

Diversity of Naturally Colonized True Mangroves and Mangrove Associates Along the Bank of Champa Canal, West Bengal, India, with Emphasis on Different Environmental Factors

AVIK BHANJA¹, PIJUSH PAYRA^{2*}, INDRAJIT SAU³, SANDIP MAKUR⁴,
DISHANI BISWAS⁵, TAPAS BHUNIA⁶ and NIBEDITA SINHA⁷

¹Dept. of Biological Sciences (Fisheries Science), Midnapore City College,
Vidyasagar University, Midnapore, India.

²Dept. of Fisheries Science, Ramnagar College, Depal, Vidyasagar University, India.

³Dept. of Botany and Forestry, Vidyasagar University, Midnapore, India.

⁴Dept. of Remote Sensing & GIS, Vidyasagar University, Midnapore, India.

⁵Dept. of Geography, Raja Narendra Lal Khan Women's College (Autonomous), Midnapore, India.

⁶Dept. of Aquaculture, Sanjeev Agrawal Global Educational (SAGE) University, Bhopal (M.P.), India.

⁷Dept. of Aquaculture Management, Ramnagar College, Depal, Vidyasagar University, India.

Abstract

Mangroves have great ecological value because of their unique intertidal ecosystems and increased sensitivity to environmental changes. This paper examines the natural colonisation and diversity of true mangroves and their associated species along the Champa Canal (Negua Diversion Canal) in the Purba Medinipur area of West Bengal, India. The study area was categorised into three distinct zones, based on salinity gradients and tidal influences: Zone I is characterised by marine dominance; Zone II represents a transitional phase; and Zone III is influenced by freshwater. Fieldwork encompassing species identification, water and soil analysis, and seasonal tidal data collection documented 10 true mangrove species across 8 genera and 6 families, including 35 mangrove associates from 31 taxa and 21 families between December 2023 and November 2024. Zone I exhibited the highest levels of salinity and species diversity, while Zone III displayed reduced variability due to the predominance of freshwater and the absence of tidal activity. In addition to soil characteristics such as electrical conductivity, pH, and nutrient levels, the water parameters exhibited significant seasonal and geographical variation. These include salinity (ranging from 2.17 to 18.9 ppt), pH (between 6.3 and 8.9), dissolved oxygen (from 3.48 to 6.5 ppm), and



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CONTACT Pijush Payra ✉ pijushpayra@gmail.com 📍 Dept. of Fisheries Science, Ramnagar College, Depal, Vidyasagar University, India.



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biochemical oxygen demand (ranging from 1.73 to 2.94 ppm). Notably, eleven non-estuarine mangrove species and six invasive alien plant species were documented, numerous invasive species rapidly occupied disturbed regions. The distribution of mangroves in the study area was closely associated with variations in environmental conditions. This comprehensive ecological study offers crucial baseline data necessary for the future preservation, monitoring, and management of mangroves in transitional estuaries.

Introduction

Mangroves are a diverse group of salt-tolerant, primarily arboreal, flowering plants that mainly thrive in tropical and subtropical regions.^{1,2} True mangroves are species that exclusively inhabit intertidal zones, whereas mangrove allies can thrive in both littoral and terrestrial environments.³ Mangrove ecosystems hold substantial ecological and economic importance in coastal protection and water quality enhancement. As one of the most productive ecosystems, they serve as a natural, renewable resource.^{4,5} Services encompass the function of mangroves as a nursery for economically significant fisheries, particularly shrimp, and also offer habitats for numerous molluscs, crustaceans, avifauna, insects, primates, and reptiles.³ Mangrove companions are typically not inundated by high tides. Mangroves are primarily found along the landward margin and include several types of plants such as herbs, ferns, climbers, vines, shrubs, trees, and orchids.⁶ The mangrove water exhibited mild alkalinity and elevated levels of pH, total hardness, calcium, magnesium, chloride, total inorganic and organic phosphate, ammonium, nitrite, and nitrate.⁷ The confluence of river water and ocean initiates numerous physical and chemical processes that might affect water quality.⁷ Tidal oscillations can induce systematic alterations in the delicate balance of conditions within these unique and vulnerable ecosystems.^{4,8} Dynamic processes of erosion and accretion continually shape and alter deltas due to the influence of semi-diurnal tides, vigorous winds, wave action, varying sediment loads, and other natural pressures.⁸

