwood Shola Reserve Forest

Longwood Shola Reserve Forest, located in the Nilgiris District, covers approximately 116 hectares (Fig. 18). The Shola forests of South India derive their name from the Tamil word "Solai," which means 'tropical rain forest.' is a critical montane ecosystem that harbors a rich diversity of flora and fauna, including unique grasslands Dominated by grasses such as Arundinella and Themeda, endemic birds, Nilgiri Tahr (*Nilgiritragus hylocrius)* Malabar Grey Hornbill (*Ocyceros griseus*) Indian Pitta (*Pitta brachyura*) and key mammals, underscoring the importance of conserving this fragile environment. The wetland has been declared as a Ramsar site with site number 2538.

Criteria for designating as Ramsar Sites

The Ramsar convention on Wetlands has designed nine criteria for identifying Wetlands of International Importance. To qualify as a Ramsar site, any site must meet one or more of the following criteria in Table 4.

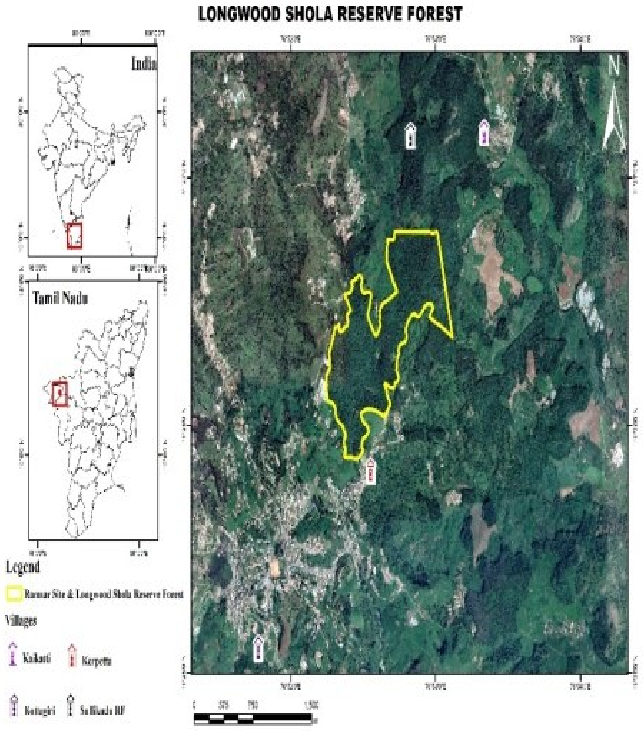

Fig.18. Map of Longwood Shola Reserve Forest. (Source: Tamil Nadu Wetland Mission Authority).

Need for preserving biodiversity

Preserving biodiversity is essential for the well-being of our planet and its inhabitants. Biodiversity provides ecosystem services, including clean air and water, pollination of crops, and disease regulation, it refers to the strategies and policies put in place to prevent, control, and manage the spread of diseases within populations. It enhances ecosystem resilience, making it more adaptable to environmental changes. Biodiversity also contributes to scientific and medical advancements, while cultural and aesthetic values enrich human experiences. Conservation efforts are crucial to maintaining a balanced, sustainable environment that supports life and safeguards ecosystems' intricate web of interdependencies.

Importance of biodiversity

Biodiversity refers to the variety of life forms within an ecosystem, which includes all organisms and their interactions with both biotic (living) and abiotic (non-living) environmental conditions(13). Biodiversity encompasses the diversity of ecosystems, which includes ecological communities in a particular habitat and the environmental conditions in which they exist, as well as the variety of organisms at all levels, from genetic variants within the same species to arrays of different species (14). The variety of life forms at all levels of organization is crucial for the health and functioning of ecosystems and is of profound importance to humanity. Biodiversity contributes to the stability and resilience of ecosystems. Diverse ecosystems can better withstand and recover from disturbances like extreme weather events, diseases, and invasive species. These ecosystems provide many ecosystem services essential for human well-being, including pollinating crops, regulating climate, purifying air and water, nutrient cycling, soil formation, and flood control.

