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Review article

Sustainability Challenges of Ashtamudi Brackish Wetland - A Ramsar Site

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ABSTRACT
This study analyses the sustainability challenges faced by Ashtamudi wetland (an estuarian ecosystem and a Ramsar Site of international importance viz., habitat degradation, soil loss and sediment export, unsustainable tourism, littoral drift, saline intrusion, overfishing, human encroachment, pollution, and violation of coastal regulatory norms faced by Ashtamudi wetland, an estuarine ecosystem and a Ramsar Site of international importance. Between 1980 and 2023, the wetland's water spread area and volume decreased by 27 and 46.30 %, respectively, with maximum depth observed near Kanjirottu Creek. Direct precipitation over the Ashtamudi wetland was reduced by 37.46 %, and the changes in land use patterns in the watershed area of the wetland demonstrated that settlements with vegetation increased by 46.55 %. In comparison, dense vegetation decreased by 34.67 %. Quantifying nutrients in the sediments of Ashtamudi wetland in 2024 demonstrated a maximum potassium and phosphorus concentration of 448 and 63 kg/ha, respectively. Heavy metals, viz. Fe, Cu, Cr, and Pb were present in the sediments of the Ashtamudi wetland, and this could be due to industrial and urban growth near the shoreline. Discharge from the Kallada River decreased by 33.08%, leading to shoal and bar formation near the Neendakara estuary, necessitating periodic dredging for the port operations. Salinity influx in the year 2024 ranged from 22.58 to 47.87 ppt from the inlet to the wetland outlet. This wetland supports a variety of flora and fauna, including 52 varieties of phytoplankton, 97 species of fish, and 116 species of birds. The Total Economic Value (TEV) of Ecosystem Services provided by Ashtamudi wetland in 2020 was estimated at $ 424,873,525. All the above issues suggest the need to devise a sustainable action plan to maintain the ecological balance of this brackish wetland system.

Key words: Conservation concerns, Habitat degradation, Estuarine ecosystem, LULC change, Biodiversity, Conservation measures.

INTRODUCTION

Water is crucial for sustaining life on earth and fundamental for the ecosystem's health, human well-being, climate regulations, agriculture, and vital resources for industries, energy production, and various day-to-day activities (Mishra et al. 2021). Beyond this essential function, water bodies such as lakes, rivers, oceans, and wetlands are the integral parts that support rich biodiversity, acting as habitats for various species and contributing to overall balance as well as providing numerous benefits to both the environment and human societies (Alikhani et al. 2021). The estuarine ecosystem, where freshwater rivers meet and mix with saltwater from the sea, has unique ecological importance. This transition zone serves numerous fish species, provides essential habitat, and filters the pollutants and sediment from upstream freshwater sources before they reach the ocean (Stoot et al. 2024).

Ashtamudi wetland, a prominent estuarine ecosystem located in the Kollam district, lies between 8°52'53" to 9°1'17" N Latitude and 76°31'49" to 76°40'40"E Longitude and is surrounded by the verdant landscape of Kerala and is designated as a Ramsar Site under criterion 1 (representative, rare or unique example of a natural or near natural wetland type), criterion 2 (support vulnerable, endangered or critically endangered species or threatened ecological communities) criterion 3 (supports populations of plants and /or animal species important for maintaining the biological diversity of a particular biogeographic region)and criterion 8 (important source of food for fishes, spawning ground, nursery and /or migration path on which fish stocks, either within the wetland or elsewhere,

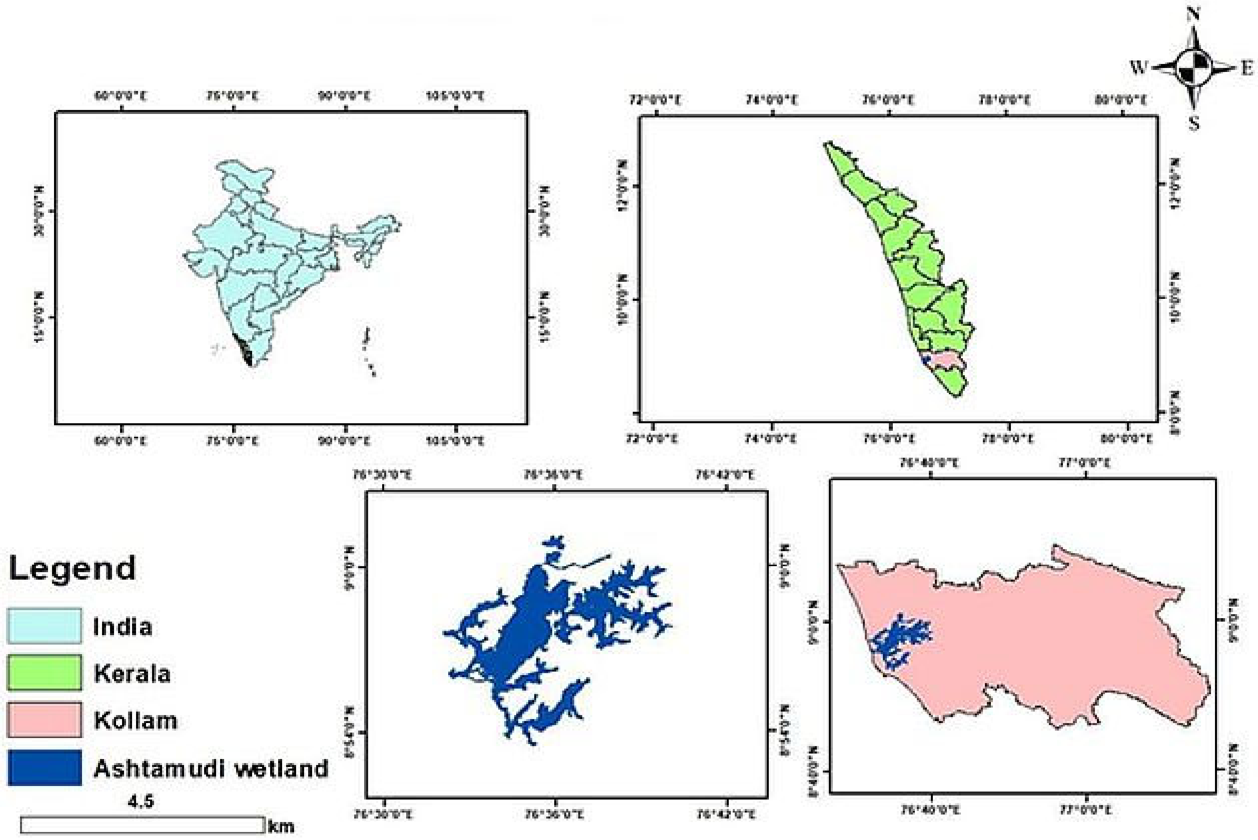

Figure 1. Location map of Ashtamudi wetland

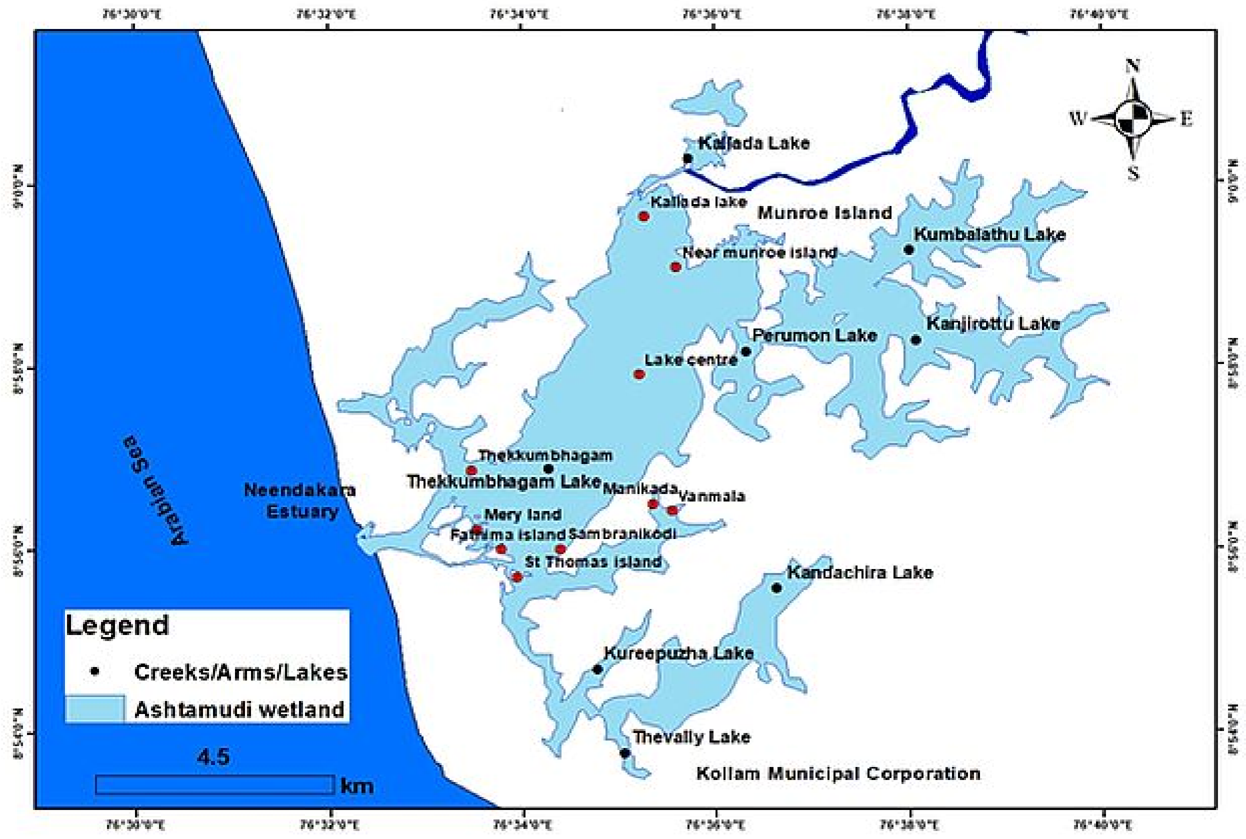

Figure 2. Location features of Ashtamudi wetland

depend) (Anonymous 1997). Combining the terms "Ashta" which means eight, with "Mudi" which means conical hair knot, results in the name "Ashtamudi" which represents the complex mesh of eight notable arms/creeks (Fig. 2) that make up the estuary (Aplin 2004).

