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The Status of Ramsar wetlands in India: A review of ecosystem benefits, threats, and management strategies

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인도 내 람사르 습지 현황 : 생태계 이점, 위협 및 관리 전략

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Abstract

Wetland also known as "Jheelon" in Hindi language is one of the most important natural resources, contributing various economic and ecological benefits. The study gave a short review of the current status of Ramsar wetlands in India. The wildlife species, conservation measures, and their significance in Indian wetlands were also explored in this review paper. As of 2022, there are 49 Ramsar sites in India covering approximately 1,09363.6 km^2 of land. The largest Ramsar wetland is Sundarbans, while the smallest is Chandertal. It was found that preventing wetland loss is important even though studies about wetland degradation in various nations including India, caused directly by human activities is still limited. Since Monitoring and protecting natural wetlands, supporting scientific studies on preservation and restoration of wetlands, demand on imposing regulations for limiting pollutant discharges were recommended allowing researchers, policymakers, and practitioners to better maintain wetland and its ecosystem services.

Key words : Biodiversity, Ecosystem-services, India Ramsar wetlands, Wetland conservation, Wetland threats

요 약

세계적으로 자연적 습지는 천연자원 중 하나이며, 다양한 경제적 이점과 건전한 생태계를 구축한다. 본 연구는 인도에서 "Jheelon"로 알려진 람사르 습지 내 야생동물 생태계, 보존현황 등에 대한 현황에 대해 분석하였다. 2022년 현재 인도에는 약 1,09363.6 km^2의 면적을 차지하는 49개의 람사르 습지가 있으며, 규모가 가장 큰 Sundarbans 습지와 규모가 작은 Chandertal 습지가 있다. 인도와 선진국에서의 인간활동에 의한 습지의 규모 감축, 기능 상실 등의 피해규모에 관한 연구는 미흡하지만 습지의 유지, 보존, 복원에 대한 중요성은 보고되고 있다. 국가 정책 및 관련 지자체들은 습지를 통한 생태계서비스 구축, 습지 보존, 복원방향, 오염물질 저감 및 배출 규제 등의 법안 마련과 습지에 대한 이해관계를 유지해야 한다.

핵심용어 : 생물다양성, 생태계 서비스, 인도 람사르 습지, 습지보전, 습지위협

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1. Introduction

India is situated in the north of the equator (between 66° E to 98° E longitude and 8°N to 36°N latitude). It has diverse wetland ecosystems that sustain immense biodiversity; However, these wetland ecosystems are under stress due to urbanization, industrialization, and unconfined agricultural practices. Wetlands are the areas that are permanently or seasonally inundated. As of 2020-2021 wetlands are spread over 1,09363.6 km^2 of the geographical area of the country. Overall, 49 sites designated as Ramsar wetlands, and 151 wetlands in India are of international importance (Ministry of Environment, Forest, and Climate change: Government of India, n.d.). The earliest Ramsar Sites in India are Chilika Lake in Orissa and Keoladeo National Park in Rajasthan. Sundarban Wetland is the largest and Renuka Wetland in Himachal Pradesh is the smallest Ramsar site in India (Neha et al., 2022).

The country is well-known for its biological richness, with over 91,000 animal species and 45,500 plant species identified across its ten biogeographic regions (Tiwari et al., 2022). India is now classified as a water-stressed country. The country is experiencing water scarcity since it harbors 17% of the world's population with only 4% of the world's freshwater resources. Generally, water scarcity issues resulted from excessive groundwater extraction, poor water management systems, and infrequent rainfall events throughout the country.

Tropical Asia is the world's most populous and disturbed region, with an annual relative deforestation rate of roughly 2% (Hughes et al., 2022). Due to the monsoonal climate, there are distinct dry and rainy seasons. The monsoonal weather in Southeast Asia is marked by significant and unpredictable interannual changes in rainfall, monsoon has an impact not just on Asian nations, but also extends beyond tropical latitudes (Gopal & Krishnamurthy, 1993; Osborne et al., 1993; Loo et al., 2015). For millennia, this has resulted in the construction of tanks and reservoirs to ensure water supplies. India has built over 5745 big dams and is one of the most active dam-building and planning countries and the third-largest dam building country globally (Roy, 2022). Water security is a term that has evolved in recent years to encompass water for humans as well as ecosystems. (Pradhan & Srinivasan, 2022). Moreover, some of the waterways in India are also severely contaminated. One of the most profound examples of a contaminated waterway in India is the Ganges River. Polluted waterways impact the wetland ecosystem since it also disrupts wildlife habitats (Dudgeon, 2003).

Wetlands are the most productive ecosystems that provide different services to humans, such as water quality, food security, and flood mitigation (Shivakrishna et al., 2021). It is a complete biological system that serves as a habitat for microorganisms, fish, mammals, and birds. Wetlands in India can be classified as inland wetlands, coastal, and marine wetlands. In India, wetlands are degrading quickly due to the expansion of human settlements, unconfined agricultural practices, and cattle grazing; however, the fundamental cause of wetland disappearance or degradation is the lack of awareness and poor urban planning. The global treaty, popularly known as the Ramsar Convention, was adopted in 1971. The convention was signed in the Iranian city of Ramsar, which is located on the Caspian Sea's shoreline, and came into force in 1975 after decades of negotiations (MOEFCC, 2020). This treaty was implemented in India in February 1982 (Ramsar Convention -Wetlands India, n.d.). Currently, there are 49 designated Ramsar sites distributed across India (see Table A1). With global warming and rising sea levels, the risk of wetland in Ramsar areas has increased in recent days (Biswas Roy et al., 2022). Ramsar sites are socio-ecological systems that focus on demographic, socio-political, cultural, and economic elements while also indexing biotic and abiotic factors to retrieve information (Kingsford et al., 2021). To represent the Ramsar Convention and prevent the vulnerability of the world's inland wetlands, environmental education and awareness are essential (Shah & Atisa, 2021). According to Lal (2008), wetland restoration is highly essential for maintaining the atmospheric carbon cycle of our ecosystem. Since the Ramsar convention, numerous studies on water pollution, water quality management, biodiversity protection, wetland ecosystem services, socio-economic values, and other topics have been conducted (Brix 1994; Mitsch & Gosselink, 2007; Zhang et al., 2010; Biswas Roy et al., 2012).

Review articles on Indian wetlands have already been published. Bassi et al., (2014) explored several benefits of wetlands in India to identify the biggest risks to their management. Ramsar sites are essential for human development and survival. These are the world's most productive habitats and biological diversity reserves, supplying water and vital goods to a diverse range of plant and animal species. Encroachment and loss of wetlands must be limited at present to preserve its future productivity (Davidson, 2016). Natural disasters are also partially responsible for the wetland degradation (Bennett et al., 2018). Chatterjee & Bhattacharyya (2020) identified important areas (i.e. population ecology, disease ecology, human-wildlife conflict, and changes in land use) that should be considered as research priorities for wetland mammals in India to make conservation efforts more effective and enable management planning, ensuring the long-term survival of these mammals.