Table 4. Criteria for designating Ramsar sites

Group A: Sites containing representative, rare or unique wetland types	**Group B:** Sites of international importance for conserving biological diversity. Criteria based on species and ecological communities
Criterion 1: If a wetland includes a representative, rare, or singular illustration of a natural or near-natural wetland type located within the suitable biogeographic area, it should be deemed internationally significant.	Criterion 2: If a wetland sustains vulnerable, endangered, or critically endangered species or imperiled ecological communities, it merits recognition as internationally significant. Criterion 3: If a wetland harbors populations of plant and/or animal species crucial for preserving the biological diversity of a specific biogeographic region, it should be acknowledged as internationally significant. Criterion 4: A wetland should attain international importance if it aids plant and/or animal species during pivotal stages in their life cycles or offers sanctuary during unfavorable conditions, with specific criteria cantered on water birds. Criterion 5: A wetland should be recognized as internationally significant if it consistently sustains a population of 20,000 or more water birds. Criterion 6: A wetland's international importance should be acknowledged if it consistently hosts 1 % of the total individuals in a population of a particular species or subspecies of water bird, with specific criteria focused on fish. Criterion 7: A wetland merits international recognition if it sustains a noteworthy portion of native fish subspecies, species, or families, along with diverse life-history stages, species interactions, and/or populations that epitomize the advantages and values of wetlands, thus enhancing global biological diversity. Criterion 8: A wetland's international significance should be acknowledged if it serves as a vital food source for fishes, a spawning ground, nursery, and/or migration route crucial for fish stocks, whether within the wetland or beyond. Specific criteria are based on other taxa. Criterion 9: A wetland warrants international recognition if it consistently sustains 1 % of the individuals within a population of one species or

Biodiversity is broadly classified into three categories based on three criteria. The first is the differences in genetic information among individuals or populations of the same species, including plants, animals, and microorganisms (15). On the other hand, species diversity is the variation of different species within a given ecosystem or region (16). Thirdly, the ecosystem diversity includes the variety of habitats, ecosystems, and physical structures, ranging from forests and wetlands to coral reefs and grasslands. (17).

Biodiversity provides a vast source of genetic variation within species, which is crucial for the survival and adaptability of organisms. This genetic diversity is essential for breeding programs in agriculture, forestry, and aquaculture, helping to develop crops and livestock with improved productivity, disease resistance, and adaptability to changing environmental conditions. Many pharmaceuticals and traditional medicines are derived from plants, animals, and microorganisms. Biodiversity provides many natural compounds used to develop drugs to treat various diseases and health conditions. Apart from these, Ramsar sites support industries such as agriculture, forestry, fisheries, and tourism. These industries are vital sources of income and livelihoods for millions of people worldwide. Additionally, they enrich human cultures and societies, inspiring art, literature, spirituality, and recreation. Many indigenous cultures have deep spiritual and cultural connections to the natural world, reflected in their traditions, beliefs, and practices..

Biodiverse ecosystems, such as forests, wetlands, and mangroves, play a critical role in regulating the earth's climate by sequestering carbon dioxide, a major greenhouse gas responsible for global warming. Biodiversity is essential for global food security. A diverse range of plant and animal species provides the genetic resources to develop new crop varieties and livestock breeds. This adaptability is crucial for coping with changing environmental conditions and pests, ensuring a stable and nutritious food supply for growing populations. It also increases the resilience of ecosystems and societies to environmental change and disturbances, including climate change, habitat loss, pollution, and invasive species. We enhance our capacity to adapt and thrive in a rapidly changing world by preserving biodiversity.

Mapping biodiversity

This mapping facilitates evidence-based conservation planning by identifying habitats, tracking species, and evaluating environmental variables such as water levels and vegetation cover. This process, facilitated by Geographic Information System (GIS) and remote sensing technologies, provides a detailed understanding of the wetland's ecological diversity. Such mapping enables evidence-based conservation planning by identifying habitats, tracking species, and assessing environmental variables. It helps prioritize areas for protection, monitor changes over time, and engage local communities in data collection and decision -making processes. Ultimately, mapping biodiversity in Ramsar sites is essential for preserving these valuable ecosystems and ensuring their long-term health and resilience.

Biodiversity e-infrastructures encourage education and successful public policies in addition to promoting data accessibility and usability for science. This is especially true for sustainable development, as important biodiversity metrics are hampered and skewed by a lack of accurate information about species' prosperity distribution and status (18).

Mapping habitats

A GIS is used to map and evaluate diverse habitats, which aids in understanding species distribution. This information is crucial for restoring and conserving habitat.