The distinctive combination of freshwater from the Kallada River and saltwater from the Arabian Sea is one of the key characteristics of Ashtamudi wetland (Mohan et al. 2017). These creeks converge to form a rich and varied habitat home to various plants and animals. Ashtamudi wetlands are an integral part of life for the local community because they supply them with resources like fish, other aquatic goods, and tourism (Sinclair et al. 2021, Joy and Paul 2021). As one of the State's largest estuaries, it provides a critical habitat for many flora and fauna (Ravinesh et al. 2021), including crabs, fish, and migratory birds (Jayakumar and Chackacherry 2011). The estuary's mangrove swamps serve as natural buffers, protecting the coast from erosion and providing habitat for economically vital fish. Ashtamudi wetland, an essential part of the Neendakara estuary, reinforces local fisheries and the livelihoods of nearby communities (Sinclair et al. 2021). The estuary's natural beauty and biodiversity make it an invaluable resource for recreation and tourism. However, the Ashtamudi estuary suffers from environmental challenges like habitat degradation and pollution, emphasizing the importance of conservation efforts to safeguard its ecological integrity and ensure the long-term health of the environment and the communities that rely upon it (Krishnan et al. 2015). The conservation issues surrounding Ashtamudi wetland necessitate a thorough and quantitative awareness of its ecological, hydrological, and social dynamics (Sreekumari et al. 2016). Initiatives should include rigorous monitoring and assessment programs that quantify the effects of volume reduction, land use changes (Devi et al. 2022), sediment export, carbon sequestration, and ecosystem service. Such efforts are critical to establishing efficient conservation practices that assure the long-term sustainability and resilience of Ashtamudi wetland and its surroundings. The conservation challenges surrounding Ashtamudi wetland are complex, involving many aspects of its ecosystems that must be carefully considered and

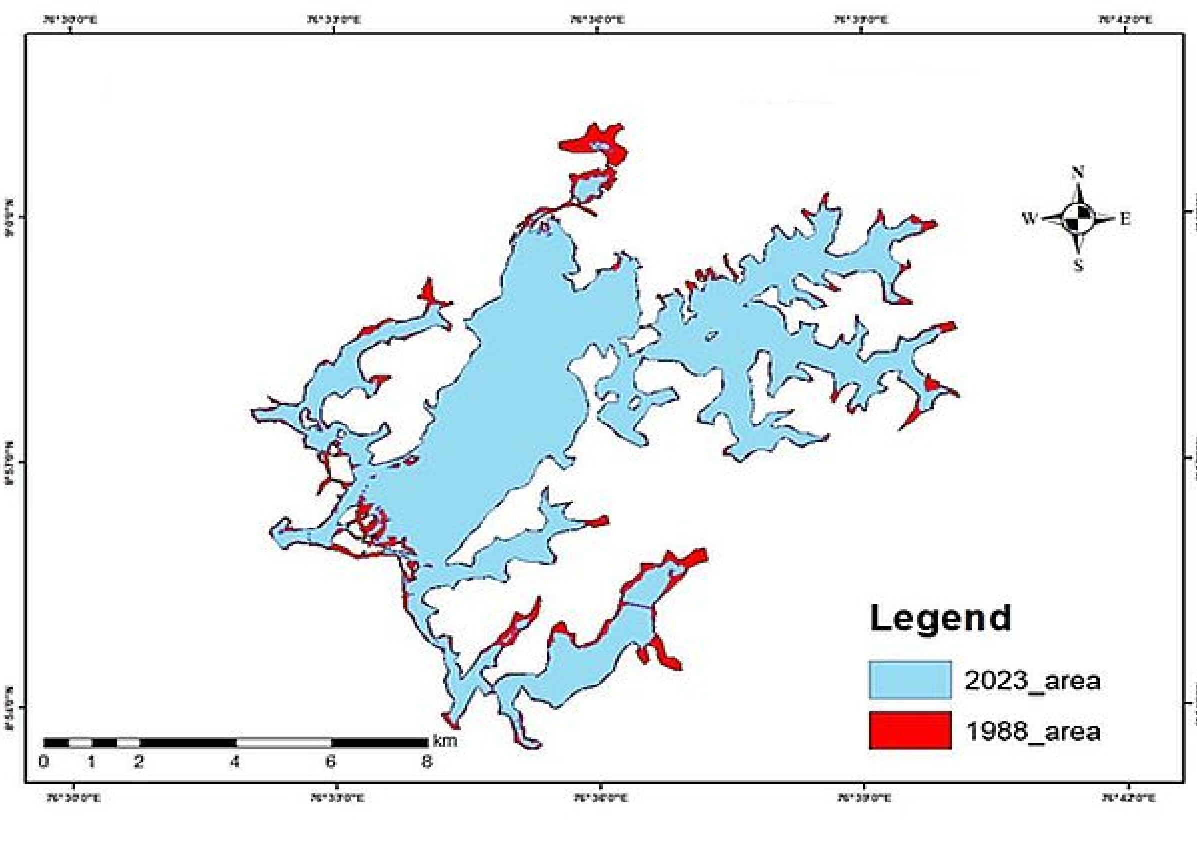

Figure 3. Change in water spread area of Ashtamudi wetland

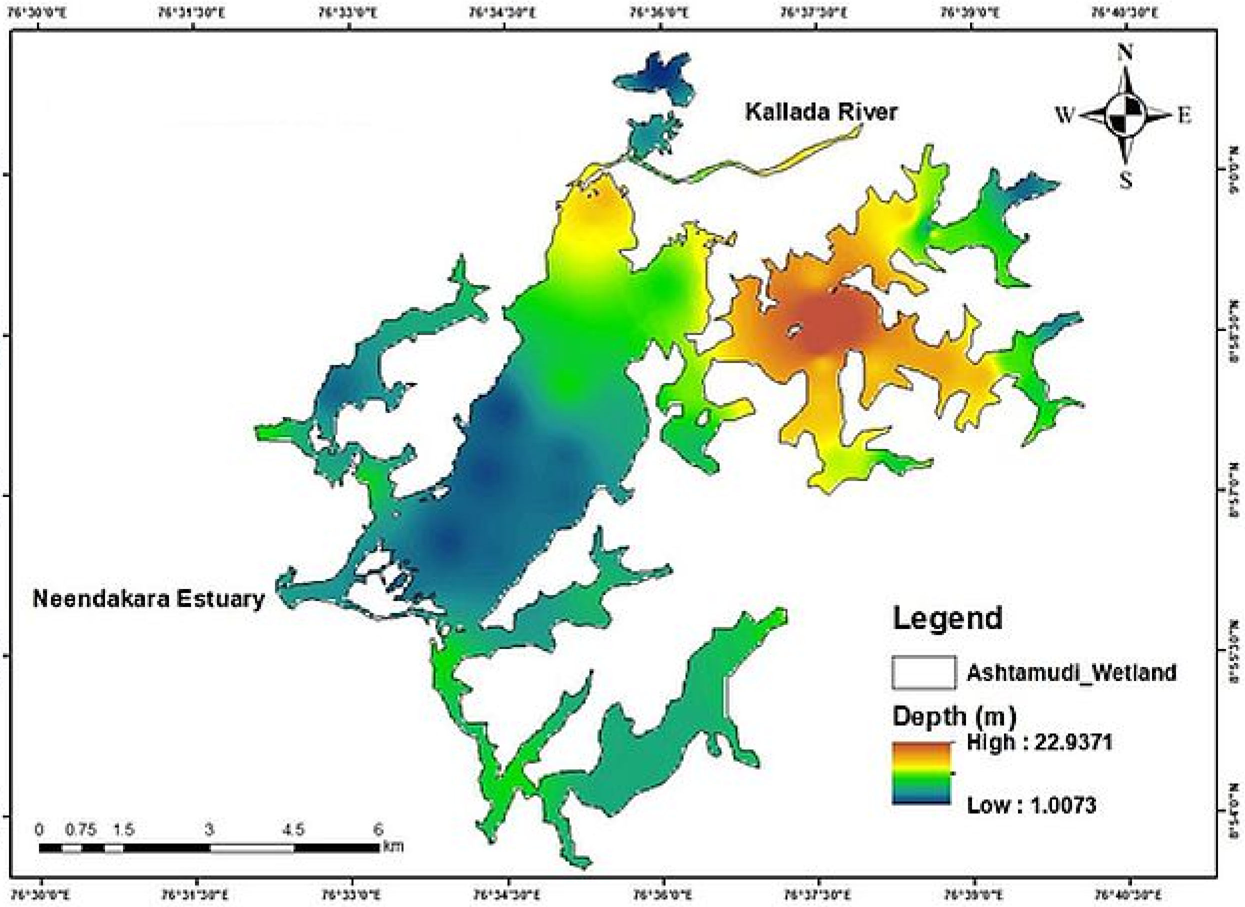

Figure 4. Bathymetry profile of Ashtamudi wetland in the year 2023

analyzed.

SUSTAINABILITY CHALLENGES FACED BY ASHTAMUDI WETLAND

Despite its ecological significance, Ashtamudi wetland suffers several threats to its overall health and sustainability. One primary concern is the wetland's reduced aerial and volume coverage (Anonymous 2014a, Mohan et al. 2017), which directly impacts its water balance (Zachariah and Johny 2008). Reduction in aerial coverage suggests a drop in the wetland's spatial extent (Ma et al. 2007). The water spread area of the wetland reduced by 27% between 1980 and 2023 (Fig. 3). The reduction was more prominent along the shoreline of the wetland, which could be due to shifts in land use patterns, sedimentation, and changes in the prevailing hydrological regime.

Ashtamudi wetland, the deepest wetland in the State of Kerala, had a maximum depth of 22.93 m in 2023. The bathymetry profile (Fig. 4) reveals a gradient in the underwater topography with maximum depth near the inlet (6 m) and only 3 m near the outlet with a funnel-shaped depression near the eastern margin (Kanjirottu Creek). Wetland was experiencing a significant volume reduction, estimated at around 46.30 %, between 1980 and 2023. This decrease indicates a substantial loss of water storage capacity, impacting the ecological balance and the species that depend on it. The decline may be due to changes in water inflow, sediment deposition, and human activities. Water balance analysis is a critical factor in maintaining the ecological health and sustainability of Ashtamudi wetland. This balance is influenced by factors such as Kallada river inflows, precipitation, evaporation, and human activities (Fig. 5).

