International Journal of Geography, Geology and Environment

P-ISSN: 2706-7483
E-ISSN: 2706-7491
IJGGE 2025; 7(1): 15-20
www.geojournal.net
Received: 15-10-2024
Accepted: 19-11-2024

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Understanding mangroves: Distribution, types, adaptations & importance

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DOI: https://doi.org/10.22271/27067483.2025.v7.i1a.324

Abstract
Mangroves are coastal ecosystems that have salt-tolerant evergreen forests. They play a crucial role in the environment. This paper explores the history and evolution of the term "mangrove," explaining their unique adaptations and ecological importance. Mangroves protect against coastal erosion, efficiently store carbon, and support diverse wildlife. Despite their ecological significance, mangroves face significant threats from human activities, such as habitat destruction due to aquaculture, agriculture, pollution, and oil spills. To effectively conserve and manage them, it is important to understand the global status and distribution of mangroves. Various methods, including satellite remote sensing, have been used to map mangrove forests worldwide. This review paper focuses on mangrove ecosystems in India, highlighting changes in their coverage over time. It also categorizes mangrove forests based on physical phenomena and adaptation strategies. Mangroves have unique adaptations, such as pneumatophores and salt-excreting leaves, that help them survive in harsh coastal environments. Additionally, they provide essential ecosystem services, including coastal protection, carbon storage, and water filtration. This review paper concludes by emphasizing the economic significance of mangroves for coastal communities, particularly in aquaculture and timber industries. It also highlights their role as storage for blue carbon and natural water filters.

Keywords: Adaptation, coastal ecosystems, geographical distribution, mangrove

Introduction
According to the Oxford English Dictionary, the words 'mangrowe' and 'mangrave' were first used in English around the 1600s. In the Americas, the Spanish and Portuguese used the words 'mangle' and 'mangue', taken from the Haytian Arawak language, to refer to certain trees and shrubs. The English word 'mangrove' later emerged, and it started to be used not only for trees of the genus Rhizophora but also for other genera like *Avicennia*, *laguncularia*, and *Pelliciera*, which grew in the same type of environment (Mepham and Mepham, 1985) [38]. Mangroves are salt-tolerant evergreen forests that grow in the intertidal zones of sheltered coastlines, tidal creeks, backwaters, lagoons, estuaries, mudflats, and marshes in tropical and subtropical regions. Mangroves, paradoxically, thrive in harsh and adverse environments. All creatures residing there are well-adapted to temperature, higher salinity, muddy anaerobic soils, wind speed, and strong tidal interference (Spalding *et al*. 1997; Sandilyan 2010; Sandilyan *et al*. 2010a, b) [48, 45, 46].
During the process of evolution, mangrove plants have developed unique adaptations. These adaptations include a strong support system of interlocking roots that also aid in breathing, a method of reproduction known as viviparity, and the ability to regulate salt levels and retain nutrients (Kathiresan and Bingham, 2001) [28]. Mangrove roots and trunks generate a baffle effect, considerably reducing tidal currents (Scoffin, 1970) [47]. As a result, sediment particles in the water settle, and the roots, by extending and binding through the silt, help to stabilize the ground. Tidal inundation influences the vertical distribution of mangrove plants (Crase *et al*., 2013; Leong *et al*., 2018) [7, 31], which acts as an indicator of other environmental conditions that affect plant growth, such as salinity, soil texture, and redox potential (Ellison *et al*., 2000) [11]. Local geomorphology influences the extent of tidal inundation (Thom, 1967) [52], which can be reliably and cost-effectively calculated using surface elevation (Leong *et al*., 2018) [31]. Previous research on mangrove forest zonation patterns focused on qualitative descriptions of how mangrove plants are dispersed in the intertidal zone (Chapman, 1976; Watson, 1928) [5, 57].