Species distribution modeling (SDM)

A GIS is used to build models that forecast species distributions in response to environmental conditions. Species Distribution Modeling aids in the identification of appropriate habitats and prospective sites for conservation by combining data on species occurrences with environmental characteristics.

The identification of biodiversity hotspots

Areas with high levels of endemism and species richness are made easier using GIS. Conservation activities might be targeted in these areas to protect the greatest number of species.

Corridor planning

Wildlife corridors must be identified and planned using GIS to preserve connectivity between fragmented habitats. By facilitating species mobility, these corridors lower the danger of isolation and increase genetic variety.

Threat mapping

The Threats to biodiversity are mapped and analyzed using GIS. It includes habitat destruction, deforestation, and climate change. This knowledge is essential for creating conservation plans that lessen these risks.

Community-based conservation

Local knowledge is incorporated into conservation efforts by including local communities through GIS. The programs to conserve biodiversity can be more successful if the resources are mapped and local communities are involved in data collection.

Monitoring and surveillance

Using satellite imagery and remote sensing, GIS makes monitoring biodiversity in real-time possible. This facilitates monitoring alterations in land use, deforestation, and other environmental elements impacting biodiversity.

Management of protected areas

Geographic Information System makes planning, organizing, and creating protected areas easier. It assists in planning new reserves, evaluating the efficacy of current ones, and keeping track of changes in land use in the surrounding areas.

Challenges in Ramsar sites

Wetlands are among the world's most threatened ecosystems, and the wildlife that depends on them is increasingly endangered due to habitat destruction, pollution, and other human activities. Wetlands face numerous and tremendous threats, such as natural and anthropogenic threats, and are disappearing three times faster than forests. Some common threats are habitat destruction, wastewater discharge, weed infestation, pollution, invasive species, over-harvesting, unregulated tourism, and climate change (19).

In developing countries, key issues include inadequate knowledge and data, population and development impacts, poor regulatory and planning processes, and socio-economic inequities and conflict (20-22). This is compounded by the uneven growth of Ramsar Sites globally, with a need for increased site and area representation, improved management, and reporting (20). As the Ramsar Convention requires, integrating wetlands into river basin management is also a challenge, with barriers including mismatched priorities and a lack of recognition of ecosystem services(21). These challenges underscore the need for comprehensive, integrative approaches that address local needs and perspectives and for increased commitment, resourcing, and stakeholder engagement (22).

The management of Ramsar sites in Tamil Nadu, India, faces various challenges, including encroachments, pollution, and inadequate governance (20,23-25). Biodiversity-related problems in Ramsar sites are critical issues that threaten the rich and diverse array of plant and animal species found in these wetland ecosystems. Some problems related to biodiversity in Ramsar sites includes:

Habitat Loss and Fragmentation

Urbanization, agriculture, and infrastructure development can result in the loss and fragmentation of wetland habitats, directly impacting the biodiversity of Ramsar sites. Habitat loss can lead to declines in populations of various species, affecting their ability to find suitable breeding, feeding, and nesting grounds (23). Habitat loss and fragmentation are significant threats to biodiversity, often exacerbated by other factors such as hunting and fire (24). Human activities, particularly deforestation and changes in land use, are key drivers of habitat fragmentation. This process can reduce continuous habitats into smaller, distinct patches, impacting the quality and connectivity of these habitats (25). The consequences of habitat fragmentation include habitat loss, increased edge habitat, and isolation effects, with variable responses from species (26). These findings underscore the need for further research and conservation efforts to address the challenges posed by habitat loss and fragmentation.

Invasive Species

The introduction of invasive plant and animal species can outcompete native species, disrupt the ecological balance, and pose a threat to the diversity of Ramsar site ecosystems. The water hyacinth has significantly disrupted nutrient cycling and outcompeted native plants in many wetland ecosystems (27). Common Reed, water hyacinths, particularly invasive plants, can drastically alter ecosystems by monopolizing resources such as sunlight and water, leading to the decline of native species. The spread of these species is facilitated by various vectors, including human activities, and effective management strategies are crucial in preventing new invasions (28). The term "invasive species" refers to non-native species that cause harm in their new environments (29). The increasing globalization of commerce, through the movement of goods and people, facilitated the spread of invasive species, necessitating the development of strategies to address this growing problem (30).