Any alterations in these components can significantly impact the wetland's water levels and storage capacity. Direct discharge from the Kallada River and direct precipitation (precipitation over the

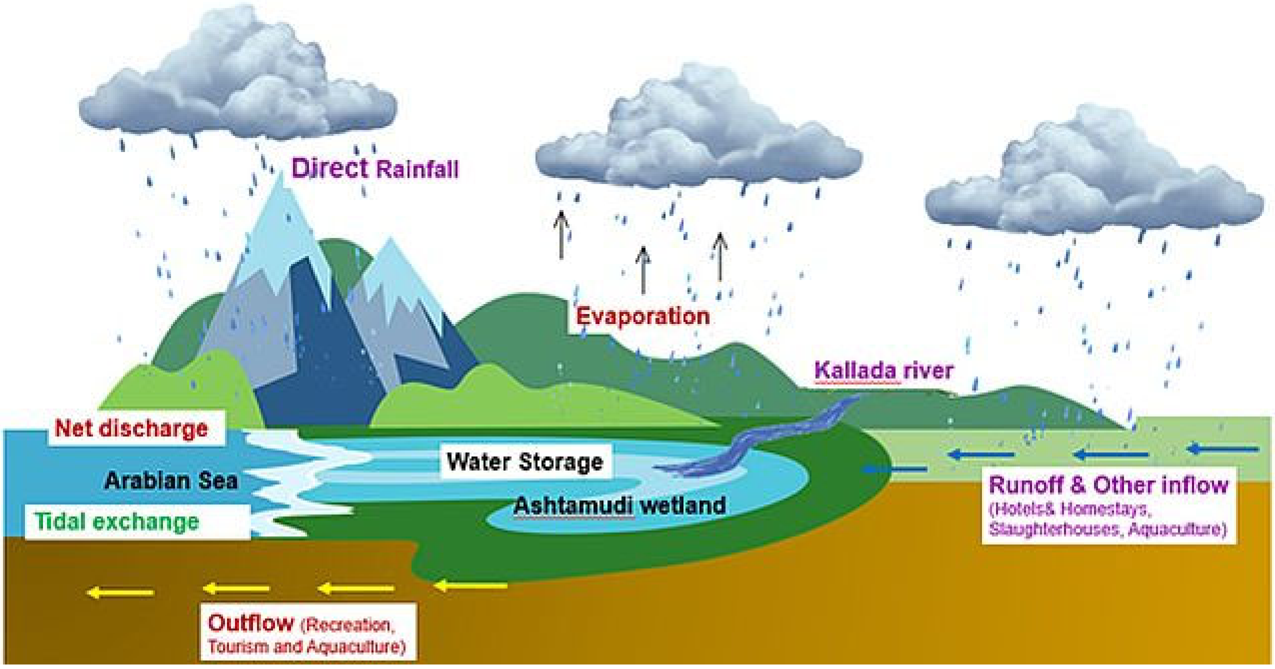

Figure 5. Water cycle of Ashtamudi wetland

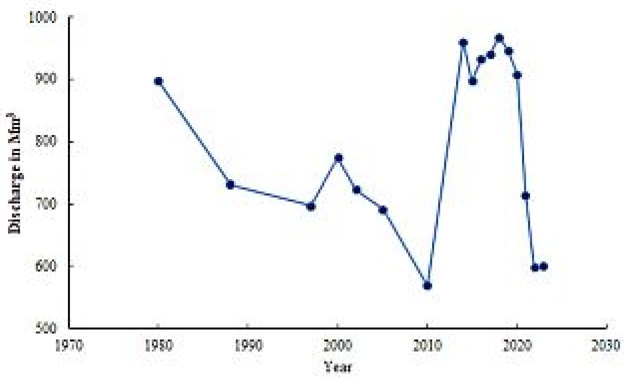

Figure 6. Variation in inflow from Kallada River

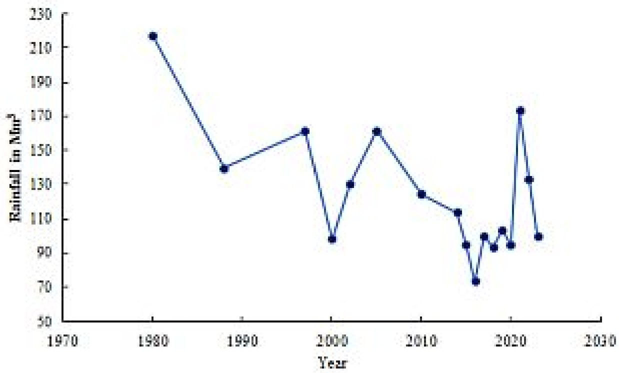

Figure 7. Variation in direct rainfall pattern

wetlands water spread area) are the two sources of freshwater in the wetland. As a result of the construction of the Thenmala Dam on the upstream side of the Kallada River in 1986, the discharge was reduced by 33.08% between 1980 and 2023 (Fig. 6). Variation in the rainfall pattern affects the direct precipitation into the wetland. It was observed that there was a 37.46 % reduction in direct precipitation between 1980 and 2023 (Fig. 7).

Ashtamudi wetland features a diverse land use pattern that includes agricultural activities, aquaculture, tourism, and urban development. This array of land uses reflects the region's economic reliance on both traditional livelihoods, such as fishing and farming, and modern industries, including tourism and commerce. While these activities provide economic benefits, they also challenge the wetland's ecological integrity. Unregulated development and intensive land use can lead to habitat degradation, pollution, and reduced water quality (Beeram et al. 2023). The growth of urban and rural areas, combined with industrial development, causes changes in land use patterns. Between 1980 and 2023 the land use pattern in the watershed area of the Ashtamudi wetland witnessed a 46.55% increase in the land use class settlement with vegetation and a 34.67% decrease in land use class dense vegetation (Fig. 8).

Mangroves, critical for coastal ecosystems and biodiversity stability, are particularly threatened, with

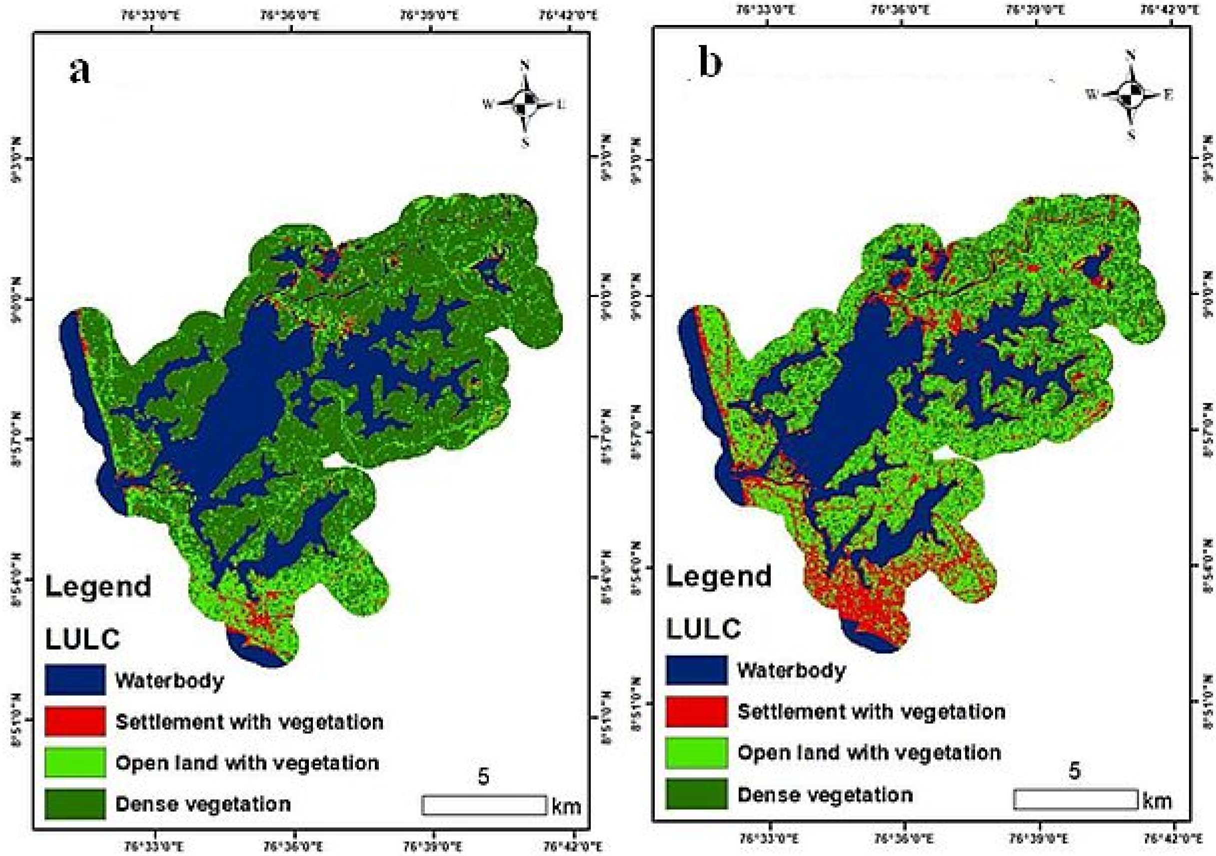

Figure 8. Changes in LULC pattern

reductions and declines caused by human encroachment. The loss of mangroves impacts not only the distinctive flora and fauna they support but also the wetland's resilience to coastal dangers and its critically important ecological equilibrium (Asari et al. 2021).

Ashtamudi wetlands face significant conservation challenges due to soil erosion and sediment export, exacerbated by anthropogenic activities such as urbanization and agriculture in the watershed (Babu et al. 2010). Sediments carried by the Kallada River into Ashtamudi contribute to sediment export and subsequent sedimentation within the wetland, impacting water quality, aquatic ecosystems, and overall ecosystem health. The presence of submerged sandbanks and flood tidal islands (Fathima Island, Samranikodi, Maryland Island, and St Thomas Island) near Neendakara's estuarine entrance reflects substantial sediment input from littoral and shoreline regions. Reduced freshwater inflow from the Kallada River has shifted the ecosystem balance towards coastal processes, leading to sediment infill in the estuary. A notable consequence is the stability impact on the eastern shoreline, with observed land subsidence at Monroe Island, inhabited by 2,400 households (Tundu et al. 2018). The net annual sediment transport rate at Kollam Beach during 1990-91 was 3.83 x 10^6 m^3, with a gross annual transport of 8.05 x 10^5 m^3 (Sajeev et al. 1997). Such significant drift under natural conditions will likely induce shoal and bar formation at the estuary mouth, periodically cleared by high-velocity river flows. Reduced inflows from the Kallada River necessitate regular dredging to maintain sufficient depth for port operations.

Ashtamudi wetland contributes significantly to environmental health by improving the quality of water, nutrient cycling, and carbon sequestration (Jayakumar and Chackacherry 2011). The wetland functions as a natural filter, cleaning water by retaining pollutants and sediments and improving quality (Babu et al. 2010). Ashtamudi wetland promotes nutrient cycling, which recycles organic matter and nutrients, increasing aquatic life productivity and acts as a significant sink for carbon, sequestering and storing carbon via the growth of plants, notably mangroves (Singh and Ramanathan 2005). This helps mitigate climate change and strengthens the general stability of the wetland ecology (Salimi et al. 2021). Water quality in the Ashtamudi estuary typically exhibits alkaline conditions, ranging from mixosaline to eusaline, with localized areas of oxygen depletion. Surface water temperatures fluctuate between 26 to 33°C annually, peaking in summer and dropping during the monsoon season. Both surface and bottom waters generally maintain alkaline pH levels, except in creeks affected by industrial pollution and untreated effluent discharge. Salinity, crucial for ecological productivity, fluctuated between 13 to 33.5 ppt from 2012 to 2015 from the inlet to the outlet of the wetland. During the pre-monsoon period, the influx of seawater combined with low freshwater discharge shifts the wetland towards eusaline conditions. This gradual shift reflects the increasing dominance of coastal processes, leading to higher salinity levels in upstream stretches. Water samples were collected from 10 sampling points (Fig. 2) for analysing the salinity, and the analysis was carried out as per (Anonymous 1988) at the Environmental Engineering Laboratory at the College of Engineering Trivandrum. The variation of salinity in the Ashtamudi wetland from its inlet (Kallada Lake) to its outlet (near Thekkumbhagam) in the year 2024 is shown in Figure 9.