Despite the known benefits of wetlands, many decision-makers, including key stakeholders, still, regard them as "wastelands." Since wetlands are in the open-access regime, they are also considered as frequently exploited resources (Verma et al., 2001). The absence or lack of existing economic, environmental, nature conservation, and development planning policies are major contributory factors to environmental degradation (Tuner et al., 2000). Given this context, this review was conducted to determine the current status of Ramsar sites in India. Specifically, the geographic distribution, characteristics, and the ecosystem goods and services they provide were compiled in this study. The different environmental stressors and wetland conservation policies implemented in India were also reviewed to determine the key management areas that need improvement or further amendments.

2. Materials and Methods

2.1 Data Sources and collection

To establish the trends and state of Wetlands research in India, a typical search for published literature in Scopus was done. The specific information on the 2022 wetlands was obtained from the Ramsar official website (Xu et al., 2019). The authors organize the information and alter the sites based on their geographic location. The other data sources are related to papers and government reports on Wetlands research, supporting literature from past times has been referenced for a more in-depth study. The query was conducted on March 3, 2022. The keywords used in the search were "natural wetland," "Ramsar wetland," "Wetland conservation," "flora," and "fauna." These keywords were combined with the phrase "India" to retrieve papers or publications done precisely in the subject region (Farheen et al., 2021). Since the term "wetland" does not cover all data connected to wetland ecosystems, additional types of wetlands that were not immediately retrievable (e.g. marshes, estuaries, glacial and swamps, etc.) were also extracted.

2.2. Characteristics and classification of natural wetlands in India

2.2.1 Types of wetlands in the Indian sub-continent

India supports extensive wetland ecosystems with varied terrain and climate regimes (Prasad et al., 2002). The existing estimates of the area covered by wetlands in India range from 1% to 5% of its total land area, but they support approximately 20% of the known biodiversity. The surface or coverage area of Indian wetlands is also affected by seasonal changes. Inland wetlands cover approximately 7.4 million hectares in post-monsoon seasons, but its area coverage can be greatly reduced to 4.8 million hectares in the pre-monsoon season. Coastal wetlands cover 1.2 million hectares in post-monsoon and 1 million hectares in pre-monsoon seasons, respectively (SAC, 2012). From post-monsoon to the peak of summer, the coverage area of all types of wetlands decreases dramatically, showing the wetlands' uses and losses. The spatial coverage of different wetland Types in India was shown in Fig. 1. In terms of distribution, river/stream-type wetlands were the most common wetland type, accounting for (34.5%) of the total area, followed by Reservoir/Barrage (16.2%), Intertidal Mudflat (15.8%), and Lagoon (8.6 percent). Other wetland types accounted for less than 5% of the total wetland area.

Wetlands and aquatic ecosystems are essential suppliers and sinks of various chemical, biological, and genetic resources and transformers of those materials. Although the usefulness of wetlands as fish and wildlife habitats has been recognized for millions of years, other benefits have only lately been discovered. Because of their vast food chains and the incredible biodiversity, they support, wetlands are often called "biological supermarkets." They contribute significantly to the landscape by providing unique habitats for a diverse range of flora and animals. Wetlands are known as the "kidneys of the landscape" because of their role in the hydrologic and chemical cycles and their ability to absorb nutrients, silt, and pollutants from natural and anthropogenic sources. Thus, wetlands fulfill one

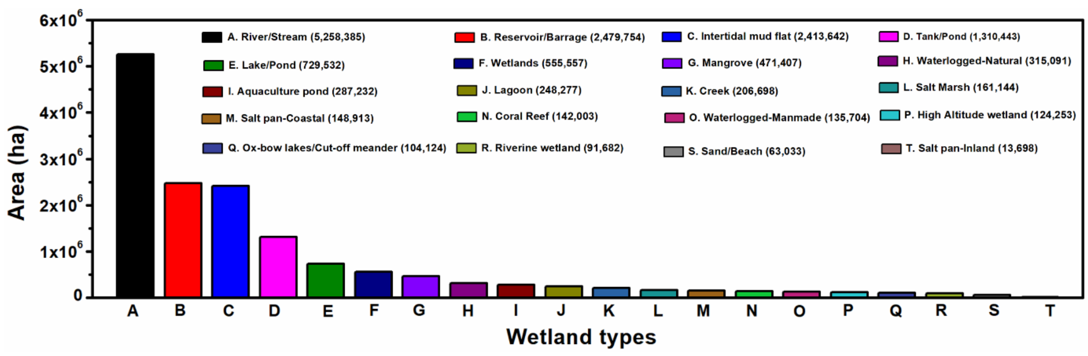

Fig. 1. Spatial coverage of wetland types in India (Adapted from Seenivasan et al., 2013).

of the essential services in human society: they provide water to humans through groundwater and surface water, ensuring water security.

Water security is one of the century's most pressing issues. Wetlands aid in securing water resources by purifying polluted water and ensuring adequate water circulation; however, natural wetlands continue to disappear due to anthropogenic pressure. Inland wetland loss has been caused mainly by clearing and drainage for agricultural purposes worldwide. Wetlands are hydrological and biogeochemically complex ecosystems. Ecotones are a type of environment that exists between terrestrial and aquatic ecosystems.

2.2.2 Biotic community: flora

The ecological status and functioning of an aquatic environment are determined by the trophic structure and abundance of producers, consumers, and detritivores. The biotic communities of wetlands in different geographic areas vary significantly. The producers, who make up the wetland vegetation, undertake a variety of tasks including nutrient recycling, sediment trapping, shoreline stabilization, pollution removal, and dissolved oxygen management in the waterbody (Barko et al., 1998). Invasive species, on the other hand, pose a hazard to the wetland by clogging, reducing contact with the atmosphere, altering the photoperiod, reducing native species habitats, and speeding up the succession. Some of the floral species commonly found in Indian Wetlands were listed in Table 2. Even though the country's geographical area cover accounts for only 2.4% of the world's total landmass, it is home to 47,513 plant species, out of a total of 0.4 million known worldwide, accounting for 11.4% of the world's flora. According to Nayar (1996), there are around 5,725 flowering plant species that are classified as endemics and account for 33.5% of the flora, with 3,471 species found in the Himalayas, 2,051 in Peninsular India, and 239 in the Andaman and Nicobar Islands. Some of the rare flora species that can be found in Indian wetlands were listed in Table 1.

2.2.3 Biotic community: fauna

The essential information regarding the diversity of accessible groups that are supposedly present in India's Ramsar wetlands has been gathered from scientific works of literature as well as the faunal exploration study available from the Indian Zoological Survey. Wetlands are crucial habitats for critical aquatic vertebrate species like fish, amphibians, reptiles, birds, and mammals, and their presence and abundance are the signs of healthy wetlands and river ecosystems. According to data obtained from the year 2010 up to 2020, a total of 4,112 species, 2,800 new species, and 1,312 new records of fauna were found in India (Singh et al., 2021).

