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A STANDARD FOR ASSESSMENT OF INDIAN MANGROVES RESPONSE TO SEA-LEVEL RISE USING RSET-MH TECHNIQUE

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Coastal systems, globally, including wetlands, marshlands and mangrove forests, face a severe threat due to climate change and rising sea levels. The Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR-6) has highlighted high-stress levels in South Asian coastal systems, particularly in the Indian Ocean. Mangrove systems are particularly vulnerable and rely on peat accumulation or landward migration to survive. The rod surface elevation table marker horizon (RSET-MH) technique finds widespread usage among researchers to comprehend the response of coastal wetlands to sea-level fluctuations. However, there is a need for national-level research on mangrove response to sea-level rise and for establishing RSET stations in mangrove forests across India. Establishing comprehensive and coordinated monitoring networks for coastal wetlands is proposed to address this gap. The present study outlined the methodology adopted in setting up the first RSET-MH station in Pichavaram mangrove forest, Tamil Nadu. The estimated cost of setting up a single RSET station ranges from INR 9,000 to INR 15,000. A coordinated monitoring system for RSET stations is crucial to ensure the survival of coastal systems in the face of climate change. The study outlined a coordinated monitoring system for RSET stations across India that will help authorities develop and implement coastal climate change adaptation strategies, critical to ensure the long-term survival of mangrove systems. It would also enable researchers to comprehend how coastal wetlands have responded to sea-level fluctuations in the past and present, and identify appropriate adaptation measures to prepare for future changes.

Keywords: Mangroves, sea-level rise, surface elevation change, vertical accretion, rod surface elevation table, marker horizon

INTRODUCTION

Growing evidence suggests that global climate change is significantly changing forest ecosystems and will continue to do so in the future. Climate changes, including mean temperature and climate extremes like droughts, storms, cyclones and wildfires can fundamentally alter the distribution, composition, phenology and structure of forest species (Deb et al. 2018). Coastal wetlands serve global coastal communities by providing direct livelihood. They support various flora and fauna, maintain water quality, protect shorelines from storms and erosion, and serve as enormous carbon sinks, helping the earth fight climate change. Mangroves are the most carbon-rich forests in the tropics, hosting a multitude of organisms. Sea level rise (SLR) threatens coastal wetlands due to their vulnerability to rapidly increasing inundation, making it a significant threat, thus, sea level mitigation and adaptation is a top priority for coastal management authorities worldwide (Webb et al. 2013a). As per the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR-6), the global sea level will rise rapidly and accelerate further in the coming century. With the rapid increase in SLR and shrinking of coastal wetlands in the coming century, there will be a substantial economic and societal loss, a sudden enormous release of carbon in the atmosphere, and an increase in susceptibility of the coast against extreme storms and erosional processes, leading to an overall increase in the cost of adaptation and mitigation measures to safeguard the shoreline (Keogh et al. 2019). The sea level has never been constant and will never be in the future. Under this situation, to understand the vulnerability of coastal wetlands, it is important to measure the surface elevation change in the tidal zone. If the surface elevation keeps pace with SLR, the coastal wetlands are at low vulnerability (Cahoon et al. 2020). Accurate estimation of the submergence exposure of mangroves worldwide is necessary to develop management strategies. Understanding subsurface and surface processes is essential in predicting organic matter accumulation patterns. Mangroves offer various ecosystem services and are highly carbon-rich. Despite the focus on their potential for mitigating climate change, sustainable development and conservation in policies and scientific literature, there has been little effort to identify a suitable location for developing a climate change mechanism (Ammar et al. 2014).

The quantification of vertical movement of coastal wetland surfaces is critical to identify the areas vulnerable to SLR. This quantification will help us stay informed to conserve and mitigate the impacts on these coastal environments (Church et al. 2004, Cahoon 2014). As per IPCC AR-6, the South Asian and Indian Ocean region is at higher risk of climate change impacts and rapidly accelerating SLR. The estimation and prediction of sea-level change globally are very advanced, but a critical gap exists in quantifying the resulting vulnerability of wetlands. More importantly, for Indian coastal wetlands, such knowledge is almost negligible. Assessment of exposure and wetland response to SLR remains unstudied for many coastal wetlands. A low-cost, high-precision wetland surface can fill this gap and shallow subsurface measurement using rod surface elevation table–marker horizon (RSET-MH) technique (Cahoon et al. 1993). Surface elevation change measurements using RSET can help assess the wetland vulnerabilities to SLR and act as added information for SLR prediction models (Lovelock et al. 2017, Stagg et al. 2016). This study addresses the gap in an organised research with the geographical extent of the RSET-MH technique, focusing on Indian mangroves. To address this research gap, RSET-MH stations were established in prominent mangrove forests across India. In March 2021, three RSET-MH stations were found in the Pichavaram reserve mangrove forest, Tamil Nadu, marking the first of their kind in India. To have a uniform coastal wetland monitoring network, it is proposed to set-up RSET-MH stations in the mangrove forests of Gujarat, Odisha, Andhra Pradesh and West Bengal. These elevation monitoring stations will help the development of constant monitoring of the response of mangrove forests to SLR and keep the authorities informed, so as to develop policy and plan conservation, adaptation and mitigation actions.