Concentration of nutrients like Nitrogen and Phosphorus significantly influences the growth of aquatic ecosystems. In Kandachira Creek, Nitrate and Phosphate concentrations ranged from 4.1 to 11.3 mg/L and 0.1 to 4.1 mg/L, respectively, peaking during the monsoon and decreasing afterward during 2015. This increase is attributed to sediment runoff from upstream areas and agricultural fertilizers. Nitrate and Phosphate levels in the estuary have progressively risen, likely due to untreated waste disposal from household drains and tourist resorts. Biological Oxygen Demand (BOD) near Thekkumbhagam Island ranged from 0.8 to 14 mg/L, exceeding pollution thresholds (>10 mg/L), possibly due to sewage and solid waste disposal at Kureepuzha along the estuary banks. In 2014, coliform levels exceeded permissible limits, with total coliform reaching 1500 MPN/100 mL and faecal coliform up to 600 MPN/100 mL (John et al. 2017).

Nutrient sampling across five sampling points viz., Thekkumbhagam, Fathima Island, Vanmala, Manikada, and Kallada Lake (Fig. 2) around Ashtamudi wetland revealed distinct concentrations. Thekkumbhagam exhibited potassium (K) levels of 327 kg/ha and phosphorus (P) levels of 52 kg/ha. Fathima island registered 291 kg/ha of K and 42 kg/ha of P. Vanmala recorded 448 kg/ha of K and 63 kg/

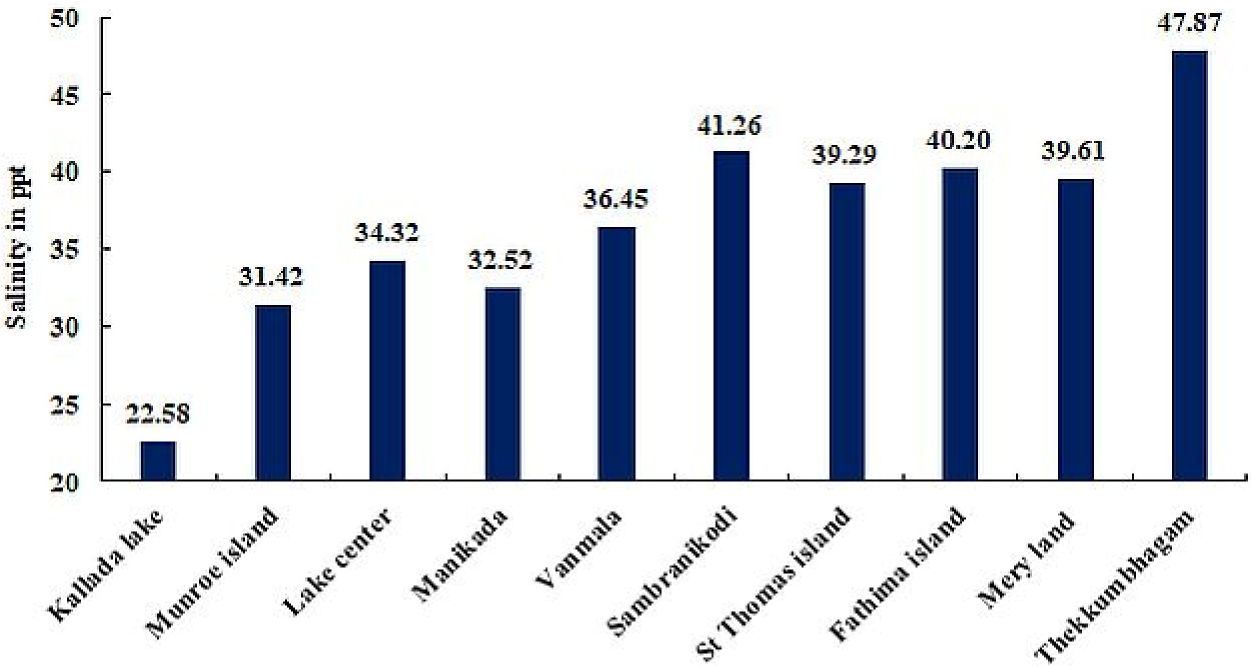

Figure 9. Variation in salinity across the wetland

ha of P, while Manikada showed similar levels with 448 kg/ha of K and 52 kg/ha of P. In contrast, the Kallada Lake region displayed lower concentrations at 233 kg/ha of K and 11 kg/ha of P. These findings underscore significant spatial variations in nutrient levels across different zones, influencing the overall health of the wetland ecosystem.

Although small-scale, coconut coir retting and related operations are widespread along coastal stretches and contribute significantly to the organic pollution of open water bodies. During the retting process, coconut husks release significant quantities of polyphenols and hydrogen sulfide, leading to anoxic conditions. Untreated retting effluents contain high concentrations of biodegradable organic matter, sulfides, nitrates, and phosphates, imposing significant BOD and Chemical Oxygen Demand (COD) stress on the surrounding aquatic environment. These stressors are particularly evident along the northern shorelines of the estuary, where much of the retting activity occurs, contributing to elevated levels of dissolved methane. In 2004, an assessment revealed that the estuary emitted 270 x 10^6 g of methane, with about 15% of the flux reaching the coast due to tidal mixing and water flow dynamics (Zachariah and Johny 2008).

The Neendakara port area experiences frequent leaching of oil, grease, and lubricants from boats, affecting fish quality, such as *Etroplus suratensis*, which has been reported to carry kerosene odours. The fish-processing unit at Neendakara, reclaimed from a water body, also releases pollutants. Waste management practices on approximately 50 houseboats operating within the estuary are inadequate, and runoff from nearby slaughterhouses further impacts water quality, resulting in Neendakara harbour and Kandachira region emerging as the most polluted parts of the estuary (Sajeev and Subramanian 2003, Jayakumar and Chackacherry 2011).

Reclamation of land for commercial use, altering a natural estuary into a constructed harbour, and other industrial developments around Ashtamudi wetland pose substantial environmental challenges (Sajeev and Subramanian 2003). Wetland regions are converted for industrial purposes by filling or draining them, resulting in habitat loss and fragmentation. This can upset the natural balance of the environment, harming flora and fauna that rely on the wetland ecology (Wu et al. 2018). Changing the natural opening of the marsh to an engineered harbour disturbs tidal and sedimentary processes. This alteration impacts water circulation, salt levels, and nutrient distribution of the wetland system (Paravat et al. 2009).

The effluent from the clay factory near the Kanjirottu creek, effluents from the Milma dairy, KSRTC (Kerala State Road Transport Corporation) workshop yard in the Kureepuzha Creek, Aluminium Industries Ltd, Kerala Ceramics Ltd, Kerala Electrical and Allied/Engineering Company near the Perumon Creek introduces heavy metal pollutants (Karim and Williams 2015, Usha and Selsa 2022) (Fe, Cu, Cr Pb, Zn and Cd) to the wetland beyond the permissible limit as per the United States Environmental Protection Agency report (Anonymous 2003) and Canadian Council of Ministers of the Environment report (Anonymous 2009) they may adversely affect the water quality, impacting the aquatic ecosystem and potentially harming the wetland environment (Priya Lekshmi and Williams Sherly 2019). Untreated sewage discharged from various sources, such as a slaughterhouse, Kollam city, houseboats, and tourist boats, contributes contaminants and nutrients to the wetland (Mekha 2022). This can result in eutrophication, hazardous algal blooms, and reduced dissolved oxygen levels, all of which severely influence the quality of water and aquatic habitats. Ashtamudi wetland hosts diverse biodiversity, supporting a rich array of aquatic flora and fauna as per the IUCN Red List of Threatened Species (Anonymous 2017), conservation status which is shown in Figure 10.

Wetland is influenced by various natural and anthropogenic factors affecting bird and animal migration, depletion of zooplankton, vegetation, and wildlife. The study found 52 phytoplankton species from 35 families and 10 classes in the estuary. *Bacillariophyceae* (35%), *Cyanophyceae* (19%), *Mediophyceae* (10%), and *Ulvophyceae* (10%) were the four most common classes (Ravinesh et al. 2021). Their abundance was highest during the monsoon season, with low salinity and high nutrient enrichment from the southwest monsoon. The study links low phytoplankton abundances during the pre-

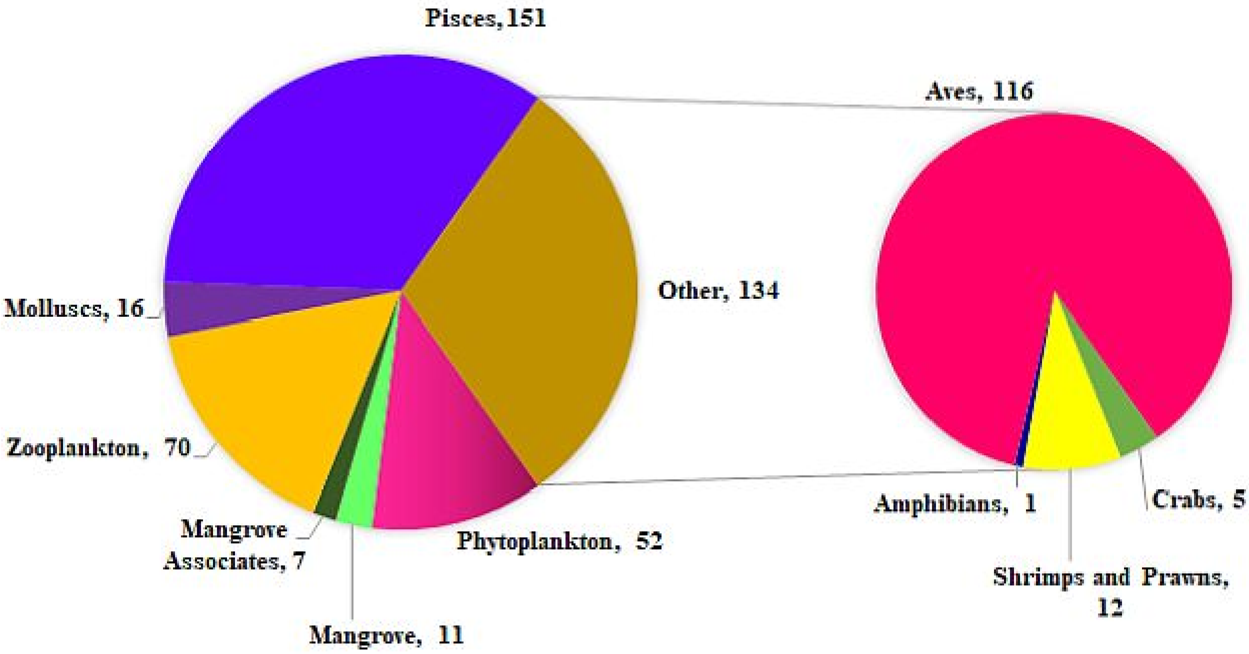

Figure 10. Conservation status of flora and fauna

monsoon and post-monsoon seasons due to contamination from coir retting grounds and effluents carried by the Kalalda River (Kumar et al. 2023).