They offer many ecosystem services, such as protecting the coast, storing carbon, and supporting biodiversity. Heavy metals are prevalent pollutants in urban water supplies (Caregnato *et al*., 2008; Sun *et al*., 2016) [4, 51]. Human-made HMs may come from sources like traffic, dust, sewage sludge, aerosol emissions, waste dumps and metal processing industries, and the use of phosphate fertilizers (which often contain cadmium as a contaminant) (Sun *et al*., 2016; Zhang *et al*., 2014a) [51, 61]. Except for some particles or vapor emitted into the air, most HMs primarily remain in the water and sediment. Sediment is considered the main repository for HMs, and their impact on the environment is most strongly felt in estuarine and coastal areas near cities, especially in intertidal mangrove wetlands (Harbison, 1986) [21].

Despite their value, mangroves are presently under intense ecological pressure, with 1/3 of the entire mangrove ecosystem destroyed worldwide in the last fifty years (Gouvêa *et al*., 2022) [19]. The losses are primarily caused by clearance and converting for aquaculture (de Lacerda *et al*., 2021) [8] or agriculture (Adame *et al*., 2021) [1], domestic as well as commercial discharges (John and Nandhini, 2022) [26], oil spills (Choudhury *et al*., 2021) [6], and ineffective dredging for coastal growth (Fryer *et al*., 2020) [47]. Mangrove habitats are a useful system for examining different viewpoints on mangrove conservation and management since they are a critically vulnerable ecosystem throughout tropical regions, notably in Southeast Asia (Hamilton and Casey, 2016; Thomas *et al*., 2017) [20, 53].

Mangrove Status and Geographical Distribution

The dependence on the littoral environment varies by species. Nonetheless, of the total number of species regarded globally as mangrove trees, 63 are solely found in mangrove communities, while 21 are essential but non-exclusive, expanding beyond the vicinity of upper tide levels. The latter is known as non-exclusive, back, or associate mangroves (Mepham & Mepham, 1985) [38]. Furthermore, (Tomlinson, 1986) [54] has separated the 'exclusive' mangroves into major and minor mangroves based on the structural contribution of the particular species; however, this distinction has not been applied here because it is geographically too varied.

Mangrove forests found along coastlines are usually in thin strips and small patches (Wang *et al*., 2019) [55-56]. As a result, the current global datasets of mangrove forests may not be enough to support in-depth scientific research and precise management. These datasets can be divided into two main categories: statistical reports from different sources and maps created using satellite images. The statistical reports were compiled by various institutions and organizations from 1981 to 2020 (FAO, 2007; Wilkie and Fortuna, 2003) [14, 58], providing an overview of mangrove forest areas in different administrative regions but without specific details about their spatial distribution.

Satellite remote sensing offers a practical, speedy, and cost-effective solution for generating consistent maps of mangrove forests worldwide (Friess *et al*., 2019; Lu and Wang, 2021; Lu and Wang, 2022) [15, 33, 34]. An example of one of the earliest comprehensive datasets for global mangrove forest mapping was the World Mangrove Atlas, first published in 1997 (Spalding, 2010; Spalding and Blasco, 1997) [49, 48]. Mangroves are distributed across 118 countries and various terrains, covering a combined area of 147,000 square kilometers globally (Ochiai *et al*., 2022) [42]. Figure 1 displays the overall distribution of mangrove forests worldwide. Approximately 75% of the total mangrove population is concentrated in just 15 countries (Du *et al*., 2023) [9], with only 6.9% thriving within protected areas (Ximenes *et al*., 2023) [60]. The majority of mangroves can be found in the Southeast Asian region, particularly in Indonesia, Malaysia, and Myanmar (Zhang *et al*., 2023) [62].