According to Animal Discoveries (2020), India has introduced 557 new species to its fauna, including 407 new species and 150 new records. With the discovery of the new species, the number of faunal species in India has risen to 1,02,718. *Trimeresurus Salazar*, a new species of green pit viper discovered in Arunachal Pradesh; *Lycodon deccanensis*, the Deccan wolf snake discovered in Karnataka and *Sphaerotheca* in Bengaluru, a new species of burrowing frog named after the city of Bengaluru, are among the new species identified in 2020; *Xyrias anjaalai*, a new deep-water snake eel from Kerala; *Glyptothorax giudikyensis*, a new species of catfish from Manipur; and *Clyster galateansis*, a new species of scarab beetle from the Great Nicobar Biosphere, were recently included in the list (Singh et al., 2021). Generally, invertebrates account for 486 of the 557 new species. The list of fauna found on Indian wetlands was summarized in Table 2.

Table 1. Rare flora species present in Indian wetlands (Adapted from Arisdason & Lakshminarasimhan, 2021).

Type	Description
Mangroves	*Acanthus Volubilis Wall, Aegialitis rotundifolia Roxb., Brownlowia tersa (L.) Kosterm., Bruguier sexangular (Lour.) Poir, Cryptocoryne ciliate (Roxb.) Schott., Cynometra iripa Kostel., Dolichandrone spathacea K. Schum, Finlaysonoia obovate Wall, Heritiera formers Buch-Ham., Heritiera kanikensis Mj.et Ban., Intsia bijuga (Colebr.) O. Kunt., Lumnitzera litttorea (Jack.) Voigt., Kandelia candle.*
Herbs and Sedges	*Allamania nodiflora, Borreria articularis, Corchorus depressus, Desmodium biarticulatum, Enicostema hyssopifolium, Fimbristylis spathacea, Geniosporum tenuiflorum.*
Shrubs And Trees	*Acrostichum aureum (a Strand Fern), Asparagus dumosus, Clerodendrum inerme, Dimorphocalyx glabellus, Halopyrum mucronatum, Jatropha glandulifera, Limnonium stocksii.*
Rock Strand	*Lotus garcinia, Myriostachya wightiana, Saccharum officinarum, Solanum Arundo, Tamarix articulata, Tamarix troupii.*
Rock Sand	*Cordia subcordata, Erythrina indica, Erythrina indica, Heritiera littoralis, Hibiscus tuliaceus, Hyphaene indica, Ixora coccinea, Maba buxifolia, Morinda citrifolia, Messerchimidia argentea.*
Coral Sand	*Pandanus tectorius, Pemphis acidula.*
Coral Rock	*Premna corymbose, Premna latifolia, Pongamia pinnata, Samadera indica, Premna serratifolia, Salvadora persica, Scaevola taccada, Streblus asper, Suriana maritima, Thespesia populnea*

Table 2. Fauna in Indian Wetlands (Adapted from Chandra et al., 2021)

Types	Description
Fish	*echinoderms, starfish (Crinoidea), Barilius bendelisis, copepods, beetles (Coleoptera), Odonata, grasshoppers (Orthoptera), Zooplankton, Crustaceans (includes crabs, shrimps, prawns, krill), octopus (Mollusca), flatworms (Platyhelminthes), eels (Anguilliformes), mullet, snails (Gyraulus), copper mahseer (Neolissochilus hexagonolepis), Assamese kingfish (Cyprinion semiplotus).*
Insects	*Thysanoptera (Trips), true bugs (Hemiptera), fly (Diptera), ants (Formicidae), springtails (Collembola), white grubs (Holotrichia), Odonata, Hymenoptera (consisting of sawflies, bees, wasps), moths (Lepidoptera, Mangina argus), honeybee (Apis dorsata).*
Birds	*Indian paradise flycatcher (Terpsiphone paradisi), Oriental darter, a flock of painted storks (Mycteria leucocephala), black duck, Parrot (Alexandrine parakeet), white-throated kingfisher (Halcyon smyrnenmsis), Indian robin (Copsychus fulicatus).*
Algae	*Protozoan ciliates, ciliate.*
Reptiles	*Olive ridley sea turtle, common snug snake (Pareas monticola), Indian flap shell turtle (Lissemys punctata), Indian-eyed turtle (Morenia petersi), agamid lizards (Agamidae), Coryphophyllax brevicaudus, Bronchocoela.*
Mammals	*Hog badger (Arctonyx collaris), hoolock gibbon (Hoolock hoolock), slow loris (Nycticebus bengalensis), gaur (Bos gaurus), greater short-nosed bat (Cynopterus sphinx), barasingha (Rucervus duvaucelii), hyenas (Hyaenidae), golden jackal (Canis aureus).*
Amphibians	*Indian bullfrog (Hoplobatractus), common Indian Toad (Duttaphrynus melanostictus), gerbil steam frog (Amolops Gerbillus), Pierre cricket frog (Fejervarya Pierre), khara's gliding frog (Pterorana Khare), point nosed frog (Clinotarus alticola), mawphlang frog (Odorrana mawphlangensis), Raorchestes shillongensis.*
Vertebrate	*Indian pangolin, Chinese pangolins, red panda, ibex, blue sheep, goral, jungle cat, wolf, snow leopard, common leopard, barking deer, Himalayan brown deer, Nematoda, Elephas maximus indicus.*

2.2.4 Status and distribution of natural wetlands in India

Wetlands are essential components of every landscape due to the diverse ecosystem services they provide. Specifically, wetlands offer provisioning, regulating, cultural, and supporting services that help maintain the balance among various ecosystem processes and contribute to human well-being. India has 49 Ramsar wetlands which approximately cover a total area of 1,096,851 hectares (ENVIS Center on Wildlife and Protected Areas, 2021). Wetlands in India are diverse due to wide variations in rainfall patterns, physiography, geomorphology, and climate. Glacial lakes, swamps, and floodplain marshes are usually found in the Himalayan Region like Leh-Ladakh, Kashmir valley, Uttarakhand, Himachal Pradesh, Sikkim, and Arunachal Pradesh. These wetlands help to keep rivers like the Ganges, Brahmaputra, and Indus flowing by acting as a buffer between glacial meltwater and outflow to smaller rivers and streams. The Ganges and Brahmaputra alluvial