The ecology of the *Halophila ovalis* seagrass bed was examined in the Kanjirottu Creek region, and the average standing stock ranged from 3.6 to 4.8 g^2 (dry) during the monsoon and post-monsoon season (Nair et al. 1983). Pollution and shoreline alteration have affected these bed areas (Balakrishnan et al. 1983). Mangroves are prominent elements of the Ashtamudi estuary, with a total of 12 valid mangrove species and 6 related species (Jeslin et al. 2021) reported around the Asramam, Neendakara, and Thekkumbhagam creek of the wetland (Mazumdar 2020). *Rhizophora apiculate* is a species that lives on the fringes. Asramam, one of Kollam District's most notable mangrove areas, had been severely damaged due to land reclamation, conversion, and real estate developments (Rafeeque et al. 2021). *Syzygium travancoricum*, a severely endangered species, is found here in minimal numbers. *Lumnitzera racemosa*, a rare mangrove species in Kerala, has a restricted range in the Asramam area (Krishnan et al. 2015). *Ceriops tagal*, previously considered extinct along the Kerala coast, has been rediscovered on Vincent Island in Kollam district (Vimal et al. 2014).

The whole area of mangroves in the Ashtamudi wetland has drastically shrunk. Mangroves decreased from 1.46 km^2 in 1967 to 0.95 km^2 in 2016 (Salahudeen et al. 2018). The existing mangrove and bird congregation areas of Ashtamudi wetland in 2024 are shown in Figure 11.

Currently, mangrove species are limited to three spots at Asramam, Munroe Island, and Kumbalathu Creek. Their regrowth has been hampered by various human-caused stresses, including habitat loss, cattle grazing, coconut husk retting, and harvest for medicine, timber, and pollution (Mohandas et al. 2014). The Zoological Survey of India conducted a comprehensive study of Ashtamudi's faunal richness between 1988 and 1991. The study identified 12 polychaeta species, 6 amphipoda species, 3 isopoda species, 13 copepoda species, 7 cladocera species, 9 prawn species, 10 timber borers, 3 chaetognatha species, 2 pelecypod species, 125 fish species, and 92 bird species in the wetland area (Upadhyay et al. 2019). The seasonal change of zooplankton, fisheries resources, distribution of benthic macrofauna, benthic foraminiferal assemblage, and aquatic bioresources of Ashtamudi were also studied to assess the estuary's faunal richness (Divakaran et al. 1982, Nair et al. 1984).

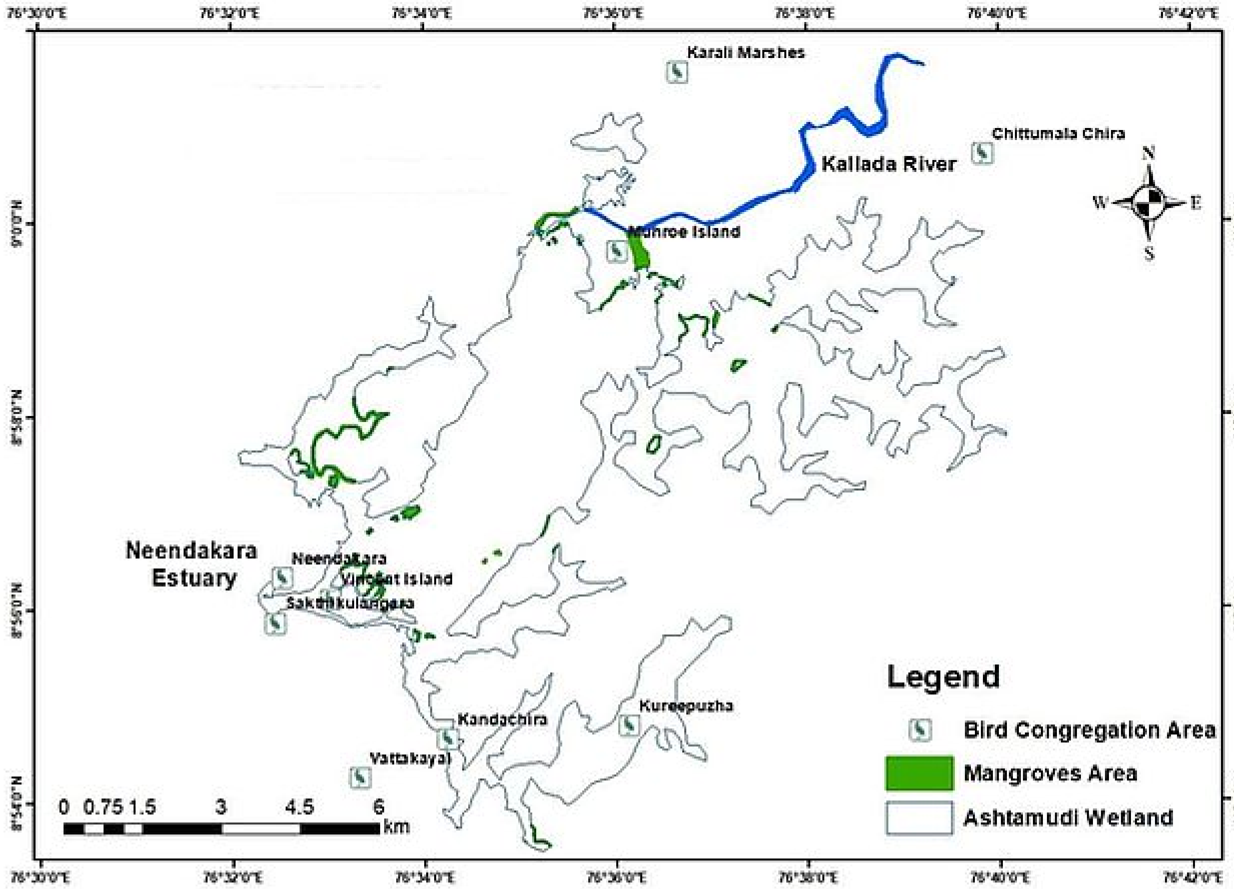

Figure 11. Existing mangrove and bird congregation centres in the year 2024

Several researches were conducted to analyze the Ashtamudi zooplankton community. The list reveals at least 70 species from seven classes representing 47 families of freshwater, brackish, and marine origin over the last three decades. The most common classes were *Polychaeta* (31%), *Malacostraca* (27%), *Hexanauplia* (20%), and *Branchiopoda* (14%). A preliminary investigation on the benthic foraminiferal assemblage of the estuary 49 was also carried out in 2000, yielding 29 benthic and 3 planktic foraminiferal species (Reghunathan et al. 2016).

Assessments conducted since 1981 suggest the presence of at least 16 mollusc species in the estuary (Nair et al. 1984, Reghunathan et al. 2016). These species are divided into bivalvia (15 species) and gastropoda (1 species), each containing eight families. Clams are the most common and prolific type of bivalves harvested in Ashtamudi. Important clam species include *Paphia malabarica*, *Villorita cyprinoides*, *Marcia opima*, and *Meretrix casta*. *P. malabarica* (short neck or yellow foot clam) (Ravinesh et al. 2021) is a widely spread and continually exploited clam for both local consumption and export (Arathi et al. 2018). Since the mid-1980s, salinity regime changes have had an impact on the abundance of molluscan species. *M. opima*, which was once prevalent in the Neendakara region, has been nearly completely replaced by *P. malabarica*, a species known for its excellent saline tolerance (Biju et al. 2019).

Preliminary assessment of Ashtamudi's fishing resources identified 97 fish species from 39 families. Approximately 50 % (42 species) were true marine, 3 were brackish, and 11 were freshwater species (Balakrishnan et al. 1983). The remaining 41 species were temporary forms, such as Chinese dip nets in Ashtamudi 50, and included estuarine-riverine, marine-estuarine, and marine-estuarine-riverine species (Vimal et al. 2014). Along with the previous inquiry, Ashtamudi's faunal variety was assessed, yielding 125 fish species in the estuary. 91 species of aquatic fauna belonging to 39 groups were

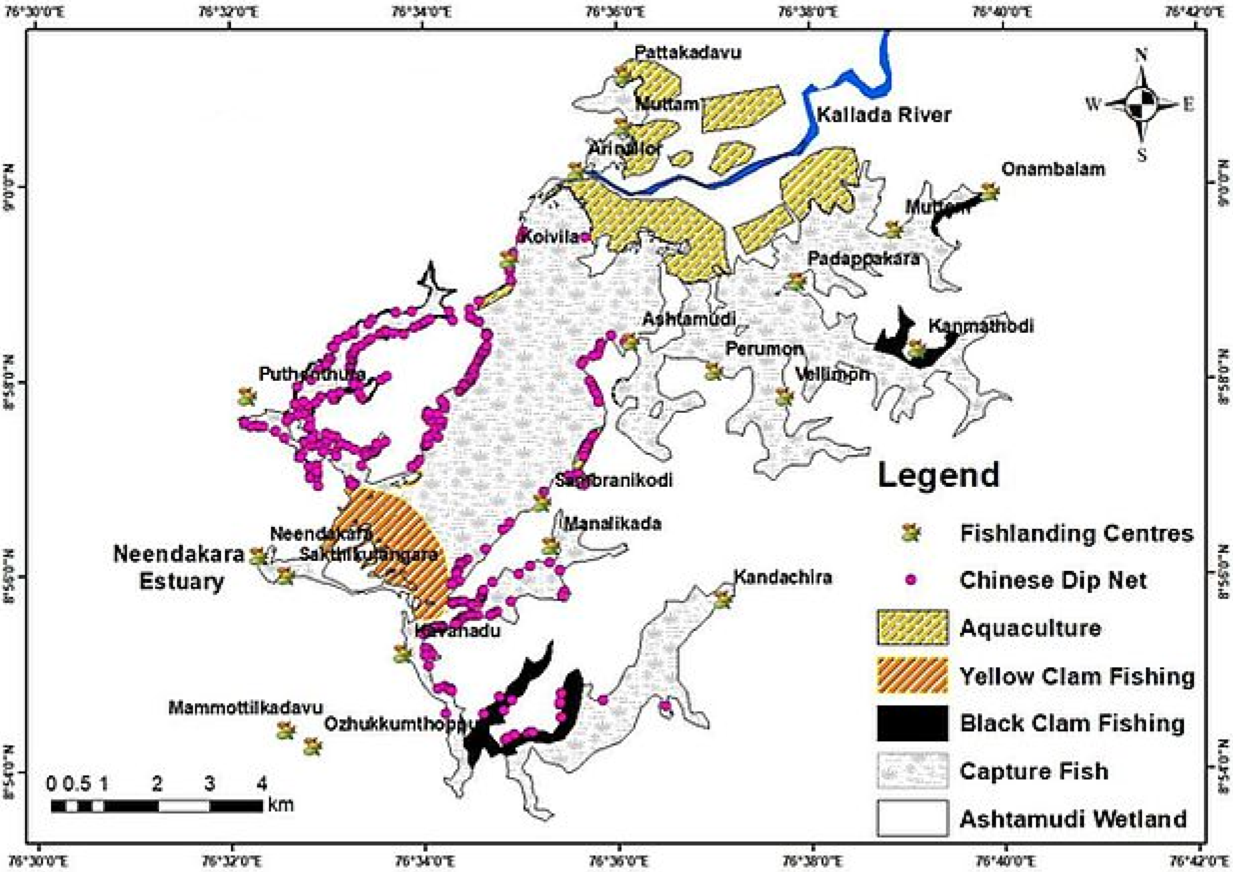

Figure 12. Aerial extent of existing fishery resources in Ashtamudi wetland (2024)

recorded from the estuary (Kumar et al. 2023). These 91 species included 68 finfish, 5 crabs, and 9 prawn and mollusc species. Of the finfish, 24 were true marine, 9 were genuine freshwater, and 4 were true estuarine species. The remaining species were transient forms found in estuarine riverine (8 species), marine-estuarine (19 species), and marine-estuarine-riverine (4 species) (Vimal et al. 2014). Aerial extent of existing fishery resources in Ashtamudi wetland in 2024 is shown in Figure 12.