Major gaps in coastal wetland vulnerability assessment

The synchronisation of a wetland's surface elevation with rising sea levels varies from region to region and within individual wetlands. Sediment accretion rates in mangrove forests differ depending on sediment sources, tidal range and environmental conditions. The surface elevation of most tropical mangroves has kept up with rising sea levels, but mangrove settings in the Caribbean, Pacific and south Atlantic have not due to climate variability and increased frequency of cyclonic events. Tide gauges do not provide accurate data on coastal wetlands' vulnerability to SLR because they do not consider surface and shallow subsurface processes such as sediment accretion, erosion, biotic contribution and decomposition of organic matter. Wetland vulnerability models must incorporate such factors to better estimate the extent of wetland elevation change in response to SLR. Despite the importance of mangrove forests in India, research on the dynamics of mangrove floor elevation has been lacking. The establishment of RSET stations could help develop mitigation strategies for the impacts of SLR.

MATERIALS & METHODS

Rod surface elevation table and marker horizon (RSET-MH)

RSET-MH provides accurate, site-specific data on wetland vulnerability by measuring vertical surface elevation changes in wetlands (Webb et al. 2013b). The RSET consists of a portable horizontal arm fixed to a rod-driven benchmark. Nine needles are lowered from the arm to the substrate to measure average surface elevation changes at frequent intervals. The installation and monthly measurement of data is a straightforward process. Still, it requires precision, as the estimated data has a confidence interval of ±1.3 mm within the annual global SLR change, making RSET a highly precise instrument to measure surface elevation change (Cahoon et al. 1993).

Additionally, RSET is commonly accompanied by shallow accretion monitoring using an artificial soil marker horizon layer placed on the wetland floor. Feldspar or sand is often used as an artificial marker to measure the rate of vertical surface accretion (Rouge 1989, Cahoon et al. 2000)

Combining local relative SLR data derived using a tidal gauge with repeated measurements obtained from marker horizon and RSET can provide an understanding of the events resulting in net surface elevation change. This can determine whether or not the wetland surface elevation has kept pace with SLR over a specific period. The use of RSET measurements can provide insights into various processes, including comparing the rates of elevation change in different hydro-geomorphic zones, understanding and comparing surface and subsurface processes in other sites in the same hydro-geomorphic settings, observing peat collapse due to lightning, measuring variation in sediment deposition after a storm, and measuring the effect of elevated CO_2 concentration in surface elevation change (Swales et al. 2019, Krauss et al. 2017).

A standard for monitoring the response of Indian mangroves to sea level rise (SLR)

The distribution of RSET stations worldwide has been influenced mainly by ad-hoc research and case studies (Webb et al. 2013b). A coordinated network of RSET stations exists in the Gulf of Mexico and along the US and Australian coastlines (Osland et al. 2017). In the state of Louisiana, there are around 340 stations as a part of their coast-wide reference monitoring system (CRMS). The CRMS consists of RSET stations and tide gauges in different vegetated scapes. The Australian coast has over 100 RSET stations (Rogers et al. 2009).

According to Webb et al. (2013a), the global expansion of the RSET monitoring system, with a particular focus on vulnerable wetlands, is recommended. Previous studies state that the international RSET stations are prejudiced toward marshes at a relatively lower threat (Feher et al. 2019, Krauss et al. 2017).

The government or private research agencies have not established any RSET station in India. However, it hosts one of the world's richest mangrove systems and the Sundarbans, declared a world heritage site by UNESCO (Selvam 2003). This constitutes a considerable deficiency in the understanding of mangrove responses on a global basis. Apart from the Sundarbans, which India and Bangladesh share, the Gulf of Kachchh mangroves in Gujarat, the Bhitarkanika mangroves in Orissa, Coringa mangroves in Andhra Pradesh, Pichavaram in Tamil Nadu, and the rich, dense, pristine mangroves of Andaman and Nicobar Islands are the significant stands in India apart from smaller areas in Goa, Mumbai and Kerala.