Mangroves are globally distributed, occurring in over 112 nations. Mangroves exist in all coastal states of India, encompassing West Bengal, Odisha, Andhra Pradesh, Tamil Nadu, Puducherry, Kerala, Karnataka, Goa, Maharashtra, Gujarat, Daman-Diu, the Andaman and Nicobar Islands, and a restricted region in Lakshadweep.⁵ India's mangrove forests

cover an area of 4,991.68 km² along the nation's coastlines.⁹ The Indian mangroves consist of roughly 59 species across 41 genera and 29 families. Among these, 34 species from 25 genera and 21 families are found along the west coast.¹⁰ The mangrove habitats of India are under significant threat due to the unrestrained exploitation of their resources for various purposes, including fodder, fuel, wood, lumber for construction, alcohol, paper, charcoal, and medicinal uses.¹¹ In addition to these factors, the transformation of forested land for aquaculture and agriculture, the development of ports and harbours, the expansion of human habitation, overgrazing, urbanisation, industrialisation, and chemical pollution are significant and prevalent activities that diminish mangrove areas.^{10,11} Due to these challenges, almost 33% of India's mangrove regions have been lost in the past 15 years. The East Coast region has had a loss of approximately 28%; the West Coast region, about 44%; and the Andaman and Nicobar Islands, over 32%.¹¹

The Purba Medinipur district in West Bengal, India, is rich in natural resources, especially its brackish water ecosystems that support a wide variety of fauna and flora.¹² The coastline of this district along the Bay of Bengal displays unique features influenced by geomorphic changes. The natural colonisation of specific mangrove and halophyte species on the mudflat is observable along this coastline.¹³ The Nega Diversion Canal (NDC), also known locally as the Champa Canal or Champa River, is situated in the district of Purba Medinipur. NDC constitutes a component of the Dubda basin project. The Dubda Basin Project commenced in 1972.¹⁴ This canal is referred to as the Champa River due to its extensive length, significant width, and notable depth. This canal originates from Kudi and flows into the Bay of Bengal. The water exhibits freshwater characteristics from its source to the syphon at Paniparul; subsequently, it transitions to brackish water after the syphon, and

finally, at Mohana, or the canal's terminus, it displays marine water characteristics.¹⁵ The Champa Canal spans approximately 30.3 kilometres, with a stretch from the syphon to the Bay of Bengal measuring around 13 kilometres. Its width fluctuates between 110 and 140 meters, influenced by seasonal changes and tidal variations in the Bay of Bengal.¹⁵

Despite many studies on the diversity of mangroves and other tidal flora along the coastal region of Purba Medinipur district,^{13,16-19} there is a significant lack of research addressing the diversity of mangroves and their associates, as well as the environmental parameters along the banks of Champa Canal or Negua Diversion Canal in Purba Medinipur district, West Bengal, India. The research aimed to investigate the diversity of mangroves and their associated species, emphasizing water and soil quality metrics with tidal fluctuations along the canal's bank.

Material and Methods

Study Area and Period

The study was carried out along the banks of the Champa Canal, also known as the Negua Diversion Canal, located in the Purba Medinipur district of West Bengal, India. The sampling sites were categorised into three distinct zones (Zone-I, Zone-II, Zone-III) according to variations in salinity and the presence of mangrove vegetation.

Zone-I (Shankarpur Mohana to east side of Chowddomile Bridge, 21°38'19.5"N 87°33'36.2"E to 21°40'42.3"N 87°34'29.6"E) is located nearest to the Bay of Bengal and is dominated by true mangroves and halophytic vegetation due to high salinity intrusion and tidal influence. The frequent tidal flushing supports rich alluvial deposition, favouring dense root systems and pneumatophores for gas exchange.

Zone-II (West side of Chowddomile Bridge to Madhabpur canal bank; 21°40'43.1"N 87°34'29.5"E to 21°42'39.4"N 87°33'22.7"E) represents a transitional zone, features moderate mangrove diversity and mixed vegetation types, as salinity and tidal effects decrease inland. It serves as an ecotone between the marine-influenced Zone-I and the freshwater-influenced Zone-III.