Since 1992, the Ashtamudi estuary has been part of the Asian Water Bird Census (a volunteer-based mid-winter water bird census program that began in 1987) and has been surveyed 15 times (Nameer et al. 2014). During the 1992–2015 census period, the bird population averaged 2165 individuals, with a peak count of 5291 in 2002, while the number of species fluctuated from 16 to 51. There are eleven significant bird aggregation locations in and around the estuary. These are essentially the estuary's coastline sections, where the water is shallower and food is more plentiful. 51 The counts across the years indicate significant volatility, primarily due to varied coverage in different years. The list of birds gathered from census data yields 69 distinct species. However, the research identified 92 bird species in the estuary. Consolidating the two datasets yields a list of 116 birds from 39 families. The major families were Scolopacidae, Laridae, and Ardeidae. Of the 116 bird species, 71 are water birds, with 86% (61 species) being winter migratory (according to the Birdlife International Database) (Neate-Clegg et al. 2020). According to the IUCN Red List of Threatened Species (version 2016-3), nine water bird species are classified as near threatened (Leroux et al. 2010). Aside from the Ashtamudi estuary, water birds are known to inhabit adjacent wetlands such as Chittumala, Karali Marshes, Monroe Island, Vattakayal, and Sasthamkotta Lake, showing the importance of Ashtamudi and its bordering marshes as a complex in supporting these habitats (Pournami et al. 2023).

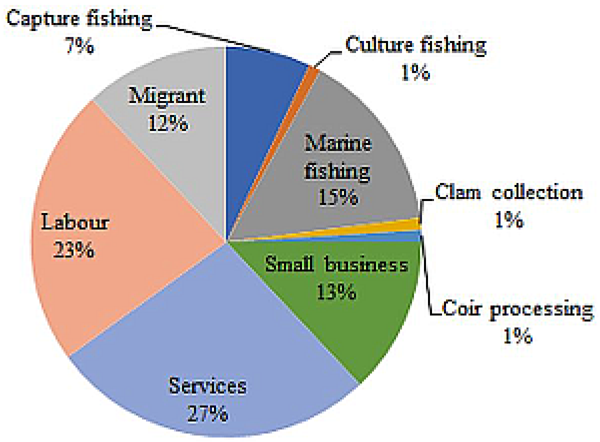

Figure 13. Occupation details of households in the watershed area

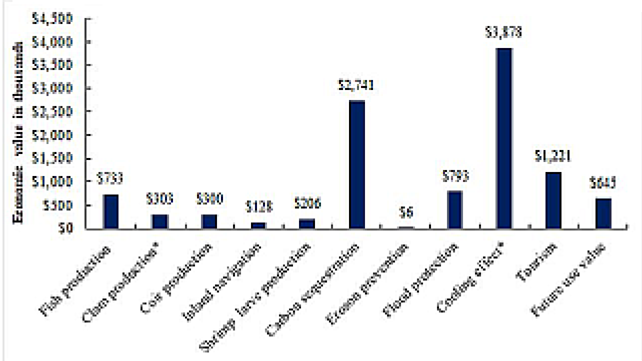

Figure 14. Economic value of individual ecosystem services provided by the Ashtamudi wetland in the year 2020 (* Should be multiplied by a factor of 100)

The existence of latrines, along with other sources of waste from humans and animals within or close to the wetland, increases the potential for fecal contamination of the surrounding water bodies (Chinnadurai et al. 2016). The contamination is a severe concern since it may introduce germs, bacteria, and parasites into the water (Anonymous 2014a). Pathogenic microbes from faecal waste can cause health threats to aquatic life and human populations that rely on the wetland for various reasons (Mekha 2022).

Densely populated shoreline of the Ashtamudi wetland encompasses 11 grama (village) panchayats and a municipal corporation. The population of these areas relies significantly on the Ashtamudi wetland for various aspects of their livelihoods, such as fishing, clam collection, tourism, small businesses, and livestock farming. Figure 13 shows the proportion of this population engaged in various activities. In 2020, a study on the economic valuation of various individual Ecosystem Services provided by Ashtamudi wetland estimated a Total Economic Value (TEV) of $ 424,873,525. Figure 14 details the economic value of individual services (Joy and Paul 2021).

Ashtamudi wetland is designated as a Ramsar Site due to its unique wetland characteristics, threatened ecological communities, diverse plant and animal species, and abundant fish stocks. Over the years these services, viz. fishery resources, clam and crab production, inland navigation, recreation and tourism, nutrient cycling, carbon cycling, aesthetics, water regulation, and water supply, have undergone changes which are evident from the studies carried out on Ashtamudi wetland in the years 1967, 2008 and 2013 and the same is shown in Figure 15 (Joy and Paul 2021). If these trends continue, the wetland may still need to meet the Ramsar designation criteria, leading to the loss of its international importance.

Among all other challenges, one of the most serious conservation issues caused by Coastal Regulatory Zone (CRZ) (Ramachandran et al. 2005) violations is the change of essential ecosystems in the wetland's coastline zones (Vincent and Owens 2021). CRZ rules are intended to safeguard coastal ecosystems, prevent deterioration, and ensure sustainable growth along coastal areas.

Delineation of the coastal zone for Kollam District carried out for implementing the CRZ Notification, includes marking the Ashtamudi wetland boundary (near the Neendakara estuary) (Anonymous 2014b). A boundary has been defined using the high tide line, which marks the highest waterline reached during the spring tide. 100 m setback line is drawn landward of the high tide line along the estuary to implement various regulatory provisions of the CRZ Notification. As a result of continuous encroachment on environmentally vulnerable areas like mangroves and marshlands, unsupervised residential and commercial construction along the shoreline violates regulatory requirements, threatening the ecosystem's delicate equilibrium and long-term health (Panigrahi and Mohanty 2012). This ecosystem is an important

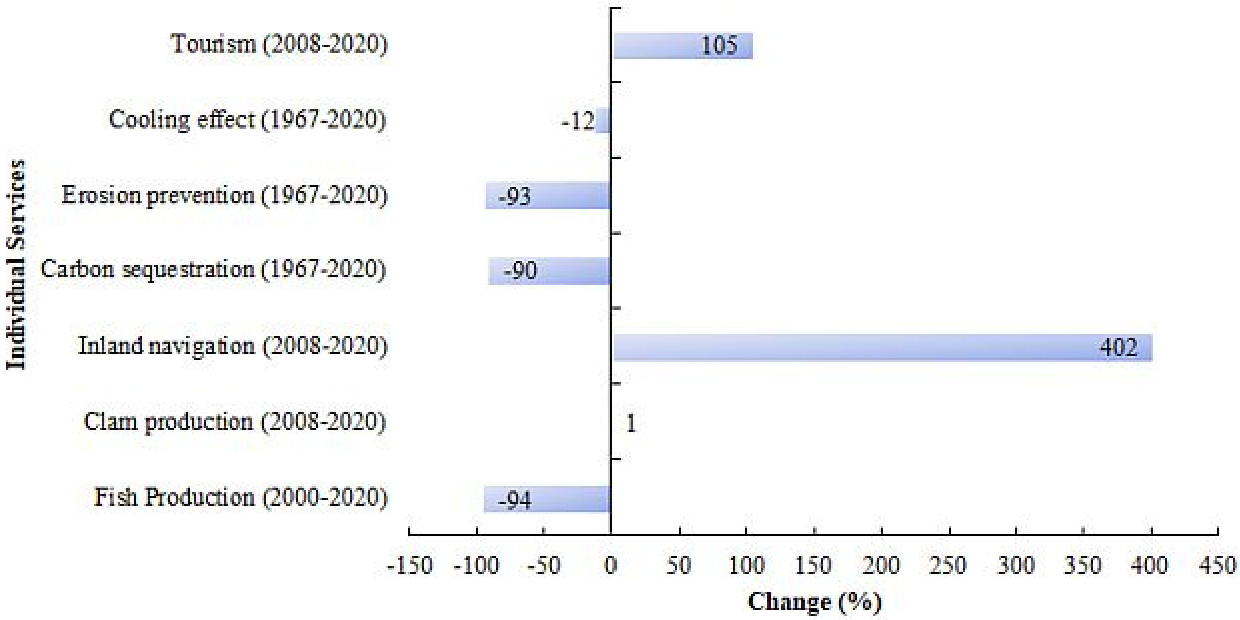

Figure 15. Change (%) in individual ecosystem services

breeding site for numerous aquatic lives and acts as a natural buffer against surges of water and tidal changes. The encroachment interferes with these services, putting the wetland's environment at risk (Anonymous 1991). Violations of CRZ restrictions frequently result in more significant pollution and habitat loss. Improper trash disposal, untreated sewage release, and using hazardous building materials add to water pollution and lower the overall quality of Ashtamudi wetland. Such pollution harms aquatic flora and animals, upsets food chains, and endangers the ecosystem and communities that rely on the wetland for various uses (Panigrahi and Mohanty 2012). The decline of natural vegetation and coastal habitats caused by CRZ violations reduces the wetland's ability to take in and preserve carbon. Coastal vegetation, particularly mangroves, is an important carbon sink for mitigating climate change. The loss of this carbon sequestration potential worsens the global environmental consequences. Addressing the breach of CRZ in Ashtamudi wetland necessitates a comprehensive and coordinated response.

CONSERVATION MEASURES

Ashtamudi wetland, nested in the green landscapes of Kerala, India, highlights the complex connection of aquatic and terrestrial ecosystems. This wetland, rich in ecosystem services and biodiversity, is under increasing threat and requires urgent conservation efforts. Understanding the importance of conservation and executing appropriate measures is critical to ensuring the continued health of this unique natural resource. Addressing Ashtamudi wetland's conservation concerns demands a multi-faced integrated strategy that includes environmental, social, and economic considerations, and certain measures are proposed to address the degradation.