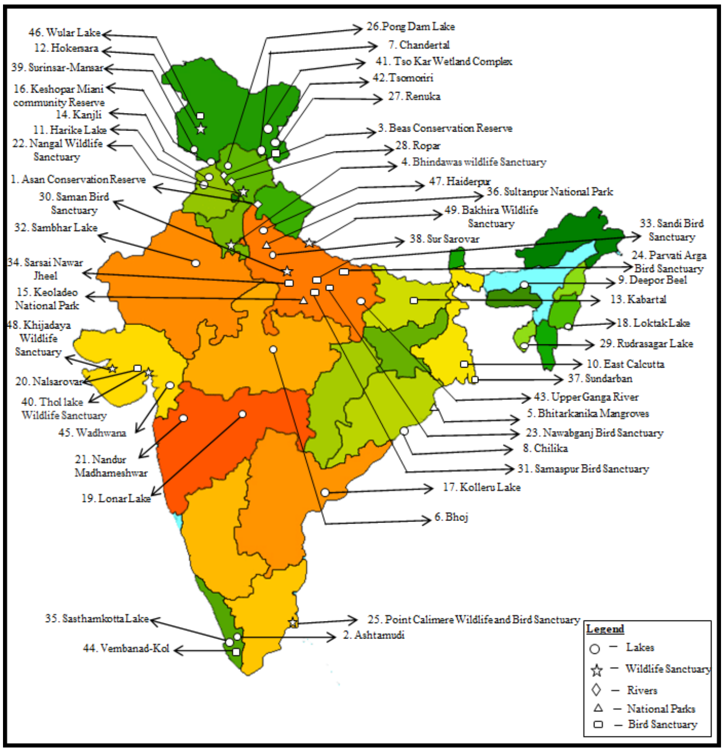

Fig. 2. Distribution of natural wetlands across India.

plains include significant riverine wetlands, such as floodplains and oxbow lakes, which are known to the locals as *maun*, *beel*, *chaur*, *jheel*, or *jhabar*. Numerous rivers and streams cut through the Western Ghats, one of India's biodiversity hotspots, creating swamps and marshes. Large saline and monsoon-fed freshwater lakes and reservoirs can be found in the desert zone of Rajasthan and Gujarat. The Deccan Peninsular region has few natural wetlands and is largely covered with man-made tanks that provide water for different human uses as well as serve as nesting, feeding, and breeding grounds for a variety of birds (Gopal, 2013).

Lagoons, salt marshes, mangroves, and coral reefs may all be found on the narrow plains of the east and west coasts, as well as on islands harbor (Lakhmapurkar et al., 2022).

Table 3. Classification of wetlands in the Indian sub-continent.

Wetland Type	Description	References
Glacial Wetlands	• These include wetlands created by glaciers' actions, such as damming rivers, scouring valleys, creating pits and depressions, and altering floodplains. • Glacial wetlands can be found in Jammu and Kashmir's Tso Moriri and Himachal Pradesh's Chandertal.	Gupta & Shukla (2016); Singh & Thakur (2021).
Crater Wetlands	• Crater wetlands are generated when meteorites or other extraterrestrial objects collide with the earth's surface, creating depressions. • Lonar, located in Buldhana, Maharashtra, is thought to have formed in a crater created by a meteor impact.	Parmar et al., 2021
Tectonic Wetlands	• The formation of these wetlands is due to the tectonic movements of the earth and the loading of large volumes of organic matter from inflowing catchments. • Nainital is a tectonic wetland in Uttarakhand.	Joshi et al., 2018
Oxbows	• Oxbows arise when a river's meander is cut off by silt or when the river changes course, isolating a crescent-shaped waterbody. • Oxbows abound in the Ganga and Brahmaputra River basins. • Ansupa is an oxbow in the peak of the Mahanadi Delta.	Saho et al., 2021
Marshes	• Herbaceous plants predominate, and water sources other than direct rainfall, such as surface runoff, groundwater, and tidal flow, are used to maintain them. • Kanwar Jheel is a marsh in the Burhi Gandak floodplains of Bihar.	Verdhen, 2021
Swamps	• Swamps are heavily forested wetlands. These have poor drainage and an adequate water supply to keep the ground wet, as well as a mineral content that encourages organism decomposition and prevents organic material accumulation. • The Sundarbans is the world's biggest single contiguous mangrove swamp, stretching between India and Bangladesh.	Nayak & Bhushan, 2022
Fens	• These are freshwater wetlands that form peat and are generally nonacidic, absorbing nutrients from groundwater sources. They are not very common in India.	Upadhyay et al., 2020
Floodplains	• These are regions near a river or stream and are periodically inundated by water overflowing the channel. The Yamuna floodplains are Delhi's principal supply of water.	Tabasum et al., 2009
Bogs	• A bog is a wetland where peat, or dead plant debris, accumulates. These wetlands have an extremely acidic pH and nutrient deficiency. These have a high-water table that is directly maintained by rains and snow, resulting in waterlogging and low relative oxygen levels. They are not very common in India.	Upadhyay et al., 2020
Estuaries	• An estuary is a brackish water feature that is partially contained along the coast, with one or more rivers or streams flowing into it and free access to the open sea. Estuaries serve as a transition zone between the river and the sea. • A coastal lagoon is a bar-built estuary formed when offshore barrier sand islands rise above sea level and form a chain, with one or more inlets connecting them. • Chilika is an Odisha lagoon divided from the Bay of Bengal by a lengthy sand barrier.	Nazneen et al., 2021
Mudflats	• Mudflats, also called tidal flats, are coastal wetlands formed by mud deposited by tides and rivers and are typically found in sheltered places such as bays and lagoons. • The Sewri mudflats in Mumbai are important flamingo nesting locations.	Shaikh & Tiwari, 2012
Backwaters	• Backwaters are coastal wetlands generated when an opposing current or the tides impede inflowing river flows. • Kerala's Malabar Coast features several backwater areas that are popular tourist sites.	Nazneen et al., 2022
Coral Reefs	• Coral reefs are wetlands along the coast that are home to reef-building corals. • Coral polyp colonies are bound together by calcium carbonate to build reefs. • The primary reef regions of India are the Gulf of Kachchh and Lakshadweep in the Arabian Sea, and the Gulf of Mannar, Andaman, and the Nicobar Islands in the Bay of Bengal.	Venkataraman, 2022

Mangrove wetlands can be found along the coasts of nine Indian states and three union territories. Major mangrove ecosystems include the Sundarbans (West Bengal), Bhitarkanika (Odisha), and Pichavaram (Tamil Nadu), as well as the Andamans. Major reef regions in the nation include the Gulf of Kachchh and Gulf of Mannar, as well as the islands of Lakshadweep and Andaman & Nicobar (Nazneen et al., 2022). Wetlands in Nort-East zone, which is at the junction of India, Indo-Malayan, and Indo-Chinese biogeographic zones, are regarded as the doorway to India's floristic and faunistic richness (Chatterjee et al., 2006). Rivers, streams, lakes, ponds, waterlogged regions, and oxbows occur in this region, particularly in Assam (Ghose et al., 2006). The distribution and description of Ramsar wetlands in India were summarized in Fig. 2. and Table 3.