Zone-III (Sabitrapur to Paniparul Syphon bridge; 21°42'39.8"N 87°33'22.2"E to 21°44'32.0"N 87°31'43.4"E) exhibits the lowest mangrove

diversity, influenced by freshwater flow dominance, lower salinity, and drying up due to different anthropogenic activities.

The investigation was carried out over the span of one year, specifically from December 2023 to November 2024.

Collection of Samples

Specimens of various types of mangroves and their associates were collected manually, either by hand or with a pruning secateur, during low tide. All samples were gathered in the pre-labelled plastic bag. The samples were then transported to the laboratory for identification purposes.

Water samples were gathered across three distinct seasons: pre-monsoon (PreM), monsoon (MoS), and post-monsoon (PoS), from four different sampling locations in each of the three zones. The samples were transported to the laboratory for detailed analysis.

Soil samples were systematically collected with a soil sampling probe across three distinct seasons: monsoon, post-monsoon, and pre-monsoon, from three designated study zones.

Soil samples were gathered in sampling bags from the surface of the tidal bank of the Champa canal, specifically at a depth of 10-12 cm, and transported to the laboratory for subsequent analysis.

Daily tidal data were recorded from the tidal gauge located on the dam of the thirty-two-chambered sluice gate near Z-I, in addition to information gathered from various websites, including Tides4fishing²⁰ and Tidechart.com.²¹

Identification of Plant Samples

The collected samples of mangroves and their associates were identified using the mangrove identification manual and standard flora references,^{6,22-26} as well as online resources such as the India Biodiversity Portal,²⁷ and eFlora of India.²⁸ Species were categorized as abundant, common, or rare according to their visual prevalence and occurrence frequency across sampling sites during field surveys. The conservation status of the species identified in this study was detailed as per the IUCN Red List of Threatened Species.²⁹

Water and Soil Parameters Analysis

The examination of Total Alkalinity (TA), Chloride, Nitrite, Nitrate, and Phosphate was conducted in accordance with standard techniques.³⁰ The temperature was recorded with the SKADIOO digital water temperature meter (range: -50~110°C and ±1°C accuracy). The pH of water was monitored via a Digital pH meter (PH-009(I)A). The Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) of the samples were assessed using Winkler’s technique. The total dissolved solids in the water samples were quantified using a digital TDS meter (Labtronics LT-25). Electrical conductivity was assessed via a digital EC meter (Systronics-308). Salinity was quantified via a portable salinity meter (ACETEQ-SALMETER).

The soil pH and electrical conductivity were assessed using standard methodology.³¹ The assessment of available nitrogen in soil was conducted according to an established procedure,³² while the quantification of available phosphorus in soil was conducted using the Olsen standard method.³³ The assessment of potassium availability in soil was conducted using standard protocols.³⁴

Statistical Analysis

Statistical analysis was performed utilising IBM SPSS Statistics Version 27.0 for Windows. Microsoft Excel 2001 was used to generate graphs for different datasets. All environmental parameter values are presented as mean ± standard deviation (SD).

Results

Mangrove Diversity

A total of 10 true mangrove species across 8 genera and 6 families were identified in this study (Table 1). A total of 35 mangrove associates from 31 genera and 21 families were recorded in this study (Table 2). The study zones, based on salinity and tidal influences, showed significant variation in biodiversity. Zone I (Marine dominated) exhibited the highest species diversity among the existing mangroves. Zone II (Transitional) exhibits considerable species overlap and variety, encompassing a transitional ecosystem. Zone-III, influenced by freshwater, exhibits the least diversity of mangroves, with the absence of numerous true mangroves.