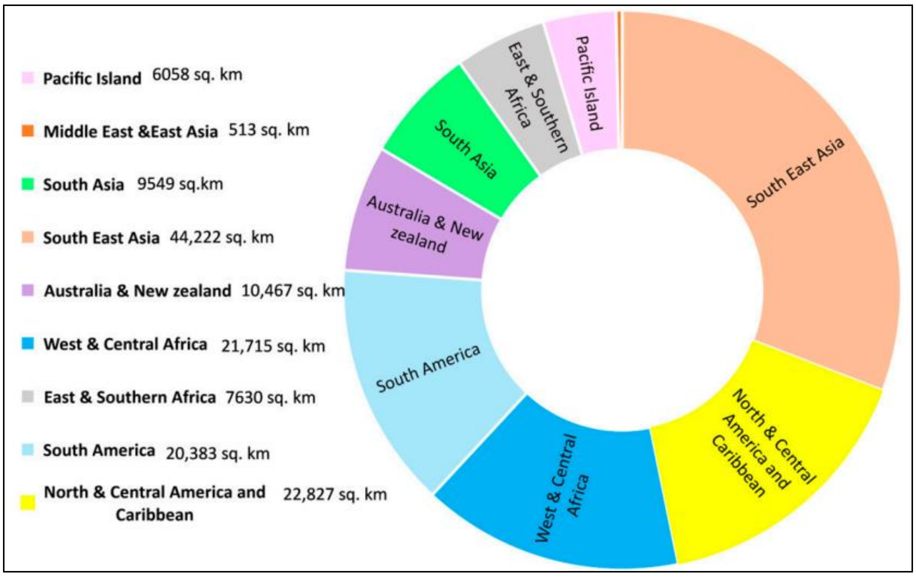

Fig 1: Shows the percentage cover of mangrove forests in various locations of the world. (Data obtained from GMW 2022).

According to a survey conducted by the Forest Survey of India (FSI) in 1987, the mangrove cover in India was estimated to span an area of 4975 km, making up approximately 3% of the total mangrove area in South Asia and 0.15% of the country's overall geographical area. The Sundarbans in West Bengal accounts for almost half of India's mangrove area. Over the past 32 years, the mangrove cover in the country has consistently increased, expanding from 4046 km sq. in 1987 to 4975 km sq. in 2019, indicating a growth rate of 22.96% as reported by the FSI.

Out of the total 4975 km sq. of mangrove area, 2020 km sq. constitutes open mangroves, 1479 km sq. is moderately dense mangroves, and 1476 km sq. is very dense mangroves. While open mangrove areas have seen consistent growth over the past 16 years (2003-2019), there has been a significant decline in the moderately dense mangrove area of the country.

There is a net increase of 17 sq km in the country's Mangrove cover compared to 2019. Odisha and Maharashtra have made large advances in mangrove cover, with 8 and 4 square kilometres, respectively. In Odisha, the growth is primarily due to natural regeneration and plantation activities in suitable sites such as riverbanks and intertidal mudflats, which are flooded by seawater daily. The districts of Kendrapara, Jagatsinghpur, and Balasore in Odisha have seen an increase. In Maharashtra, the growth is primarily attributable to natural regeneration. The South 24 Parganas district of West Bengal has also experienced a rise. The graph below shows the extent of Mangrove cover and changes in three canopy density classes by state/UT, compared to the 2019 assessment (ISFR, 2021) [24].