Pollution

Agricultural runoff, industrial discharges, and untreated sewage can introduce pollutants into wetland ecosystems, affecting water quality and directly threatening aquatic biodiversity. Pollution can lead to declines in sensitive species, especially those ad Environmental pollution, defined as introducing harmful substances or products into the environment, has become a significant global issue (31). This pollution can take various forms, including air, noise, and water (32). Air pollution, in particular, is a major concern, with contaminants such as dust, fumes, and gas threatening human health and the environment (33). The sources of pollution are diverse, ranging from industrial plants and garbage dumps to military facilities (34). These findings underscore the urgent need for effective pollution control measures to safeguard the environment, public health, and specific water quality conditions.

Climate Change

Changes in temperature, precipitation patterns, and sea levels associated with climate change can alter the habitats and distribution of species within Ramsar sites. Climate-induced stress can affect the reproductive success and survival of various plant and animal species. Climate change is a complex and multifaceted issue driven by various factors, including carbon emissions, deforestation, and changes in atmospheric composition. While natural processes have historically influenced the earth's climate, human activities have significantly accelerated these changes, mainly by releasing greenhouse gases (35). The impacts of climate change are far-reaching, affecting water resources, ecosystems, food production, and human health. These impacts are expected to intensify in the future, with potential consequences including extreme weather events and rising global temperatures (36)

Over-Exploitation of Resources

Unsustainable fishing, hunting, and harvesting of plants can lead to declines in populations of economically and ecologically important species, affecting the overall biodiversity. Over-extraction of water can alter wetland hydrology, impacting the conditions necessary for diverse species to thrive .The over-exploitation of renewable resources is often driven by misperceptions and inappropriate mental models (37). This is evident in the case of Jordan, where overuse of groundwater resources has led to a drop in levels and deterioration in quality, with significant socio-economic implications. However, the under-exploitation of natural resources can also occur due to market failures and the double role of resource stocks in economies with overlapping generations (38). Despite these challenges, there is hope for the future of food systems, with the potential for new, more sustainable production methods (39).

Disease Spread

Increased human activity, including tourism, can contribute to the spread of diseases affecting wildlife in Ramsar sites. Disease outbreaks can have cascading effects on biodiversity, leading to declines in susceptible species. For example, the chytrid fungus (*Batrachochytrium dendrobatidis*) has caused significant declines in amphibian populations worldwide, resulting in the extinction of several frog species (40). The spread of diseases in Ramsar, Iran, is a significant public health concern, including leishmaniasis, malaria, dengue fever, Zika virus, and schistosomiasis, all of which are influenced by the region's unique ecological conditions and require effective monitoring and control measures (41) . Rabbit Haemorrhagic Disease, a highly fatal viral disease, has been spreading in the Arabian Peninsula, posing potential risks to local wildlife and ecosystems. This is particularly relevant to Ramsar sites in the region, given their ecological importance and proximity to the affected areas. Similarly, there are reports on the occurrence of Rift Valley Fever, a zoonotic disease affecting livestock and humans, in the Arabian Peninsula (42). The spread of these diseases underscores the need for effective surveillance and control measures in Ramsar.

Altered Hydrology

Changes in water flow and hydrological patterns due to human activities, such as dam construction or land drainage, can impact aquatic species' reproductive and feeding behaviors (43). The alteration of hydrology in Ramsar wetlands has been a significant concern, with studies highlighting the impact on vegetation and ecosystems. The Bakhau Wetland has experienced habitat reduction for migrating birds and fish due to upstream dam building, resulting in disturbances to their nesting and feeding patterns (44). The reduced freshwater inflow in the Sundarbans has caused declines in native mangrove species like Sundari (*Heritiera fomes*), which is vital for shoreline stability and biodiversity (45). In Vembanad Lake, changes in water flow have facilitated the spread of invasive water hyacinth (*Eichhornia crassipes*), which outcompetes native flora and disrupts local fish populations (46). One study demonstrated the successful restoration of a coastal salt marsh in an Australian Ramsar site through controlled tidal inundation (47). In Greece, rising water levels at the Kerkini Reservoir led to the disappearance of reedbeds and a decline in forested areas, negatively impacting local biodiversity (48). Another study emphasized the need to consider historical inundation patterns in the restoration and management of the Doñana marshes, which have been significantly altered by human transformations (49). A study highlighted the critical need for ecosystem management and restoration in the Sambhar wetland in India, noting a substantial decrease in waterbody size and a loss of saline characteristics (50). These studies highlight the complex and varied impacts of altered hydrology in Ramsar wetlands, underscoring the need for site-specific restoration and management strategies.