Rules and regulations for encroachment prevention

Establishing strict restrictions is critical to protecting the wetland area and preventing encroachment. Establishing Coastal Regulatory Zones (CRZ) and other applicable criteria would reduce unplanned urbanization, preserve key ecosystems, and protect the Ashtamudi ecosystem.

Habitat regeneration

To mitigate habitat deterioration, restoring the wetland through replanting native plants is critical. This includes re-establishing mangroves, marshlands, and other native plants that act as breeding grounds and nurseries for various aquatic animals.

Pollution management

Monitoring and regulating sources of pollution, especially industrial discharge and agricultural runoff, will help to maintain water quality. Stringent procedures must be implemented to guarantee that everyone follows environmental standards and prevent the entrance of dangerous pollutants into Ashtamudi wetlands.

Control measures for erosion and sediment export

Erosion management measures must be implemented to stop shoreline erosion and sedimentation. This involves preserving the wetland's size and safeguarding its sensitive ecology through engineering solutions, vegetation restoration, and natural buffers.

Social conscience

It's critical to increase awareness in the neighborhood. Communities that rely on Ashtamudi wetland are encouraged to adopt sustainable practices and develop a perception of responsibility by being informed about the wetland's significance and its dire need for conservation.

Monitoring biodiversity

Regular biodiversity surveys are necessary to understand the health of the habitat. These surveys assist in tracking changes in populations of species, detect possible threats, as well as inform adaptive management options.

Productive fisheries management

For fish populations to remain healthy over time, sustainable fisheries management techniques must be put into practice. Ensuring a balanced aquatic environment requires enforcing laws to stop overfishing and habitat loss while ensuring fisheries run within the highest feasible yield levels.

Sustainable tourism practices

Transforming regional tourism is crucial in Ashtamudi Wetland. Implementing sustainable tourist techniques reduces their effect on the wetland and its environs. Regulations for sustainable tourism should be devised and implemented to safeguard the sensitive wetland ecology from the possible harm caused by unauthorized tourist activities.

Transforming backwater tourism into ecotourism

The transition from traditional backwater tourism into ecotourism is revolutionary. Promoting ecologically sound tourism practices that focus on conservation and education improves visitor experiences while preserving the integrity of the Ashtamudi wetland. The area demands holistic and collaborative efforts to implement conservation strategies. The collective effort of the communities, authorities, and stakeholders is essential for the successful conservation and safeguarding of Ashtamudi wetland for the next generation and beyond.

Separate watershed prioritization

Assess the vulnerability of the creek to environmental stressors such as pollution, habitat degradation, and climate change impacts. Identify areas within the watershed that are particularly sensitive to disturbances and prioritize their conservation.

Integrated wetland management authority

Initiatives involving collaborative efforts from a diverse group of stakeholders, including the State Wetland Authority, State Water Transport Department, Pollution Control Board, Tourism Department, Fisheries Department, urban and local administrative representatives, Neendakara port, Houseboat Association, and fisherman cooperatives, aim to raise awareness and promote understanding of the biodiversity and ecosystem service values of the wetland and Engage nearby study centres and research institutions to facilitate continuous monitoring of waste management, water quality, and environmental impact assessments related to various stressors.

CONCLUSION

The study sheds light on the critical conservation challenges of the brackish wetland of Kerala. As a distinct and biodiverse environment, Ashtamudi wetland faces numerous issues, including encroachment, pollution, habitat destruction, and unsustainable practices. The findings highlight the necessity and significance of implementing extensive conservation measures to protect this brackish wetland treasure. The violation of CRZ is a major concern, resulting in the loss of habitat and the disruption of vital biological functions. Encroachment, caused by urbanization and unrestrained development, is a direct danger to the vital equilibrium of wetland ecosystems. Pollution from numerous sources, such as industrial effluent and agricultural runoff, degrades water quality, affecting aquatic species and the general health of the wetland. Despite these limitations, the study proposes conservation measures, including strict regulations, habitat restoration, pollution control, erosion management, community awareness, biodiversity monitoring, sustainable fisheries management, responsible tourism practices, and climate change adaptation, which present a comprehensive strategy for addressing Ashtamudi wetland's countless problems. The coordinated efforts of local people, political entities, environmental organizations, and international stakeholders are critical to conserving Ashtamudi wetland for current and future generations by implementing the proposed measures.

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REFERENCES

Alikhani, S., Nummi, P. and Ojala, A. 2021. Urban wetlands: A review on ecological and cultural values. Water, 13(22), 3301. https://doi.org/10.3390/w13223301

Anonymous. 1988. IS 3025-32: Methods of Sampling and Test (physical and chemical) for Water and Wastewater, Part 32: Chloride [CHD 32: Environmental Protection and Waste Management]. Bureau of Indian Standards, Delhi.

Anonymous. 1991. The Gazette of India. Ministry of Environment, Forests and Climate Change, Government of India, New Delhi.

Anonymous. 1997. The Ramsar Convention Manual: A guide to the convention on wetlands of international importance especially as waterfowl habitat, 2nd. ed. Ramsar Convention Bureau, Gland.

Anonymous. 2003. Framework for Cumulative Risk Assessment. United States Environmental Protection Agency. National Academy Press, Washington DC.

Anonymous. 2009. CCME Setting Strategic Directions for Water. Canadian Council of Ministers of the Environment (CCME), https://scics.ca/wp-content/uploads/CMFiles/830973004_a1e1OUA-9152010-257.pdf Accessed on 22nd June 2024

Anonymous. 2014a. Analysis Report-Kallada River 2014, Kollam, Kerala. Kerala State Pollution Control Board, Thiruvananthapuram, Kerala.

Anonymous. 2014b. Coastal Zone Management Plan of Kollam District, Kerala. National Centre for Earth Science Studies, Thiruvananthapuram, Kerala.

Anonymous. 2017. The IUCN Red List of Threatened Species. https://www.iucnredlist.org/en

Aplin, P. 2004. Remote sensing: land cover. Progress in Physical Geography: Earth and Environment, 28, 283-293. https://doi.org/10.1191/0309133304pp413pr

Arathi, A.R., Oliver, P.G., Ravinesh, R. and Kumar, A.B. 2018. The Ashtamudi Lake short-neck clam: Re-assigned to the genus *Marcia* H. Adams & A. Adams, 1857 (Bivalvia, Veneridae). Zoo Keys, 799, 1-20. https://doi.org/10.3897/zookeys.799.25829

Asari, N., Suratman, M.N., Mohd Ayob, N.A. and Abdul Hamid, N.H. 2021. Mangrove as a natural barrier to environmental risks and coastal protection. pp 305-322. In: Rastogi, R.P., Phulwaria, M. and Gupta, D.K. (Eds.). Mangroves: Ecology, Biodiversity and Management, Springer, Singapore.

Babu, K.N., Omana, P.K. and Mohan, M. 2010. Water and sediment quality of Ashtamudi estuary, a Ramsar site, southwest coast of India - a statistical appraisal. Environmental Monitoring and Assessment, 165, 307-319. https://doi.org/10.1007/s10661-009-0947-0

Balakrishnan, N.N., Arunachalam, M., Abdul Azis, P.K. Dharmraj, K. and Kumar, K.K. 1983. Ecology of seagrass bed of *Halophila ovalis* (Hook) in the Ashtamudi Estuary, SW Coast of India. Indian Journal of Geo-Marine Sciences, 12, 151-153. http://nopr.niscpr.res.in/handle/123456789/38880

Beeram, S.N.R., Suhanas, P.V., Padama, S.K. and Thendiyath, R. 2023. Impact of change in land use/land cover and climate variables on groundwater recharge in a tropical river basin. Environment, Development and Sustainabiligy, 26, 14763-14786. https://doi.org/10.1007/s10668-023-03216-x

Biju, K., Ravinesh, R., Oliver, P.G., Tan, S.K. and Sadasivan, K. 2019. Rapid bioinvasion of alien mussel *Mytella strigata* (Hanley, 1843) (bivalvia: Mytilidae) along Kerala coast, India: Will this impact the livelihood of fishers in Ashtamudi Lake? Journal of Aquatic Biology & Fisheries, 7, 31-45. https://www.jabf.in/articles/Vol7/1-2/5_Bijukumar_etal.pdf

Chinnadurai, S., Mohamed, K.S., Sharma, J., Venkatesan, V. and Kripa, V. 2016. Assessment of bio-accumulation of bacteria in oysters from shellfish growing waters in Ashtamudi Lake (Kerala, India): A RAMSAR wetland. Regional Studies in Marine Science, 7, 118-122. https://doi.org/10.1016/j.rsma.2016.05.016

Devi, A.B., Deka, D., Aneesh, T.D., Reji, S. and Nair, A.M. 2022. Predictive modelling of land use land cover dynamics for a tropical coastal urban city in Kerala, India. Arab Journal of Geosciences, 15, 399. https://doi.org/10.1007/s12517-022-09735-7

Divakaran, O., Arunachalam, M., Nair, N. and Balasubramanian, N.K. 1982. Seasonal variation of zooplankton of the Ashtamudi Lake, south-west coast of India. Mahasagar, 15(1), 43-50.

Jayakumar, K.V. and Chackacherry, G. 2011. Ashtamudi Wetland, Kerala: Values and Threats. In: National Workshop on Ramsar Designated Wetlands of India, Kolkota, India.