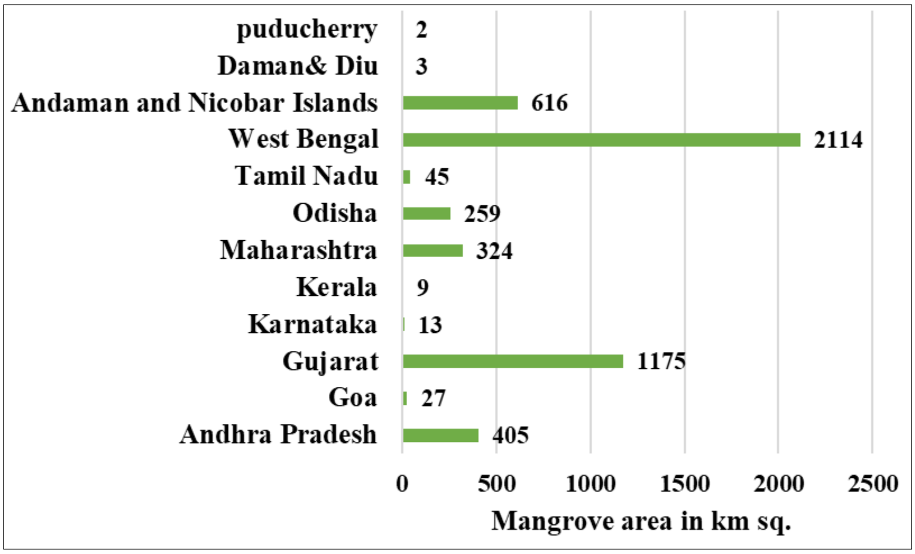

Fig 2: Mangrove cover in India

Types

There are six different categories of mangrove forests known as over-wash, fringe, riverine, basin, scrub, and hammock forests (Lugo and Snedaker 1974; Woodroffe 1992) [35, 59]. The previous categorization does not include details about the actual physical phenomena occurring within mangrove forests. Because of the physical processes involved, an alternative categorization has been suggested, consisting of three types of mangrove forests: (1) those dominated by rivers, (2) those dominated by tides, and (3) interior mangrove forests that exhibit lesser impact from rivers or tides (Woodroffe 1992) [59].

There are six main types of mangrove environments categorized by tidal range and sedimentation. The first type is large deltaic systems with low tidal range and fine sediment, like Borneo and Sundarbans. The second type is tidal plains where mudflats form from alluvial sediments and mangroves grow there. The third type is composite plains influenced by tidal and alluvial conditions, like lagoons behind wave-built barriers. The fourth type is fringing barriers with lagoons found in regions with high wave energy and sediments of fine sand and mud, such as the Philippines. The fifth type is drowned bedrock valleys, like in Northern Vietnam or Eastern Malaysia. Lastly, the sixth type is coral coasts where mangroves grow on coral sand or platform reefs, like in Indonesia and Singapore (Kathiresan, 2021) [28].

Adaptation

Mangrove species share a range of adaptations that allow them to survive in the challenging and unstable mangrove habitat. Around 84 plant species from 39 genera and 26 families are identified as mangroves due to their possession of these adaptations and their habitat preference Tomlinson 1986 [54], Duke 1992, Naskar and Mandal 1999, Kathiresan and Bingham 2001) [54, 10, 41, 28]. Mangroves have developed specialized features to adapt to their coastal environment. These include exposed breathing roots, extensive support roots and buttresses, salt-excreting leaves, and water-dispersed propagules that are viviparous. The specific adaptations vary among different species of mangroves and depend on the physical and chemical characteristics of the habitat they inhabit (Duke, 1992) [10].

Among the various adaptations, the stilt roots of Rhizophora, pneumatophores (aerial roots) of Avicennia, Sonneratia, and Lumnitzera, root knees of Bruguiera, Ceriops, and Xylocarpus, and buttress roots of Xylocarpus and Heritiera are particularly remarkable (Emilio, 1997) [12]. These specialized roots play a vital role in facilitating gas exchange for mangroves living in oxygen-deprived soil. The exposed surfaces of these roots may contain numerous lenticels, which are small openings that enable gas exchange to take place (Tomlinson, 1986) [54]. Avicennia, for example, possesses pneumatophores equipped with lenticels that allow oxygen to diffuse passively. The degree to which the lenticels are open depends on the prevailing environmental conditions (Ish-Shalom-Gordon and Dubinsky, 1992) [25]. In Avicennia marina, the spongy pneumatophores are generally short (< 30 cm), but they become larger and more numerous in anaerobic and oil-polluted conditions. This increased growth enhances the surface area available for gas exchange (Saifullah and Elahi, 1992) [44]. Sonneratia, on the other hand, develops stout pneumatophores that can reach a length of 3 meters due to substantial secondary thickening

(Tomlinson, 1986) [54]. Additionally, oxygen can also permeate through non-lenticellular sections of the pneumatophores. In cases where newly formed tips lack lenticels, horizontal structures known as subrisules play a significant role in facilitating air exchange, especially in rapidly growing pneumatophores (Hovenden and Allaway, 1994) [23].