Table 1: List of true mangrove species collected from the Champa canal bank and their availability status

Sl. No.	Species Name	Family	Local/ Common Name	Flowering period	Conser- vation Status	Habit	Availability Status		
							Z-I	Z-II	Z-III
1.	<i>Acanthus ilicifolius</i> L.	Acanthaceae	Holly mangrove/ Sea holly/Holly-leaved Acanthus	August -March	LC	Tree	++	++	+
2.	<i>Aegiceras corniculatum</i> (L.) Blanco	Primulaceae	Khalsi/ Teluni/ Goat's Horn Mangrove	September -March	LC	Tree	+	_	×
3.	<i>Avicennia alba</i> Blume	Acanthaceae	Kala bani/ Vilva mada	November - April	LC	Tree	++	+	×
4.	<i>Avicennia marina</i> (Forsk.) Veierh	Acanthaceae	Gray Mangrove/ Venkandal	March - July	LC	Tree	++	_	×
5.	<i>Avicennia officinalis</i> L.	Acanthaceae	Baen/ Bain/ Bani/ Piara baen	July - March	LC	Tree	++	+	_
6.	<i>Bruguiera gymnorrhiza</i> (L.) Savigny.	Rhizophoraceae	Oriental Mangrove/ Kankra Gach / Natinga	Year -round	LC	Tree	+	_	×

7.	<i>Ceriops decandra</i> (Griffith) Ding Hou	Rhizophoraceae	Goran/ Gedara/Yellow Mangrove/ Bara Garan	October - January	NT	Tree	+	-	x
8.	<i>Derris trifoliata</i> Lour.	Fabaceae	Kaliya lata/ Common Derris/ Karanj Vel	December - April	LC	Climber	++	+	-
9.	<i>Excoecaria agallocha</i> L.	Euphorbiaceae	Geoa/ Blinding tree/ milky mangrove/ poisonfish tree	Year -round	LC	Tree	++	++	+
10.	<i>Sonneratia apetala</i> Buch.-Ham.	Lythraceae	Sonneratia Mangrove/ Keora/ Mangrove Apple	June - November	LC	Tree	+	x	x

Z-I = Zone-I, Z-II = Zone-II, Z-III = Zone-III

'++' Abundant, '+' Common, '-' Rarely available, '___' Extremely rare, 'x' Not found

Table 2: List of mangrove associates collected from the Champa canal bank and their availability status

Sl. No.	Species Name	Family	Local/ Common Name	Flowering period	Conser- vation Status	Habit	Availability Status		
							Z-I	Z-II	Z-III
1.	<i>Sesuvium portulacastrum</i> (L.) L.	Aizoaceae	Jadu Palang/ Sea Purslane/ Shore Purslane	October - April	LC	Herb	+	+	x
2.	<i>Trianthema portulacas- trum</i> L.	Aizoaceae	Horse Purslane/ Black Pig Weed/ Shwet Punarnava	April - June	NE	Herb	-	+	+
3.	<i>Suaeda maritima</i> (L.) Dumort.	Amaranthaceae	Indian Saltwort/ Gira sak	June - January	NE	Succulent	++	-	x
4.	<i>Suaeda monoica</i> Forssk.ex Gmel.	Amaranthaceae	Eelakura/ Ilakura	May - December	NE	Succulent	++	+	___
5.	<i>Suaeda nudiflora</i> (Willd.) Moq.	Amaranthaceae	Gira sak/ Eelakura/ Ilakura	November - April	NE	Succulent	+	x	x
6.	<i>Calotropis gigantea</i> (L.) W.T. Aiton	Apocynaceae	Aakanda/ Giant Milkweed/ Crown Flower	Year -round	NE	Shrub	-	++	++
7.	<i>Phoenix sylvestris</i> (L.) Roxb.	Arecaceae	Khejur/ Date Sugar Palm	March - May	NE	Tree	+	+	+
8.	<i>Pluchea indica</i> (L.)	Asteraceae	Indian camphor- weed/ Indian	February -April	NE	Shrub	+	+	+