Jeslin, I.J., Benny, N., Thomas, L.C. and Padmakumar, K.B. 2021. Short term spatio-temporal variabilities of microphytobenthic assemblages in the mangrove ecosystems along the southwest coast of India. Wetlands Ecology and Management, 29, 689-702. https://doi.org/10.1007/s11273-021-09787-8

John, S.E., Rajimol, T.R., Mohan, S.V., Maya, K. and Padmalal, D. 2017. Environmental degradation of a tropical estuary due to human interferences - a case study from southern Kerala, SW India. Arab Journal of Geosciences, 10, art 352. https://doi.org/10.1007/s12517-017-3112-z

Joy, N.M. and Paul, S.K. 2021. Analysis of the Economic Value and Status of the Ecosystem Services Provided by the Ashtamudi Wetland Region, a Ramsar Site in Kerala. Journal of Indian Society of Remote Sensing, 49, 897-912. https://doi.org/10.1007/s12524-020-01263-9

Karim, L.R. and Williams, E.S. 2015. Accumulation of Heavy Metals in the Surface Water of Asthamudi Lake, Kollam, Kerala. Nature Environment and Pollution Technology, 14, 431-434. https://neptjournal.com/upload-images/NL-52-36-(34)B-3108.pdf

Krishnan, J.U., Saroja Devi, S., Jithine, J.R., Ajesh, G. and Lekshmi, N.R. 2015. Pollution status of Ashtamudi Lake, Kerala, India and its impact on some key stone mangrove species - A case study. International Journal of Innovative Studies in Aquatic Biology and Fisheries, 1, 17-22. https://mail.arcjournals.org/international-journal-of-innovative-studies-in-aquatic-biology-and-fisheries/volume-1-issue-2/3

Kumar, A.A, Ph, A.A. and Sreekanth, G.B. 2023. Fish assemblage and guild structure in the Ashtamudi Estuary, a tropical Ramsar site in India. Journal of Environmental Management, 334, art 117401. https://doi.org/10.1016/j.jenvman.2023.117401

Leroux, S.J., Krawchuk, M.A., Schmiegelow, F., Cumming, S.G., Lisgo, K., Anderson, L.G. and Petkova, M. 2010. Global protected areas and IUCN designations: Do the categories match the conditions? Biological Conservation, 143, 609-616. https://doi.org/10.1016/j.biocon.2009.11.018

Ma, M., Wang, X., Veroustraete, F. and Dong, L. 2007. Change in area of Ebinur Lake during the 1998-2005 period. International Journal of Remote Sensing, 28, 5523-5533. https://doi.org/10.1080/01431160601009698

Mazumdar, A. 2020. Recent contributions to the geochemistry and sedimentology of estuaries, mangroves, and mudbanks along the Indian coast: A status report. Proceedings of Indian National Science Academy, 86, 343-350. https://doi.org/10.16943/ptinsa/2020/49779

Mekha, S.B. 2022. Field Study Report. Department of Zoology, Sree Narayana College, Kollam, 69100, Kerala.

Mishra, B., Kumar, P., Saraswat, C., Chakraborty, S. and Gautam, A. 2021. Water Security in a Changing Environment: Concept, Challenges and Solutions. Water, 13(4), 490. https://doi.org/10.3390/w13040490

Mohan, S.V., Limaye, R.B., Padmalal, D., Ahmad, S.M. and Kumaran, K.P.N. 2017. Holocene climatic vicissitudes and sea level changes in the south western coast of India: Appraisal of stable isotopes and palynology. Quaternary International, 443,164-176. https://doi.org/10.1016/j.quaint.2016.07.018

Mohandas, M., Lekshmy, S. and Radhakrishnan, T. 2014. Kerala mangroves - Pastures of estuaries - Their present status and challenges. International Journal of Science and Research (IJSR), 3(11), 2804-2809. https://www.ijsr.net/archive/v3i11/U1VCMTQ0Mw==.pdf

Nair, N.B., Abul Azis, P.K., Arunachalam, M., Dharmaraj, K and Krishnakumar, K. 1984. Ecology of Indian estuaries: Ecology and distribution of benthic macrofauna in the Ashtamudi Estuary, Kerala. Mahasagar (Bulletin of the National Institute of Oceanography, 17(2), 89-101.

Nair, N.B., Kumar, K.K., Nair, J.R., Abdul Azis, P.K., Dharmaraj, K. and Arunachalm, M. 1983. Ecology of Indian estuaries-XI. A preliminary survey of the fishery resources of the Ashtamudi estuarine system. Fishery Technology, 20(2), 75-83. https://epubs.icar.org.in/index.php/FT/article/view/70961

Nameer, P.O., Jayadevan, P., Tom, G., Sreekumar and Sashikumar, C. 2014. Long term population trends of waterbirds in Kerala (1987-2014). Waterbirds of India. ENVIS Bulletin: Wildlife & Protected Areas, 2015, 44-70.https://wiienvis.nic.in//PublicationDetails.aspx?SubLinkId=547& LinkId=627& Year=2015

Neate-Clegg, M.H.C., Horns, J.J., Adler, F.R., Aytekin, M.C.K. and Sekercioglu, C.H. 2020. Monitoring the world's bird populations with community science data. Biological Conservation, 248, 108653. https://doi.org/10.1016/j.biocon.2020.108653

Panigrahi, J.K. and Mohanty, P.K. 2012. Effectiveness of the Indian coastal regulation zones provisions for coastal zone management and its evaluation using SWOT analysis. Ocean & Coastal Management, 65, 34-50. https://doi.org/10.1016/j.ocecoaman.2012.04.023

Paravat, K., Jayadee, T., Sheik Pareet, P.I. 2009. Influence of estuarine breakwater constructions on Kerala Coast in India. Pp. 1219-1223. In: Zang, C. and Tang, H. (Eds.) Advances in Water Resources and Hydraulic Engineering. Springer, Berlin Heidelberg. https://doi.org/10.1007/978-3-540-89465-0_212

Pournami, P, Neetu, G. and Lekshmi, L. 2023 Diversity of Avifaunal Assemblage in Ashtamudi Lake, Southern Kerala, India. Advances in Zoology and Botany, 11, 129-138. https://doi.org/10.13189/azb.2023.110205

Priya Lekshmi, V, Williams Sherly, E (2019) Current status of selected heavy metal content in water and sediment from Ashtamudi Lake, Kollam, Kerala, South India. International Journal of Engineering Applied Sciences and Technology, 4, 146-153. https://doi.org/10.33564/

IJEAST.2019.v04i02.026

Rafeeque, M.K., Rameshan, M. and Sreeraj, M.K. 2021. Measuring the vulnerability of coastal ecosystems in a densely populated west coast landscape, India. Remote Sensing of Ocean and Coastal Environments, 2021, 203-224. https://doi.org/10.1016/B978-0-12-819604-5.00013-5

Ramachandran, A., Enserink, B. and Balchand, A.N. 2005. Coastal regulation zone rules in coastal panchayats (villages) of Kerala, India vis-à-vis socio-economic impacts from the recently introduced peoples' participatory program for local self-governance and sustainable development. Ocean & Coastal Management, 48, 632-653. https://doi.org/ 10.1016/j.ocecoaman.2005.03.011

Ravinesh, R., Biju Kumar, A. and Anjana, V.L. 2021. Diversity and distribution of molluscan fauna of Asthamudi estuary, Kerala, India. Wetlands Ecology and Management, 29, 745-765. https://doi.org/10.1007/s11273-021-09791-y

Reghunathan, V.M., Joseph, S., Warrier, C.U., Hameed, A.S. and Moses, S.A. 2016. Factors affecting the environmental carrying capacity of a freshwater tropical lake system. Environmental Monitioring and Assessment, 188, 615. https://doi.org/10.1007/s10661-016-5636-1

Sajeev, R. and Subramanian, V. 2003. Land use/land cover changes in Ashtamudi wetland region of Kerala - A study using remote sensing and GIS. Journal of Geological Society of India, 16, 573-580. https://www.geosocindia.com/index.php/jgsi/article/view/83568

Sajeev, R., Chandramohan, P., Josanto, V. and Sanakaranarayanan, V.N. 1997. Studies on sediment transport along Kerala Coast, south west coast of India. Indian Journal of Marine Sciences, 26, 11-21. http://drs.nio.org/drs/handle/2264/2028

Salahudeen, J.H., Reshmi, R.R., Anoop Krishnan, K., Ragi, M.S. and Vincent, S.G.T. 2018. Denitrification rates in estuarine sediments of Ashtamudi, Kerala, India. Environmental Monitoring and Assessment, 190, 323. https://doi.org/10.1007/s10661-018-6698-z

Salimi, S., Almuktar, S.A.A.N. and Scholz, M. 2021. Impact of climate change on wetland ecosystems: A critical review of experimental wetlands. Journal of Environmental Management, 286, 112160. https://doi.org/10.1016/j.jenvman.2021.112160

Sinclair, M., Vishnu Sagar, M.K., Knudsen, C., Sabu, J. & Ghermandi, A. 2021. Economic appraisal of ecosystem services and restoration scenarios in a tropical coastal Ramsar wetland in India. Ecosystem Services, 47, 101236. https://doi.org/10.1016/j.ecoser.2020.101236

Singh, G. and Ramanathan, A. 2005. Nutrient cycling in Mangrove ecosystem: A Brief Overview. International Journal of Ecology and Environmental Sciences, 31, 231-244.

Sreekumari, V.M., John, S.E., Rajan, R.T., Kesavan, M., Kurian, S. and Damodaran, P. 2016. Human interventions and consequent environmental degradation of a protected freshwater lake in Kerala, SW India. Geosciences Journal, 20, 391-402. https://doi.org/10.1007/s12303-015-0049-7

Stoot, L.J., Butler, G.L., Niella, Y., Doran, G.S., Thiem, J.D., Taylor, M.D. and Baumgartner, L.J. 2024. Environmental effects on the seasonal distribution of an estuarine species *Neoarius graeffei* in Northern New South Wales, Australia. Estuaries and Coasts, 47, 229-243. https://doi.org/10.1007/s12237-023-01269-9

Tundu, C., Tumbare, M.J. and Kileshye Onema, J-M. 2018. Sedimentation and its impacts/effects on river system and reservoir water quality: Case study of Mazowe Catchment, Zimbabwe. Proceedings of IAHS, 377, 57-66. https://doi.org/10.5194/piahs-377-57-2018

Upadhyay, A.K., Kumar, A., Narwaria, R., Singh, R. and Bhatnagar, M. 2019. A rapid assessment of Ashtamudi Lake - Current status, climate change impact, conservation measures, tourism potential. Technical Report. Indian National Trust for Art and Cultural Heritage, New Delhi. 83 pages. https://doi.org/10.13140/RG.2.2.12586.80321

Usha, S. and Selsa, S. 2022 Monitoring of the bioaccumulation of heavy metals in the Ashtamudi Lake, Kerala, Ramsar Site in Kerala. International Journal of Science and Research, (IJSR) 11, 832-836. https://www.ijsr.net/archive/v11i3/SR22316130348.pdf

Vimal, R.R., Raju, B., Soumhya, W., Shibu, A., Lekshmi, S., Shibu Vardhanan, Y., Sruthi, S. and Radhakrishnan, T. 2014. Aquatic Bioresources of Ashtamudi Lake, Ramsar Site, Kerala. Journal of Aquatic Biology & Fisheries, 2(1), 297-303. https://www.keralamarinelife.in/Journals/Vol2-1/39%20Vimal%20Raj%20R%20V.pdf

Vincent, S.G.T. and Owens, K.A. 2021. Coastal wetlands of India: Threats and solutions. Wetlands Ecology and Management, 29, 633-639. https://doi.org/10.1007/s11273-021-09824-6

Wu, W., Yang, Z., Tian, B., Huang, Y., Zhou, Y. and Zhang, T. 2018. Impacts of coastal reclamation on wetlands: Loss, resilience, and sustainable management. Estuarine, Coastal and Shelf Science, 210, 153-161. https://doi.org/10.1016/j.ecss.2018.06.013

Zachariah, E.J. and Johny, C. 2008. Methane in Estuarine Discharges to Coastal Ocean – A Study at Ashtamudi Estuary, Kerala, India. Asian Journal of Water, Environment and Pollution, 6(2), 15-22. https://content.iospress.com/articles/asian-journal-of-water-environment-and-pollution/ajw6-2-03

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