Plants that inhabit environments with high salt concentrations have adapted in ways that minimize water loss to avoid dehydration and prevent the buildup of salts that could harm their metabolism. Previous studies by Barhoumi *et al*. (2007) [2] and Maricle *et al*. (2009) [37] focused on investigating the internal structure of grass leaves when exposed to salinity. However, there is a limited body of research that explores the connection between leaf anatomy, and the micro-morphology of stems, leaves, and roots in mangrove plants that have adapted to high saline and high light-intensity conditions (Gielwanowska *et al*., 2005) [18]. In 1992, Munns put forward a hypothesis suggesting that the salts absorbed by plants do not directly affect growth by influencing turgor, photosynthesis, or the activity of a specific enzyme. Instead, he proposed a two-phase response to salinity in plant growth. Initially, growth is hindered due to a decrease in soil water potential, which creates water stress. Subsequently, a specific aftereffect occurs as salt levels rise in older leaves. These leaves gradually perish due to the rapid accumulation of salt in the cell wall or cytoplasm, reaching a point where vacuoles can no longer sequester the incoming salts.

Importance

Coastal Communities and Job Opportunities

Mangrove-associated aquaculture within the ASEAN region (Indonesia, Malaysia, and the Philippines), mangrove-related aquaculture makes up 21% (about 1.4 million tonnes annually) of the fisheries along the coastline. These fisheries yield approximately 1.09 million tons of fin fish and 0.4 million tons of shrimp/prawn each year (Broszeit *et al*., 2022) [3]. The foliage of mangrove trees, particularly *Avicennia marina*, is considered a healthy food source for domestic animals (Mitra, 2020) [39]. Mangrove wood is highly resistant to decay and pests, making it valuable for both timber and fuel wood. The timber from Rhizophora spp., *Xylocarpus sp.*, *Bruguiera sp*., and *Sonneratia sp.* is particularly sought after due to the durability of their wood and the large size of their trunks (Olorunnisola, 2023). Certain mangrove-associated species, like *Abonnema* and *Nypa fruticans*, have exhibited antimicrobial activity against plant and animal pathogens. These extracts have been traditionally used to treat skin ailments and stomach issues (Friess *et al*., 2020) [16].

Blue Carbon Storage (Carbon Sink)

Mangroves act as carbon sinks, with the capacity to store approximately 1023 megagrams of carbon per hectare. Several studies have demonstrated that mangroves have a higher ability to sequester carbon compared to other ecosystems like grasslands or tropical rainforests (Zhu & Yan, 2022) [63]. According to a 2022 report by the Global Mangrove Alliance (GMA), global mangrove forests store an estimated total of 21,896.56 million metric tons of CO_2 equivalents, with 2817.23 million metric tons in above-ground biomass and 19,079.32 million metric tons in the top meter of soil (Leal & Spalding, 2022) [30].

Natural Water Filters

Mangroves have the remarkable ability to thrive in saline water and effectively remove 90% of sodium ions (Na^+) from the surrounding seawater (Hastuti *et al*., 2023) [22]. Their roots possess a three-layered pore structure in the root epidermis, aiding in the filtration of Na^+ (Li, 2022) [32]. Furthermore, the pneumatophores and prop roots of mangroves create a low-energy environment that allows contaminants present in wastewater to persist for a prolonged duration (Jusoff, 2013) [27]. Mangrove plants also can sequester various metals, including zinc (Zn), manganese (Mn), and copper (Cu) (Wang, 2019) [55-56].

Conclusion

This review discusses mangroves, including their distribution, types, adaptations, and ecological importance. Mangroves are special forests that can handle high salt levels and are vital to coastal ecosystems. They provide important services like protecting coasts, storing carbon, and filtering water. Mangroves thrive in harsh coastal environments and support diverse wildlife through adaptations like pneumatophores, viviparity, and salt-excreting leaves. However, human activities pose significant threats to mangroves. Habitat destruction, pollution, and oil spills are major challenges. To effectively conserve and manage mangroves, understanding their global distribution and current status is important. Satellite remote sensing is a useful method for achieving this. Mangroves also have economic value for coastal communities, especially in aquaculture and timber industries. This emphasizes the need for sustainable management practices to ensure their long-term survival and preserve their invaluable services. Protecting mangroves allows us to benefit from their resources while maintaining the health and balance of coastal environments.

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