	Less.		fleabane/ Indian pluchea						
9.	* # <i>Chromo- laena odorata</i> (L.) R.M.King & H.Rob	Asteraceae	Tivra Gandha/ Christsmas Bush/ Common Floss Flower	October - May	NE	Shrub	+	+	+
10.	* # <i>Parthen- iumhystero- phorus</i> L.	Asteraceae	Gajar Ghas/ Congress Grass	May-March	NE	Herb	_	+	+
11.	<i>Heliotropium curassavicum</i> L.	Boraginaceae	Seaside Helio- trophe/ Monkey Tail/ Salt Helio- trophe/ Quail Plant	February - April	NE	Herb	++	+	_
12.	* # <i>Opuntia dillenii</i> (Ker Gawl.) Haw.	Cactaceae	Eltham Indian Fig/ Nagphan/ Phani/ Mahavr- iksha	March -May	NE	Shrub	_ _	_	_
13.	# <i>Capparis zeylanica</i> L.	Capparaceae	Kalokera/ Gobindaphal/ Ceylon Caper/ Karambha	February -April	NE	Shrub	+	_	×
14.	# <i>Casuarina equisetifolia</i> L.	Casuarinaceae She-Oak/	Jhau/ Coastal - July Junglisaru	December	LC	Tree	_	×	×
15.	<i>Ipomoea pes caprae</i> (L.) R.Br.	Convolvulaceae	Chagol pa/ Bayhops, Beach morning glory	March - October	LC	Creeper	++	+	×
16.	<i>Ipomoea sagittifolia</i> Burm.f.	Convolvulaceae	Purple Heart Glory/ Banka- lami/ Manjika	Year-round	LC	Climber	_	_	+
17.	<i>Cyperus rotundus</i> L.	Cyperaceae	Nut grass/ Mutha -bon/ Coco-grass	June - October	LC	Herb	+	+	++
18.	<i>Fimbristylis ferruginea</i> (L.) Vahl	Cyperaceae	Rusty Sedge/ West Indian Fimbry	June - October	LC	Herb	+	+	+
19.	# <i>Euphorbia lactea</i> Haw.	Euphorbiaceae	Elkhorn/ Frilled Fan/ Candelabra Plant/ False Cactus	April - June	DD	Shrub	_	_	_
20.	<i>Guilandina bonduc</i> L.	Fabaceae	Nicker nut/ Fever nut	December - April	LC	Climber	++	+	+
21.	# <i>Neptunia oleracea</i> Lour.	Fabaceae	Lajjabati/Water mimosa/ sensitive neptunia	December - March	LC	Herb	+	+	+
22.	* <i>Prosopis juliflora</i> (Sw.) DC.	Fabaceae	Algaroba/ Velvet mesquite/ Kabuli Keekar/ South- west Thorn	March - April	NE	Tree	+	+	+
23.	<i>Rothia indica</i> (L.) Druce	Fabaceae	Indian Rothia/ Papra	August -December	NE	Herb	_	_	_
24.	<i>Clerodendrum</i>	Lamiaceae	Kundali/ Banajui/	November	NE	Shrub	++	+	_ _

	<i>inermis</i> (L.) Gaertn.		Glory Bower/ Wild Jasmine	-December					
25.	<i>Acacia nilotica</i> (L.) Del.ssp. <i>indica</i> (Benth.) Brenan	Mimosaceae	Babul/ Kikar/ Babool	June - September	NE	Tree	+	+	+
26.	<i>Pandanus odoratissimus</i> Linn.f.	Pandanaceae	Keora/ Kewda/ Kea/ Talai	July - February	LC	Bushy shrub	+	+	+
27.	<i>Cynodon dactylon</i> (L.) Pers.	Poaceae	Durba/ Bermuda grass/ Bahama grass/ Dog's Tooth grass	March- October	NE	Herb	++	++	++
28.	<i>Leersia hexandra</i> Sw.	Poaceae	Arail/ Rice Grass/ Swamp rice grass	Year-round	NE	Herb	×	_	+
29.	<i>Myriostachya wightiana</i> (Nees ex Steud.) Hook.f.	Poaceae	Nalai/ Darbha- gaddi/ Mangrove grass	April - September	NE	Herb	++	_	_
30.	<i>Porteresia coarctata</i> (Roxb.) Tateoka	Poaceae	Wild rice/ Dhani ghash/ Mangrove Wild Rice	June - October	DD	Herb	++	_	_
31.	<i>Portulaca oleracea</i> L.	Portulacaceae	Nunia Sag/ Common Purslane/ Brihalloni	June - September	NE	Herb	+	_	×
32.	<i>Azima tetraantha</i> Lam.	Salvadoraceae	Bee-sting bush/ Needle Bush/ Four-thorns/ Stink Bush	October- January	LC	Shrub	++	+	_
33.	* # <i>Solanum sisymbriifolium</i> Lam.	Solanaceae	Swetrangani/ Sticky Night- shade/ Wild Tomato/ Sada kantikari	February -April	NE	Shrub	+	+	+
34.	<i>Solanum trilobatum</i> L.	Solanaceae	Agnidamini/ Purple-fruited pea eggplant	January- August	NE	Shrub	+	+	+
35.	* # <i>Lantana camara</i> L.	Verbenaceae	Vanacchedi/ Gubon/ Lantana Weed/ Banmarich	Year- round	NE	Shrub	+	+	+