RESULTS & DISCUSSIONS

Setting up of RSET-MH network at Pichavaram mangrove forest, India

Pichavaram Reserve mangrove forest is located at the northern end of the Cauvery Delta in Cuddalore District, Tamil Nadu. It covers an area of about 1100 ha, of which 50% is vegetation, 40% is waterways, and the remaining 10% comprises mudflats and sandflats. The forest has 51 islets with an area ranging from 10 m^2 to 2 km^2 and intricate waterways connecting many creeks and channels (Selvam et al. 2003). Pichavaram has a sub-humid climate with warm summers, as the average atmospheric temperature is more than 30 °C, according to the Koppen climate classification. The area's precipitation to evapotranspiration ratio varies from 0.5 to 0.75 (Khan et al. 2012).

Pichavaram acted as a shield from the giant waves of the 2004 tsunami, but these waves brought sediments that changed the nutrient cycle of the estuary (Kathiresan et al. 2005). A study on nitrogen concentration shows an increase in inorganic nitrogen and phosphorus concentrations, causing eutrophication in the region. The construction of dams and diversions for irrigation has caused a reduction in freshwater input resulting in increased salinity in the estuarine complex (Subramanian et al. 1999). As a result, some salt-tolerant mangroves occupy a significant portion of the forest. The salinity levels in the Pichavaram mangrove forest have experienced a considerable rise over time. This increase is thought to be caused by several factors, such as anthropogenic activities upstream and the elevation of sea levels, leading to a decline in freshwater input in the estuary (Singh et al. 2023). This rise in salinity has adversely affected the variety of mangrove species in the area, as many species cannot withstand elevated salt levels, thus decreasing their population. The forest department caused a loss of around 411 ha of mangrove cover out of 1165 ha. It reduced freshwater input from 157 thousand million cube (TMC) per year in 1930 to 34 TMC in the 1990s, resulting from coupe felling for revenue generation between 1930 and 1994 (Selvam et al. 2003). To understand whether Pichavaram mangroves will survive with rapidly increasing sea level rise, it is essential to analyse the mangrove floor dynamics of Pichavaram. For this reason, setting up of RSET-MH stations in three locations in the reserve forest, namely Pattradi (S1), Pallamvangal (S2) and Kiricadvangal (S3) was necessary, as shown in Figure 1.

The methodology adopted in the selection of sampling locations

The sampling design and setup of RSET-MH stations in the mangrove forest were conducted according to a worldwide protocol for monitoring elevation changes of wetlands. This method was developed by USGS, NPS and NOAA (Callaway et al. 2015). The RSET-MH stations, smaller habitats within the mangrove forest, were established throughout the entire sample space. These stations were used to measure vertical accretion and surface elevation change. The number of RSET-MH stations within the sample space depended on the sampling approach, which could be either monitoring or hypothesis testing. In the case of monitoring, the stations were dispersed throughout the mangrove forest to ensure representation, while in hypothesis testing, the stations were clustered to reduce variability. The sampling approach used in this study was monitoring, and the representative sites were selected based on their vulnerability. The Ministry of Environment, Forest and Climate Change (MoEFCC) and Tamil Nadu Forest Department officially permitted the establishment of RSET stations in Pichavaram mangrove forest in February 2021, and the deployment was subsequently executed (E1/49112/2021).

Cost considerations for establishing RSET-MH stations in mangrove forests

The expenses associated with setting up RSET stations can be classified into installation and sampling costs. Installation costs are one-time expenses and are influenced by site conditions, logistical considerations and the type of benchmark used (shallow or deep). On the other hand, sampling costs are recurrent and are associated with the long-term monitoring of RSET-MH stations. These costs include travel expenses to the sample station and are dependent