3. Results and Discussion

3.1 Characteristics of the largest Ramsar sites in India

3.1.1 Sundarbans wetland

Sundarbans Wetland shown in Fig. 3b is the largest mangrove forest in the world with area of 133,010 ha (4230 km^2). It is located in West Bengal (21° 56’42” N, 88° 53’45” E) and was designated as a Ramsar site on January 30, 2019 (RC, 2021). The Sundarbans encompasses hundreds of islands and a maze of rivers, rivulets, and creeks, in the delta of the Rivers Ganges and Brahmaputra on the Bay of Bengal in India and Bangladesh (Mallick, 2013). The Indian Sundarbans, covering the south-westernmost part of the delta, constitutes over 60% of the country’s total mangrove forest area and includes 90% of Indian mangrove species (Das et al., 2021). The mangrove forests protect the hinterland from storms, cyclones, tidal surges, and the seepage or intrusion of saltwater into inland waterways (Choudhury et al., 2021). They also serve as nurseries to shellfish and finfish and sustain the fisheries of the entire eastern coast (Mukherjee et al., 2021). The Sundarban Tiger Reserve is situated within the Site and part of it has been declared a critical tiger habitat under national law and a tiger conservation landscape of global importance (Choudhury et al., 2021). The Sundarbans are the only mangrove habitat which supports a significant population of tigers that have unique aquatic hunting skills. The site is also home to many rare and globally threatened species such as the critically endangered northern river terrapin (*Batagur baska*), the endangered Irrawaddy dolphin (*Orcaella brevirostris*), and the endangered fishing cat species (*Prionailurus viverrinus*) (Rahman, et al., 2014). Due to the rich biodiversity and extensive local, regional, and global ecosystem services it provides, the Sundarbans wetland is considered as a priority conservation area (Chandra et al., 2021).

3.1.2. Vembanad-kol wetland

In Fig. 3c the Vembanad-Kol Wetland, which covers 151,250 hectares (1512 km^2) in Kerala (076° 45'E, 09° 50'N), was designated as a Ramsar site on August 19, 2002 (RC, 2021). It is considered as the largest freshwater natural ecosystem situated in humid tropical region of India's southwest coast.

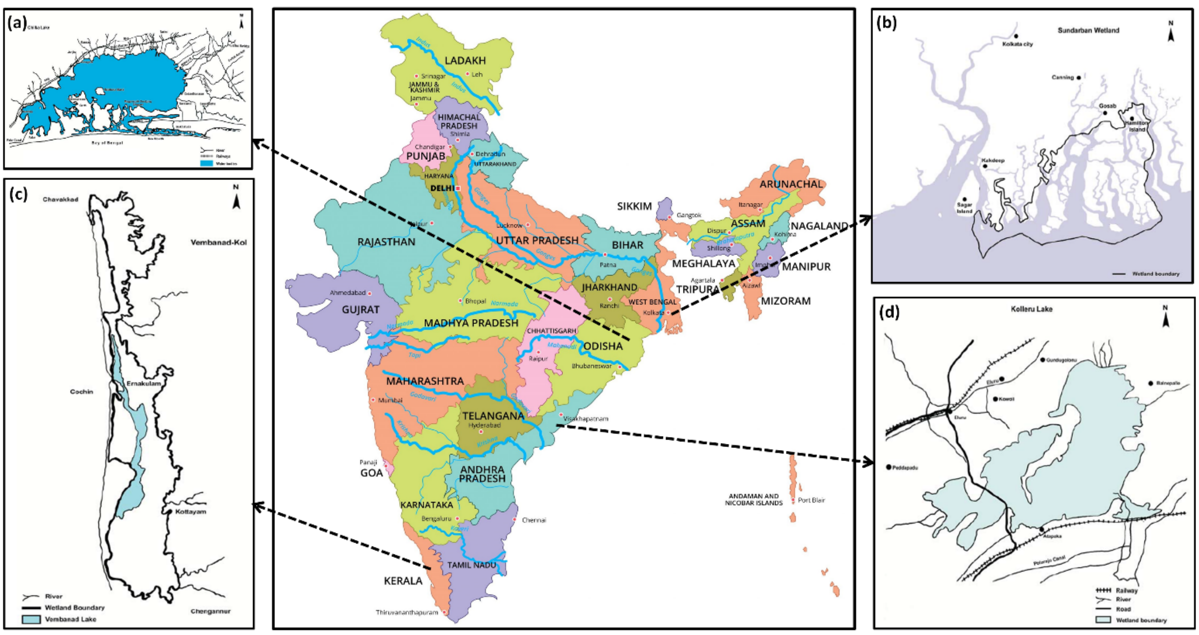

Fig. 3. Location map of largest Ramsar sites in India 3a) Chilika wetland 3b) Sundarbans wetland 3c) Vembanad-kol wetland 3d) Kolleru wetland (Adapted from Chandra et al., 2021).

Since the western coast contains vast estuarine systems, the wetland was fed by ten rivers (Nisari & Sujatha, 2021). The wetland harbors India's third-largest waterfowl population during the winter months and is also known for its vast clam population. Over 90 endemic species of birds and 50 species of migratory birds are found in the Kol area (Remani et al., 2010). The most profound benefits of the Vembanad-Kol Wetland include flood protection for densely populated coastal areas in three districts of Kerala, groundwater recharge for the wells in the region, and a considerable contribution to the economic and transport system for the locals (Choudhury et al., 2021). Pollution from wastewater discharges is regarded as the major threat to the Vembanad-Kol Wetlands ecosystem. Wastewater effluents from domestic, industrial, and military camps contributed to a significant number of pollutants, including heavy metals and pesticides, that ultimately resulted in water quality deterioration (Chandra et al., 2021). The Vembanad estuary had high alkalinity, low dissolved oxygen (DO), and high biochemical oxygen demand (BOD) (Manoj, 2019). Land use and land-use changes (LULUCs) within the watershed area also affected the wetland ecosystem. A study by Roopa & Vijayan (2017) indicated that land cover in the Vembanad wetland was mainly comprised of agricultural land, forests, and built-up areas. Moreover, it was highlighted that the wetland area experienced5% depletion from 1967 to 2001 and 2% depletion from 2001 to 2014. Paddy field cultivation was the primary agricultural activity in Kerala. With 55,000 acres of paddy fields, Kuttanad is known as Kerala's "rice bowl." It was previously reported that the indiscriminate use of chemical pesticides (i.e., organochlorine pesticides) in the fields caused extensive damage to the environmental matrices including soil, water, and biota. Moreover, it was found that only 0.3% of the pesticides reach the target species, whereas the remaining percentage usually end up in the environment (Sruthi et al., 2016). Moreover, agricultural activities (i.e., crop cultivation and aquaculture) generate wastes that continuously degrade and damage the aquatic ecosystem in the area. Overall, the extensive agricultural practices in the areas surrounding the wetland led to high nitrate (0.05 to 5.9 μmol L^{-1}) and phosphate (0.18 to 6.49 μmol L^{-1}) concentrations in the estuaries draining into the Vembanad-Kol wetland (Asha et al., 2016).