Lack of Connectivity

Infrastructure development and habitat fragmentation can disrupt ecological connectivity within Ramsar sites. Lack of connectivity can isolate populations, reduce genetic diversity, and increase the vulnerability of species to environmental changes (51). The issue of connectivity in various contexts has been addressed in several studies. A study proposed an obstacle-avoiding connectivity restoration strategy for mobile robotic sensor networks (52), while a multi-hop network for Earth-Mars communication was developed in another study (53). A separate study detailed the ONERA RAMSES system, a synthetic aperture radar system, and its applications in urban environments. Finally, a connectivity protocol for star topology using wireless sensor networks was also introduced (54). These studies collectively highlight the importance of connectivity in different fields and the need for innovative solutions to address connectivity challenges.

Inadequate Conservation Measures

Insufficient protection and enforcement of conservation measures can leave Ramsar sites vulnerable to various threats, jeopardizing the biodiversity within these ecosystems. Lack of effective management plans may fail to address the specific needs of different species (55). The Ramsar Convention, while successful in expanding its network of wetlands, faces challenges in ensuring effective conservation measures (56). These challenges include inadequate management planning and reporting and a lack of representativeness in the network. The Convention's effectiveness in preserving wintering waterbirds in the Mediterranean is also questioned, with regional disparities in its impact (57). In the case of the Deepor Beel Ramsar site in India, the lack of a single authority for wetland management and the dependence of local communities on its resources further highlight the need for improved conservation measures (58). Public awareness and education are also crucial in enhancing conservation efforts, as demonstrated in the case of Ramsar wetlands in Slovenia (59).

Management strategies available

The management strategies of Ramsar sites in Tamil Nadu can draw insights from various studies from regions like the Sundarbans and Kerala for wetland ecology, the Godavari Delta for water resource management, Odisha for community involvement, the Gulf of Mannar for climate change adaptation, Vembanad Lake for pollution control, and Chilika Lake for sustainable ecotourism (60). "The need for sustainable ecotourism development is emphasized, with its application to Ramsar sites in the region being particularly significant. It highlight the importance of involving local communities in conservation efforts, a strategy that could greatly benefit Ramsar sites, including those in Tamil Nadu (61). Research highlights the significance of catchment-scale management for the sustainability of Ramsar sites, which could be a key consideration for the region's sites.

Integrated management plans

Developing comprehensive management plans these are essential as they enable a holistic approach to health challenges by optimizing resource allocation, facilitating stakeholder coordination, ensuring preparedness for emergencies, establishing evaluation metrics for continuous improvement, and fostering public trust through organized and proactive management for each Ramsar site is essential (62). These plans should involve stakeholders such as government agencies, local communities, NGOs, and researchers. The plans should outline strategies for conservation, restoration, and sustainable use of wetland resources. A number of research has examined the development and implementation of Integrated Management Plans (IMPs) in Ramsar sites. The adoption of systems-thinking methodology, utilizing the viable system model and partial least squares path modelling, has been conducted to assess the sustainable management of Ramsar sites. A study also emphasized the importance of stakeholder participation and accountability in the planning, implementing, and reviewing of an IMP for the Okavango Delta Ramsar Site in Botswana (63). Another study focused on the adaptive management of the Macquarie Marshes, a Ramsar-listed wetland in Australia, and incorporating climate change adaptation into the IMP (64). Lastly, an evaluation of Turkey's Uluabat Integrated Wetland Management Plan was also performed, highlighting the need for plan revision, additional activities, and integration with a regional rural development project (65). These studies collectively underscore the significance of stakeholder engagement, adaptive management, and continuous plan evaluation in the development and implementation of IMPs in Ramsar sites.

Biodiversity conservation

Conservation of biodiversity within Ramsar sites is a priority. This involves identifying and protecting key habitats, species, and ecological processes within the wetlands. Monitoring programs should be established to track changes in biodiversity over time. Established in 1975, the Ramsar Convention is a key international agreement for the conservation and sustainable use of wetlands. In Jammu and Kashmir, India, Ramsar sites play a crucial role in biodiversity conservation, with 15.6 % of the state-designated protected areas (66). Similarly, in Nepal, Ramsar sites are vital for conserving high-altitude, mid-hill, and terai wetlands, home to endemic and endangered species (67).In Assam, India, the Deepor Beel Ramsar site is a significant wetland with rich biodiversity, including rare, vulnerable, and endemic species (68). These studies collectively highlight the importance of Ramsar sites in biodiversity conservation in various regions.