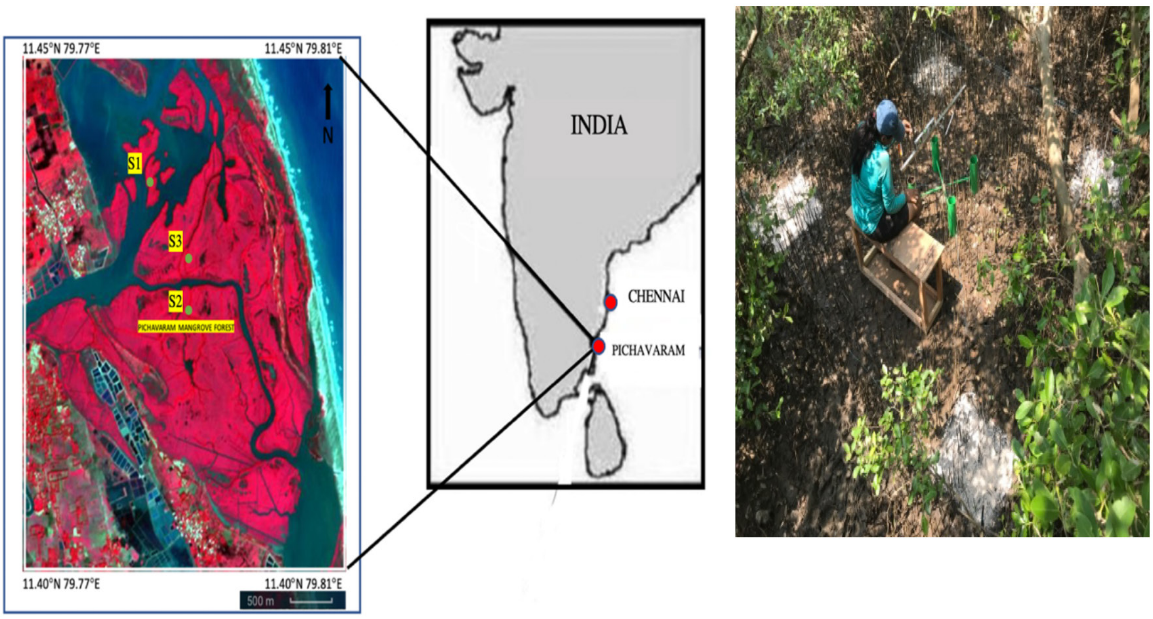

Figure 1 Three RSET-MH locations at the Pichavaram mangrove forest and an established station at one of the sites

on the sampling frequency (monthly or yearly). Estimated installation costs for RSET-MH stations are presented in Table 1, while sampling costs are detailed in Table 2.

Sundarbans mangrove forest, West Bengal

The Sundarbans mangrove forest, situated at the confluence of the Brahmaputra, Ganges and Meghna rivers, is the largest block of tidal halophytic forest, globally, covering an area of 2082.17 sq. km (Ghosh et al. 2015, Chowdhury et al. 2016). The forest is of global significance due to its abundant flora and fauna. It is vulnerable to inundation and wetland loss due to a rise in mean sea level, erosion and subsidence. Studies suggest that erosion is the more dominant threat to the Sundarbans, which has caused a 96% loss of tiger habitat. While the Lovelock model predicts the Sundarbans will persist beyond 2100. It does not consider the effect of tides, erosion, subsidence and storms on mangroves (Swales et al. 2019). The south Parganas District of West Bengal alone contributes 41.85% of India's mangrove cover.

Setting up of five RSET-MH stations in Sundarbans mangrove forest

To establish RSET-MH stations in the Sundarbans mangrove forest, it is essential to consider the zonation of mangroves and topography. The region was divided into three zones based on the proximity of the mangroves to the sea: Zone 1 (fringes), Zone 2 (intermediate) and Zone 3 (internal zone). These zones can be further subdivided based on the density and aerial spread of the mangroves to have a complete understanding of the response of mangroves to SLR. Figure 2 provides proposed sites for setting up RSET-MH stations, and five sites were identified for the initial phase of the RSET-MH network in India. However, due to the large area of the region, shallow and deep RSET-MH stations are needed, after the initial five stations,

Table 1 Estimated RSET-MH installation cost in the year 2023

Installation cost	Number	Price in 2023		Notes
		INR	USD	
RSET benchmark and steel receiver	1 per sample station or site	9000–12000	145	Custom made
Hand pounder or hammer	1	300–500	10	Flat pounding type hammer, renting or borrowing
Miscellaneous (cement, PVC pipe, measuring tape)	Site-specific	1500–2500	30	-
Feldspar (50 kg)	1/2 bag per site	2242	30	50 kg bag
Benches and platform (optional)	1 per site	2500–3000	35	Depends on the access to the site
Site access	-	-		Cost of travel to the sample station depends on the site logistics

Table 2 Estimated RSET-MH sampling cost in the year 2023

Sampling cost	Number	Price in 2023		Notes
		INR	USD	
RSET instrument	1	7000–8500	105	RSET being a portable instrument, only one instrument needed
Miscellaneous (knife, sampling bags, etc.)	1	1000	12	Knife to cut marker horizon cores and sampling pouches or bags to carry soil samples
Site access for sampling	-	-		Depends on the sampling frequency