3.1.3 Chilika wetland

Fig. 3a represents Chilika Wetland was listed as a Ramsar wetland site on October 1, 1981. It is located in Odisha (19° 42'N 085° 21'E) and has an area of 116,500 hectares (RC, 2021). The site is an important area for breeding, wintering, and staging for 33 species of waterfowl. It also supports 118 species of fish, including commercially important species (Choudhury, 2021). A Significant number of people are dependent upon the lake's resources for drinking, irrigation, energy production, and fisheries, among others (Das & Mohanty, 2008). Chilika also acts as a sink for organic matter and nutrients, efficiently recycling the inputs obtained through multiple transport modes. The nutrient cycling capacity of the wetland increased the overall production in the wetland ecosystem (Amir et al., 2019; Ganguly et al., 2018). The dense *Phragmites karka* on the lagoon's northern coast acts as ecological filters by trapping nutrients and pollutants, thus contributing to the maintenance of water quality (Behera et al., 2018). Natural and anthropogenic concerns also affected the overall characteristics of the Chilika Lake. Siltation, variations in the salinity level, overgrowth of aquatic plants, and aquaculture activities were among the natural and anthropogenic pressure were among the factors that influence the productivity in the wetland area. The Ramsar Convention included the lagoon to the Montreux Record list of threatened wetlands in 1993, in response to the concerns about the biological threats to the wetland; however, the Chilika Development Authority (CDA) successfully restored the lagoon environment in 2002 (Mishra et al., 2022). Due to its enormous water storage capacity inside a highly populated area, Chilika also serves as a significant buffer zone for floods and storms that are known to affect the east coast terrain regularly. Large waterbodies, such as Chilika, may control microclimates by removing ambient heat and enhancing wind circulation through evapotranspiration and heat storage. Carbon is stored and sequestered within vegetation and sediments in large swaths of seagrass and patches of mangroves, eliminating harmful greenhouse gases from the atmosphere (Finlayson et al., 2020). Chilika, with its rich biodiversity and attractive natural environment, is a famous tourist destination on India's east coast, accounting for 8–10% of the state's total tourist arrivals (Kumar & Pattnaik, 2012). Chilika tourism is the basis of a thriving economy for tourist boat owners, hoteliers, and travel agencies (Finlayson et al., 2020).

3.1.4 Kolleru wetland

Kolleru Wetland is shown in Fig. 3d is a 90,100-hectare lake in Andhra Pradesh (16° 37'N 081° 12'E). It was listed in the Ramsar wetland site on August 19, 2002. Kolleru Wetland is considered a natural eutrophic lake, situated between the two major river basins of the Godavari and Krishna. The wetland is fed by two seasonal rivers and several drains and channels which function as a natural flood balancing reservoir between the deltas of the two rivers. It provides habitat for several endemic and migratory birds and supports aquaculture, agriculture, and other related livelihood activities of the residents. Damage and losses due to flooding are commonly observed in the area during the monsoon seasons, whereas partial drying of surface water can be noted during the summer season. It serves as a flood-control reservoir between the Krishna and Godavari delta plains as well as a home for migratory and resident birds such as Siberian cranes, ibises, painted storks, and grey pelicans, waterfowl, and hundreds of traditional fishermen (Nageswara et al., 2004). The significant amount of pollutant discharges from industrial effluent, domestic waste, and sewage containing heavy metals in water and sediment samples of Kolleru lake were reported by Das (2019). In this lake water, various potentially harmful metal ions such as chromium (4.5 to 80 g/L), copper (1 to 20 g/L), manganese (1 to 313 g/L), and zinc (1.2 to 57 g/L) were also detected (Das, 2019). Water quality degradation, habitat loss, and the reduction in aquatic and avian biodiversity were the most pressing concerns in the Kolleru Lake Basin. Climate change has hastened these changes, which were triggered by anthropogenic activities. The wetlands have grown into a regional center for rice production, aquaculture, and a variety of recreational activities Kolleru Lake also harbors a rising population of 0.3 million people, including 14,000 households that rely on the lake's resources. Aquaculture has also become one of the most common sources of income in the area (Koli, et al., 2020).

3.2 Threats to natural wetland ecosystems in India

3.2.1 Land use and land-use changes (LULUCs)

The ability of wetlands to manage flow regimes, cycle nutrients, and maintain biodiversity is determined by their water holding capacity. Wetlands, serve as natural sediment traps, which play an important part in their long-term succession. LULUCs accelerate sedimentation rates, thus altering the basic ecosystem processes and services. In the case of agricultural areas, excessive nutrient concentrations from the runoff may result in eutrophication. In India, the continuous silt accumulation from Shivalik catchments resulted in an 86% loss of Harike's water holding since 1954 (Chandra et al., 2021). The considerable decrease in water level has diminished this wetland's capacity to moderate its hydrological regime, which along with high levels of nutrient enrichment, has aided the Eichhornia invasion.

Using remote sensing data, researchers have also looked at the land use and land cover changes, as well as the growth of urban areas, in Guwahati, India. Land surfaces with high groundwater recharge potential have also been transformed into urban areas due to population growth (Nath et al., 2021). The conversion of natural landscapes into agricultural land and urban areas has been shown to be detrimental to a variety of ecosystem services, including social benefits, genetic resources, nutrient cycling, erosion control, climate regulation, water availability, and soil fertility (Yirsaw et al., 2017). The change in the LULC pattern under the classes was examined in this study between 1988 and 2016. Water covered the most area of this Kanwar wetland (59.58%) in 1988, followed by scrub/open (39.79%), agricultural (0.39%), and settlement (0.25%), but by 2016, the waterlogged and scrub/open areas had been decreased to 35.84% and 29%, respectively. During dry seasons, such as the summer, water was concentrated in patches, while open/scrub regions were used for various uses by the local population (Singh et al., 2021).

3.2.2 Over-harvesting of resources

Wetlands are frequently subjected to over-harvesting of resources and modification to boost provisioning services like wood, fish, and water at the expense of regulatory and cultural services. In most inland wetlands, harmful fishing practices such as small mesh size nets are commonly used (Remesan, 2019). The sustainable yield limit for a specific swamp is frequently unknown and, in some cases, ignored by stakeholders. By-catch loss also puts a strain on wetlands' biodiversity and wider food webs. In addition, agricultural and aquaculture uses frequently require different inundation regimes. The livelihoods of nearly 15,000 fisherfolks in the Kabartal wetland (Kanwar Jheel) area in North Bihar, resulted in notable disruption in the natural wetland ecosystem (Kumar et al., 2017). Reduced groundwater levels and flooding caused by shrinking wetland coverage have also influenced agricultural practices (WISA, 2014). The Maguri-Motapung Beel wetland is one of the most critically threatened floodplain wetlands in Assam's Tinsukia district, with overexploitation being one of the biggest risks. The population residing within the vicinity of the wetland relies heavily on the wetland's benefits and resources, such as bird viewing and wood harvesting, and thus, the degradation of the wetland ecosystem may have a direct or indirect effect on the people's livelihood. While the people recognize that overexploitation and siltation as the main concerns leading to the wetland's degradation, the poor execution of national regulations and the lack of a management plan for the region are also crucial factors contributing to the wetland's degradation (Bhatta et al., 2016).