Water Quality Management

Ensuring good water quality is crucial for the health of Ramsar sites. Measures such as controlling pollution from agricultural runoff, industrial discharge, and sewage should be implemented. Wetland restoration projects can help improve water quality by filtering pollutants and reducing nutrient loading. Afenourir Lake in Morocco, the Indus Delta in Pakistan, and the Ropar Wetland in India, all Ramsar sites, face water quality challenges due to both natural and anthropogenic factors (68-70). These challenges include the influence of climatic hazards, pollution, and contaminants such as heavy metals and coliform bacteria. The need for urgent management and monitoring of these sites is emphasized, with a focus on protecting water-chemistry characteristics and developing guidance for wetland managers (69) .

Sustainable use

Ramsar sites often support local communities that depend on wetland resources. Sustainable use of wetland resources should be promoted through activities such as regulated fishing, eco-tourism, and traditional agriculture practices. A range of studies have explored sustainable use in RAMSAR sites. A systems thinking approach, using the Viable System Model and Partial Least Squares Path Modeling, was introduced to assess sustainable management in RAMSAR sites. Identification and assessment of developmental options were done on Ghana's coastal RAMSAR sites, focusing on environmental compatibility, technical and economic viability, and social acceptability (70). The Songor Ramsar site in Ghana, covering approximately 85,000 hectares, is a vital wetland ecosystem providing habitat for migratory birds, supporting biodiversity, and offering opportunities for sustainable fishing and ecotourism, while facing threats from industrialization, pollution, and overfishing. (71)

Community engagement

Engaging local communities in managing Ramsar sites is vital for their long-term sustainability. Community participation can include involvement in decision-making processes, environmental education programs, and capacity-building initiatives.

Research and monitoring

Regular monitoring and research activities are essential for assessing the health of Ramsar sites and understanding ecosystem dynamics. This includes monitoring water levels, biodiversity indicators, and human impacts on the wetlands.

International collaboration

Collaboration with international organizations and other Ramsar sites worldwide can provide valuable insights and resources for managing wetlands in Tamil Nadu. Sharing best practices and lessons learned can help improve conservation efforts. The management of Ramsar sites in Tamil Nadu can draw valuable insights from international experiences. Integrated management plans, as seen in the Great Barrier Reef catchments (72), are crucial for conservation and restoration. Biodiversity conservation, a priority in Ramsar sites, can be achieved by protecting key habitats and species. Water quality management, as demonstrated in the Mekong Delta wetlands (73), is essential for the health of these sites. Sustainable use, a key aspect of Ramsar site management, can be promoted through regulated activities such as fishing and eco-tourism (74). Community engagement, as seen in the Hikkaduwa Marine Sanctuary, is vital for the long-term sustainability of these sites. Research and monitoring, as emphasized in all the studies, are crucial for assessing the health of Ramsar sites and understanding ecosystem dynamics. Lastly, international collaboration, as highlighted in the Mekong Delta wetlands, can provide valuable insights and resources for managing wetlands in Tamil Nadu.

Conclusion

Exploring issues and solutions in biodiversity management at Ramsar sites underscores the critical importance of preserving these wetland ecosystems. Challenges such as habitat degradation, pollution, climate change impacts, and unsustainable resource use demand immediate attention and innovative solutions. Implementing effective conservation measures, including habitat restoration, sustainable practices, and international cooperation, is paramount. Engaging local communities, incorporating advanced technologies for mapping and monitoring, and promoting adaptive management strategies are integral components of a comprehensive solution. The commitment to biodiversity management in Ramsar sites is responsible for safeguarding diverse ecosystems and investing in the well-being of nature and humanity. Through collaborative efforts, informed decision-making, and a dedication to sustainable practices, we can ensure the resilience and vitality of Ramsar sites for current and future generations.

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Authors' contributions

All the authors contributed valuable insights to this manuscript. AAN carried out the writing process (Methodology, Conceptualization) and drafted the manuscript. KPR supervised and corrected. SP aided in Data Analysis. DM participated in visualization. PC participated in coordination and helped in gathering data.

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