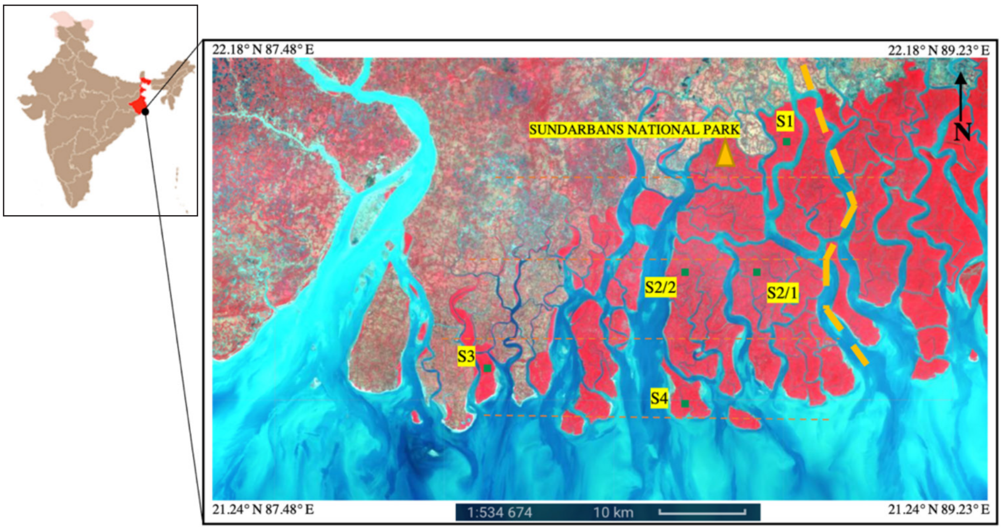

Figure 2 Sampling locations to set up RSET-MH stations at Sundarbans mangrove forest, West Bengal

to understand the wetland floor dynamics clearly. These five sites were identified to represent each zone in the region.

The first site proposed for setting up a RSET-MH station is Hamilton Island (S1). This deltaic island is one of the first inhabited islands in the Sundarbans, and its sedimentation and erosion rates vary. Some parts of the island have submerged over the years, while others have experienced high sediment input. Hamilton Island is at an elevation of 5.5 m from the mean sea level, and it is prone to storm surges and yearly flooding.

The central part of the Sundarbans (S2/1, S2/2) is the ecologically richest part of the region, home to the Royal Bengal tigers. The dense mangrove vegetation of this zone makes it less vulnerable and more stable due to the thick mangrove cover. Understanding the effect of sediment fluxes in the area is essential to plan for the future.

Bakkhali (S3) is located at the western end of the Sundarbans, near Sagar Island. This is where river Ganges and Brahmaputra join and empty into the Bay of Bengal. Bakkhali has a popular beach facing the Bay of Bengal to the south and dense mangroves in the east, west and north. Bakkhali had lost mangrove forest cover over the years and has experienced landward erosion in many parts due to the rapid sea-level rise and coastal erosion.

Dalhousie Island (S4) is one of the most threatened islands in the Sundarbans region. The island's rich, dense mangrove cover has reduced over the years, experiencing the highest level of erosion of mangrove forest land. The island is 1 m from sea level, and the seaward side has eroded and submerged significantly over time. Studies also indicated severe starvation of sediments in the region, and the rate of SLR is higher than the sediment input.

Gulf of Kutch, Gujarat

The Kutch mangroves are situated in a desert district adjacent to the Arabian Sea, which is diametrically opposite to the Sundarbans, the largest mangrove forest in the world. According to the Indian state forest report 2019, the Kutch region has consecutive creeks and mangrove islets spreading over 1,177 sq. km. The Gulf of Kutch stretches along a coastline of 300 km with a tidal range varying from 2.1 to 6.2 m, experiencing high diurnal equality. The region has a semi-arid climate with minimal rainfall of 346 mm y^{-1}, high seasonal temperature variation, and evapotranspiration of 146 mm y^{-1}. The Gulf mangroves face an extremely fluctuating environment throughout the year (Rajal et al. 2019).

The western part of the Gulf of Kutch is formed by the delta of the Indus River, with dense mangrove vegetation and an extensive network of mudflats. The region has two distinct estuarine formations - from Modwa to Jakhua, where waves and coastal processes dominate the coast. At the same time, the mudflats from Kandla to Mundra are tidal-dominated, with vast mudflats and mangroves. There are three major mangrove regions along the Gulf of Kutch - Kandla port and Satsaida Bet, Mundra region and the central coastal belt, and Kori creek and the nearby area in the western and northwestern side, as shown in Figure 3.

Anthropogenic activities have led to extreme stress on the Gulf of Kutch. The Kharai camel population, which feeds on *Avicennia marina* and is known for swimming through the mangroves in herds, has been declining due to human interference. The region's special economic zone has several industries, including Deen Dayal Port Trust, a thermal power plant, and salt manufacturing units, which block the inlets from creeks and lead to increased saline conditions and reduced sediment input. Several research articles have pointed out this gradual degradation of mangroves (Srivastava et al. 2014).