3.2.3 Climate change

Climate change is rapidly becoming a significant driver of wetlands loss and change. It can impact a wetland environment by raising temperatures, modifying hydrological patterns, and altering the ecosystem's biogeochemistry (Erwin, 2009; Stewart, 2014). Rising temperatures, changes in rainfall intensity and frequency, and extreme climatic events (i.e. drought, flooding, and frequent occurrence of storm events) can directly and indirectly, affect wetlands. Changes in hydrology and temperature can alter the biogeochemistry and function of wetlands to the point where some critical services are rendered ineffective. Heavily impacted wetlands may no longer provide a water purification service. In extreme cases, wetland vegetation may also begin to decompose and release nutrients into surface water, causing problems such as eutrophication and acidification of water bodies (Roulet et al., 2006; Stets & Cotner, 2008).

As a result of climate change, a wetland with a faster decomposition rate than production (photosynthesis) may emit methane, a profound example of greenhouse gas, into the atmosphere (Laiho, 2006; Flanagan & Syed, 2011). In addition, more nitrous oxide emissions from wetlands may occur due to increased microbial activity and a faster rate of nitrification and denitrification (Huang et al., 2013; De Klein & Vander Werf, 2014). The lower amount of precipitation and high evaporation rates can increase soil salinity and consequently reduce the wetland's productivity. In India, the effect of climate change can be evidently observed through the rise in water level of Tsomoriri Lake in Ladakh, a glacially fed high altitude lake. The increase in water level submerged crucial breeding grounds for endangered migratory birds such as the Black necked Crane and Bar-headed Goose (Padmavati & Srinu, 2017). In a seasonally open floodplain wetland in West Bengal, India, Sarkar et al., 2021 investigated the influence of climatic variability and fisher's response to climate-induced risks. The climatological trend study revealed a rise in air temperature over the previous two decades and a 36.9% decrease in rainfall from 2000 to 2019. This wetland has undergone significant changes in recent years, including a reduction in average water depth (74.3%), an increase in nitrate concentration (44.4%), area shrinkage (77.7%), macrophyte infestation (80%), plankton diversity (54%), macro-zoo-benthos diversity (31%), fish diversity (22.8%), and fish production, making the wetland fisheries more vulnerable (Sarkar et al., 2021).

3.2.4 Point and non-point source pollution

Wetlands within urban and peri-urban areas have become waste receptacles due to a lack of suitable waste management infrastructure. In addition, water quality in rural wetlands has also been degraded due to agricultural intensification and greater usage of chemical fertilizers. Most of the Gangetic floodplain wetlands are in an advanced condition of eutrophication as a result of the continuous discharge of untreated sewage and agricultural runoff. Oil and petroleum spills, industrial acid deposits of ammonium and nitrate from fertilizer units pesticide residues from agricultural paddy fields, and immersion of idols and religious ritual waste damage the biodiversity of wetland ecosystems in India (Padmavati & Srinu, 2017). Total and mild acid-leachable trace elements in surface sediments throughout the Hooghly (Ganges) River Estuary and Sundarban Mangrove Wetland, were investigated by Mondal et al., 2018. The results indicated that Cd (0.17±0.13 mg/kg), Pb (14±3 mg/kg), Mn (517±102 mg/kg), Cu (33 ± 11 mg/kg), and Se (0.37 ± 0.10 mg/kg), were present in the soil samples from Sajnekhali, a wildlife sanctuary in Sundarbans. Comparison with the sediment pollution indices, both enrichment factor, and contamination factor, also revealed that the sediments in the area are heavily polluted by Ag (Mondal et al., 2018).

3.3 Government programs and policies for wetlands conservation

Wetlands are identified as key components of freshwater resources in the National Environment Policy (2006), which calls for their integration into development planning, management based on smart-use techniques, ecotourism promotion, and the construction of a regulatory framework. The Directory of Indian Wetlands lists 147 sites as noteworthy, with 68 of them protected under the Indian Wildlife Protection Act of 1972, as part of the National Protected Area Network (WWF and Asian Wetland Bureau, 1995). The Salim Ali Centre for Ornithology and Natural History (SACON) identified 200 wetlands as prospective Ramsar sites because of a significant UNDP program to establish conservation solutions for inland wetlands (Garg, 2015). The Bombay Natural History Society (BNHS) created this list, followed by thorough documentation about these wetlands (Islam et al., 2010).

Over 180 wetlands of national significance have been identified by the Ministry of Environment, Forests, and Climate Change's National Plan for Conservation of Aquatic Ecosystems (NPCA). Wetland conservation is also a part of three of the 12 National Biodiversity Targets set by the Ministry of Environment, Food, and Climate Change under the Convention on Biological Diversity's Strategic Plan 2011-2020. On February 1, 1982, India became a signatory to the Ramsar Convention, pledging to protect the country's wetland resources. The Ministry of Environment, Forests and Climate Change has recognized 46 wetlands (1,071,861 ha) in India as Wetlands of International Importance - Ramsar sites, the highest number in South Asia (Ramsar Sites Information Service, 2020).

In India, wetlands policy includes the National Wetland Conservation Programme (NWCP) which was established in 1985. The goal of this program includes the promotion of the protection and intelligent use of wetlands throughout the country to prevent future deterioration. The Central Wetlands (Conservation and Management) Rules were initially issued in 2010 with the goal of improving wetlands management and regulation across the country. The Central Wetlands Regulatory Authority (CWRA) was established, but its term expired on March 31, 2015, and it has not been recreated since. Recognizing the importance of wetlands, the National Environment Policy of 2006 asks for the creation of a national inventory of such wetlands as well as the implementation of a wide range of policies and programs for wetland conservation and environmental impact assessment (EIA). The (NPCA) was released in 2015 with the goal of providing a policy framework and support to state governments for integrated wetlands management. The NWCP and the National Lake Conservation Plan, two independent Centrally Sponsored Schemes (CSS), were merged to form this effort (NLCP) (Khatik, 2022). Capability Development Centre for Wetlands is being considered in order to strengthen the capacity of wetland managers by Upgrading the current Chilika Development Authority Wetland Research and Training Centre at Barkul, Odisha into the National (Padmavathi & Srinu, 2017). In recent years, India has implemented a large number of restoration projects throughout the country for example Sembakkam lake in Chennai about to launch a restoration model to demonstrate how wetlands and urban lakes provide ecosystem services like flood sinks, pollution reduction, carbon sinks, etc. The Ministry of Environment and Forests implemented the 'Wetlands Rejuvenation' initiative as part of the Government of India's 169 revolutionary ideas, which included "starting work on restoration and rejuvenation of at least 100 significant wetlands across the country." The Ministry, in collaboration with a network of knowledge partners, sponsored regional workshops around the nation to provide technical assistance to wetlands managers in executing the initiative.