Setting up of RSET-MH stations in the three major mangrove regions of the Gulf of Kutch

The Kandla Port and Satsaida Bet (S1) area is characterised by sporadic mangrove growth due to a flat landform subjected to extreme environmental conditions caused by anthropogenic factors such as numerous salt pans and restricted freshwater flow, leading to increased salinity. The region is also impacted by port activities that have led to the degradation of mangroves. A high level of anthropogenic and industrial stressors in the Kandla Port area makes it essential to establish an RSET-MH station to understand its impact on the dynamics of the mangrove floor. In contrast, Satsaida Bet has witnessed a significant increase in mangrove density due to the efforts of the Gujarat Forest Department, Gujarat Ecology Commission, local communities, and organisations. The region's plantation activities have contributed significantly to Gujarat's rapid increase in mangrove cover. An RSET-MH station in this area will help us gain further insights into the mangrove dynamics.
The Mundra region (S2) is a transition zone inhabited by intertidal mangroves, with studies suggesting that port-related activities pose the most significant threat to the mangroves in the region. Erosion is relatively higher in this area than in the other four major mangrove regions in Kutch, leading to damage to the mangroves and changes in the topography. Establishing an RSET-MH station in this region will enable us to understand the erosion rate in the area, which is the most vulnerable among the four other mangrove regions to SLR.

Kori Creek (S3) area is abundant in nutrients due to sediment input from the Indus River and is relatively free from anthropogenic activities because of its proximity to the international

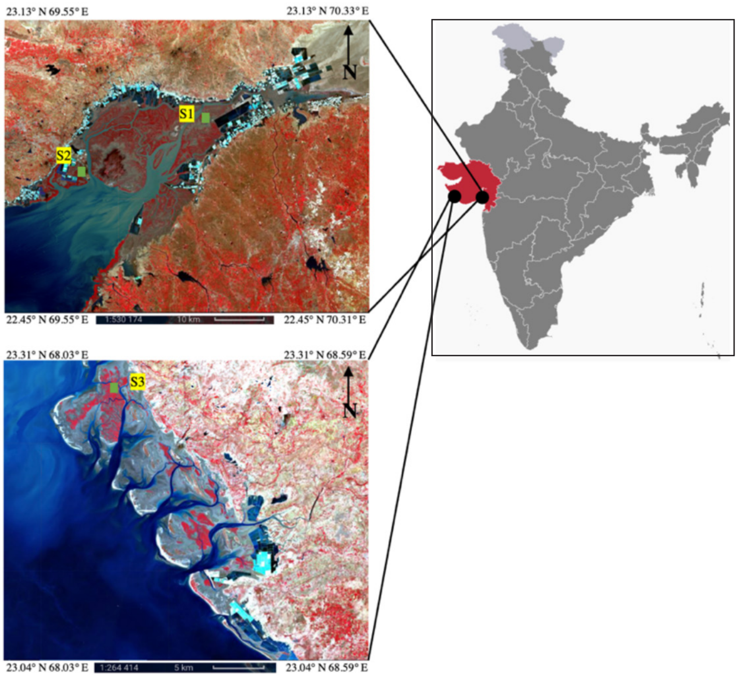

Figure 3 Sampling locations at the Gulf of Kutch

border. The region has a more natural mangrove setting than artificial plantation efforts, with severe mangrove uprooting and sediment deposition during the 1999 and 2001 cyclones. Naturally forming mangroves, sediment input and erosion make this region suitable for placing an RSET-MH station.

Bhitarkanika mangrove forest, Odisha

Bhitarkanika reserve forest, located in Odisha, covers an area of 65,000 hectares and is formed by the deltaic mangrove forest at the confluence of Brahmani and Baitarani Rivers, bordering the Bay of Bengal with a tidal range of 1.5 to 3.4 meters and high current. This forest is a Ramsar wetland site and a nesting place for the olive Ridley Sea turtle, an endangered species (Banerjee et al. 2021). The region has numerous rivers and creeks with high alluvial silt content and regular tidal inundation. The mangrove leaf litter contributes to the high detrital content of the soil, which is classified as clayey loam with sand and a rich layer of humus. The region's climate is tropical, with rainfall ranging from 920–3000 mm annually and three seasons. The estuarine part of Bhitarkanika covers 150 square kilometers of dense mangrove, which can be divided into two zones: the outer funnel estuarine zone and the narrow interior river zone. These two zones are distinctly different regarding their exposure to environmental factors and level of protection from the shore. However, the mangroves in Bhitarkanika are facing high levels of anthropogenic pressure due to the increasing aquaculture in the region, resulting in many creeks being dyked for shrimp and fish farming. The major threats to the Bhitarkanika mangrove forest include saline embankments and numerous aquaculture sites leading to reduced freshwater input, clearing of mangrove forests for paddy cultivation, increased pisciculture in the peripheral river system, excess cutting of mangroves for housing, fencing and fuelwood, and illegal poaching of wild animals.

Setting up of RSET-MH stations in the two major mangrove regions in the Bhitarkanika mangrove forest

According to a hydro-ecological evaluation by the Ministry of Environment, Forest and Climate Change, the area's potential urbanisation could significantly impact the mangrove's growth. The study forecasts a 50% decrease in water flow, leading to increased salinity levels. The freshwater input reduction will substantially affect the health of the mangroves, with Dangmal and Bhitarkanika regions being the most vulnerable. The loss of freshwater would result in increased salinity and reduced sediment input. It is recommended that RSET-MH stations be set up in these two hotspots to monitor and study the mangrove dynamics.

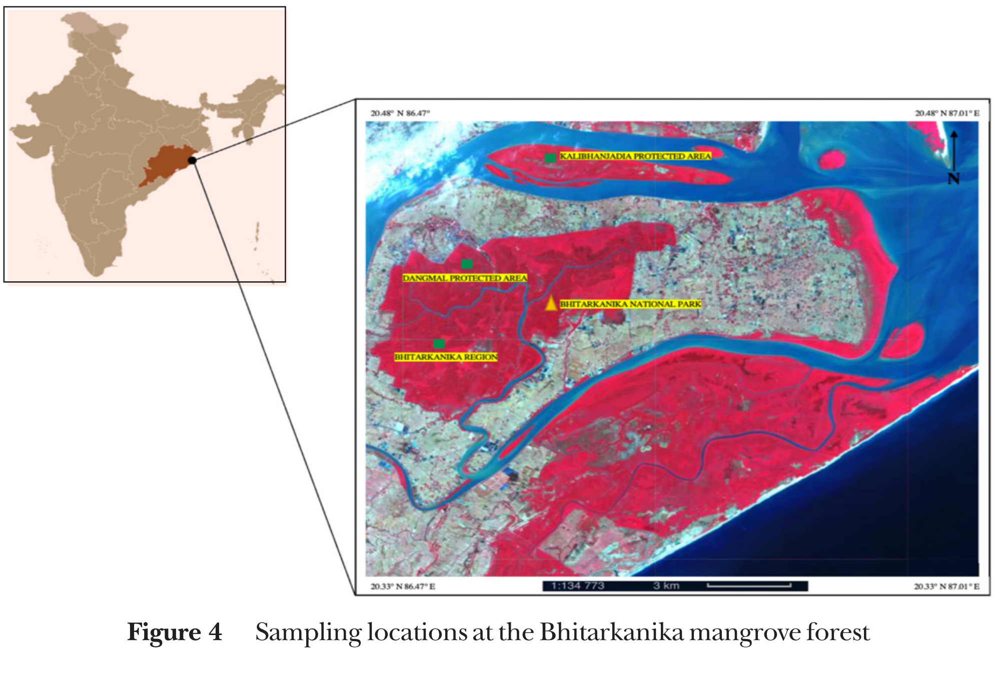

Figure 4 Sampling locations at the Bhitarkanika mangrove forest

In contrast, the Kalibhanjadia region, which is farther away, could be set up as a future RSET-MH station to understand mangrove floor dynamics better. The Dangmal and Bhitarkanika regions are located about 15 km from the Mahipura River mouth and are the core of the Bhitarkanika reserve forest. The soil sediment in the area comprises new and old alluvium mixed with sand, silt, clay and pebbles and has high moisture content. The Dangmal block is spread over 636 hectares and is located in the forest's center. At the same time, Bhitarkanika is located in the lower portion of the Mahipura River and is rich in flora and fauna.

Coringa mangrove forest, Andhra Pradesh

The Coringa mangroves are named after the Coringa River, a Gautami and Godavari Rivers' branch. The Coringa Sanctuary is well-known for its diverse bird population, both resident and migratory, and it covers an area of 208 sq. km. The mangroves are home to 15 different mangrove species, which cover a total area of 3,156 hectares under the reserve forest zone and 9,442 hectares under the extension forest zone, including waterways. The region's water circulation is affected by the seasonal freshwater input from the Godavari and Gautami Rivers and the tides. The Coringa mangroves are influenced by a semidiurnal tidal cycle with a mean spring tide of 1.05 meters, and tides have a maximum variation during the monsoon (Ramasubramanian et al. 2006).