4. Conclusion and Recommendation

Wetlands in tropical nations are subjected to increasing anthropogenic pressures because of rising population and expanding economic activity, resulting in fast ecosystem degradation. Most of these pressures are due to the conversion of wetlands for agriculture, intensive aquaculture, tourism, transportation, industrial waste disposal, untreated sewage discharge, and construction of encroachments. The most effective strategy to maintain wetlands is to manage wetlands' natural resources in a sustainable manner for the long-term benefit of many people of India. There are currently existing policies for wetland conservation in India; however, these policies can be considered as unsatisfactory due to the evident continuous degradation of wetland ecosystems in the country. In recent years, India has implemented a large number of restoration projects throughout the country. Based on the identified status of wetlands in India, the following recommendations were formulated to promote wetland conservation and improve the ecosystem services of these natural features:

1) Natural wetlands should be constantly monitored to ensure that ecosystem services are properly maintained or improved. An inventory of the wetlands' resources should also be created to track the changes in the benefits of natural wetlands.
2) Additional government policies regarding the protection of natural wetlands and the limits for the utilization of various wetland resources should be formulated to ensure that the loss of wetlands' productivity can be prevented.
3) The support for scientific studies on wetland preservation and restoration should be expanded. Large-scale initiatives for ecological wetlands restoration and scientific research on important technologies for wetland conservation and restoration should also be conducted.
4) Regulations limiting pollutant discharges can be imposed in order to mitigate wetland degradation. This may be accomplished by integrating wetland and river basin environmental management strategies.
5) Marsh wetlands were the most threatened wetland types. The exploitation of biological resources should be temporarily prohibited or limited, and attention should be given to the restoration of wetlands that harbors migratory, rare, and endangered animal species.

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Table A1. Ramsar sites in India (Ramsar Convention, 2021)

Site No.	Wetland Name	Wetland Type	Location	Area (ha)
1.	Asan Conservation Reserve River	Barrage/ freshwater reservoir	Dehradun district, Uttarakhand	444.4
2.	Ashtamudi Wetland Lake	Estuary	Kollam district, Kerala	6,140
3.	Beas Conservation Reserve	River stretch	north-west Punjab	6,428.92
4.	Bhindawas wildlife Sanctuary	Water storage areas/Reservoirs	Jhajjar district, Haryana	412
5.	Bhitarkanika Mangroves	Mangroves and tidal flats	Odisha	65,000
6.	Bhoj Wetland	Reservoir	Bhopal district, Madhya Pradesh	3,201
7.	Chandertal Wetland	Freshwater lake	Lahul and Spiti district, Himachal Pradesh	49
8.	Chilika Lake	Natural lagoon	Puri Khurda and Ganjam district, Odisha	116,500
9.	Deepor Beel	River floodplain	Kamrup district, Guwhati city	4,000
10.	East Calcutta Wetlands	Aquaculture ponds and wastewater treatment areas	Kolkata	12,500
11.	Harike Lake	Reservoir and water storage area	Jakopur Khurd, Punjab	4,100
12.	Hokersara Wetland	Marshes	Jammu and Kashmir	1,375
13.	Kabartal Wetland	Oxbow lake, freshwater marshes	Bihar	2,620
14.	Kanjli	River stretch	Kapurthala district, Punjab	183
15.	Keoladeo National Park	Freshwater marsh and swamp	Bharatpur, Rajasthan	2,873
16.	Keshopar Miani community Reserve	Marshes and aquaculture ponds	Punjab	343.9
17	Kolleru Lake	Lakes, marsh, and aquaculture ponds	Andhra Pradesh	90,100
18.	Loktak Lake	Freshwater marsh	Manipur	26,600
19.	Lonar Lake	Alkaline lake	Buldhanas district, Maharastra	427
20.	Nalsarovar	Marsh	Gujarat	12,000
21.	Nandur Madhmeshwar	Barrage and water storage area	Nashik district, Maharashtra	1,437
22.	Nangal Wildlife Sanctuary	Reservoir	Shivalik foothills, Punjab	116
23.	Nawabganj Bird Sanctuary	Marsh	Unnao district, Uttar Pradesh	224.6
24.	Parvati Arga Bird Sanctuary	Freshwater marsh	Gonda district, Uttar Pradesh	722
25.	Point Calimere Wildlife and Bird Sanctuary	Mangrove swamps, lagoons, mudflats, salt pans	Tamil Nadu	38,500
26.	Pong Dam Lake	Reservoir	Kangra district, Himachal Pradesh	15,662
27.	Renuka Wetland	Freshwater lake and marshes	Himachal Pradesh	20
28.	Ropar	Barrage or Water storage area	Punjab	1,365
29.	Rudrasagar Lake	Freshwater lake and marshes	Melaghar, Tripura	240
30.	Saman Bird Sanctuary	Freshwater marsh	Manipuri district, Uttar Pradesh	526.3
31.	Samaspur Bird Sanctuary	Freshwater marsh	Raebareli district, Uttar Pradesh	799.371
32.	Sambhar Lake	Natural saline lake	West of Jaipur, Rajasthan	24,000
33.	Sandi Bird Sanctuary	Freshwater marsh	Hardoi district, Uttar Pradesh	308.54
34.	Sarsai Nawar Jheel	Marsh	Etawah district, Uttar Pradesh	161.27
35.	Sasthamkotta Lake	Freshwater lake	Kerala	373
36.	Sultanpur National Park	Freshwater lakes and pools, seasonal/intermittent freshwater lakes	Gurgaon district, Haryana	13,727
37.	Sundarban Wetland	Mangrove swamps, lagoons, mudflats	Bay of Bengal	423,000
38.	Sur Sarovar	Water storage areas/ Reservoirs	Agra	431
39.	Surinsar-Mansar Lakes	Freshwater lakes	Jammu and Kashmir	350
40.	Thol lake Wildlife Sanctuary	Water storage areas/Reservoirs	Mehsana district, Gujarat	699
41.	Tso Kar Wetland Complex	Brackish/ alkaline lake and freshwater lake	Changthang region, Ladakh	9,577
42.	Tsomoriri	Inland wetlands	Ladakh	12,000
43.	Upper Ganga River	River stretch	Uttar Pradesh	26,590

Table A1. Continue

Site No.	Wetland Name	Wetland Type	Location	Area (ha)
44.	Vembanad-Kol Wetland	Lagoon and floodplain complex	Kerala	151,250
45.	Wadhwana wetland	Water storage freshwater, flowing water; Permanent rivers/streams/creeks	Gujarat	575
46.	Wular Lake	Freshwater lake and marsh	Bandipora district, Jammu and Kashmir	18,900
47.	Haiderpur Wetland	freshwater, flowing water; Permanent rivers/streams/creeks	Uttar Pradesh	6,908
48.	Khijadaya Wildlife Sanctuary	Water storage freshwater, flowing water; Permanent rivers/creeks	Gujarat	510
49.	Bakhira Wildlife Sanctuary	Permanent freshwater marshes/pools	Uttar Pradesh	2,894