A bathymetry study in the region reveals that the mangroves located towards the north of the Coringa mangroves, near the Kakinada Bay region, are low-lying mangroves. Protecting and comprehending how mangroves respond to SLR is essential to prevent the effects of rapid inundation, a higher threat in Kakinada due to the minimal difference between the land and sea levels (Satapathy et al. 2007).

The mangrove forest has been separated into three zones for representative sampling sites, as displayed in Figure 5. Site S1 is located towards the north, near Kakinada, S2 is in the intermediate region, and S3 is in the far south of the Coringa sanctuary. These sites have been established to study sediment accretion and erosion. Site S3, in particular, is closer to the Gautam Godavari River, and studies have suggested that erosion and sedimentation are more prevalent in this area than in other zones. All three sampling sites are situated in the core mangrove region of the forest. Predictions based on climate suggest that a sea-level rise of 0.6 meters could lead to high saline conditions in an area of about 894 km in

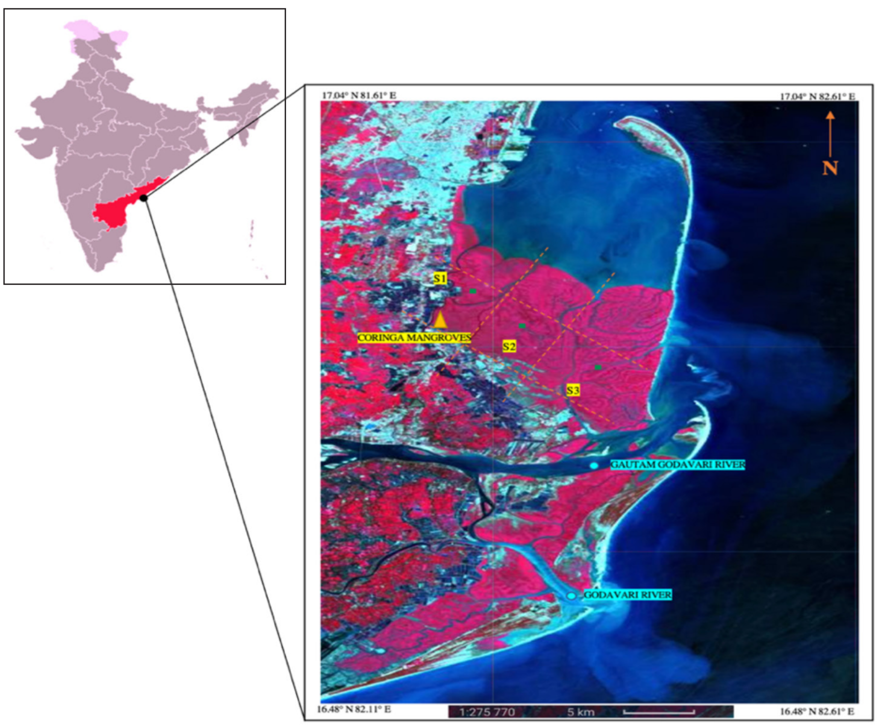

Figure 5 Sampling locations at Coringa mangrove forest, Andhra Pradesh

the Krishna-Godavari Delta region, which would pose a significant threat to the survival of various mangrove species in this region.

CONCLUSION

Efficient monitoring of the vulnerability of coastal wetlands is crucial for preparedness against the impacts of climate change. According to the findings in this research paper, it is recommended to establish a plan for creating RSET networks based on studies that show the vulnerability of wetlands. A national RSET network can be developed to monitor sediment elevation trends in major mangrove forests such as Sundarbans, Gulf of Kutch, Bhitarkanika, Coringa and Pichavaram. RSET-MH stations are already present in wetlands and mangrove forests worldwide, except in India. This network will help bridge a significant gap in assessing wetland vulnerability. It is crucial to observe and monitor the RSET-MH networks over long term for the assessment of wetlands. Governmental agencies, wetland authorities, research institution and conservation societies should work together to ensure long-term data observations and sharing of data on the response of wetlands to SLR to ensure transparency and long-term data acquisition.

A vast network of RSET-MH stations provides opportunities for collaborative research and data exchange. International climate change forums, such as the United Nations Framework Convention on Climate Change and the Ramsar Convention on Wetland Secretariat, use RSET-MH observations to rank wetlands and focus on the most vulnerable wetlands. Mangroves are of great concern worldwide as they are vital carbon sinks that support multiple ecosystems. Therefore, a vulnerability study is the initial phase of any adaptation plan for climate change. It is essential to analyse the impact of SLR on mangrove forests and coastal communities that depend on them. Measuring the surface elevation change of wetlands in major mangrove forests of India will help fill this crucial gap.

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