*Invasive alien plant species can grow in the tidal plain as tidal vegetation

#Species are not exclusive mangrove associates

Z-I = Zone-I, Z-II = Zone-II, Z-III = Zone-III

'++' Abundant, '+' Common, '_' Rarely available, '___' Extremely rare, 'x' Not found

species distribution patterns revealed that Z-I supported the richest diversity, with 6 dominant and 4 commonly occurring true mangrove species, along with 34 mangrove associates, out of which 10 were abundant and 16 common species. Z-II recorded 9 true mangrove species, comprising 2

abundant, 3 common, and 4 rare species, along with 33 associate species, most of which were common (n=21). In contrast, Z-III exhibited the lowest diversity, with only four true mangrove species (2 common, 2 rare) and 28 associate species, including 3 abundant, 16 common, 7 rare, and 2 extremely rare (Figure 1 and 2).

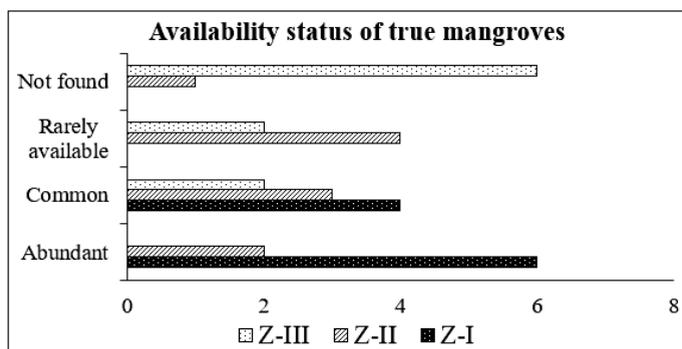


Fig. 1: Availability status of true mangroves along the bank of the Champa Canal

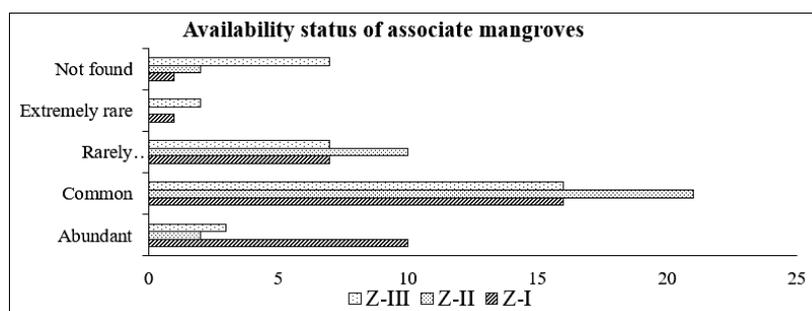


Fig. 2: Availability status of mangrove associates along the bank of the Champa Canal

Acanthaceae (40%) was the dominant family among true mangroves, while Fabaceae and Poaceae were

most common (11%) among mangrove associates (Figure 3 and 4).

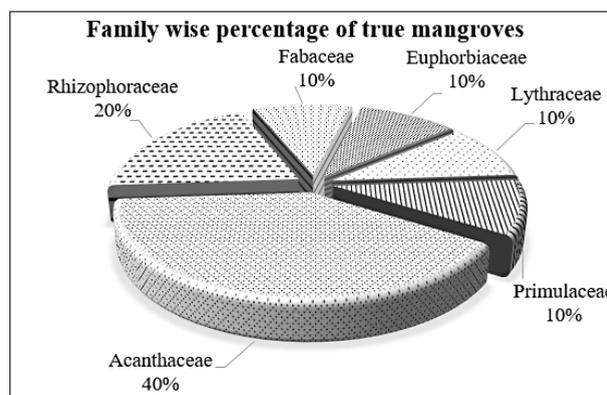


Fig. 3: Family-wise percentage of true mangroves recorded along the bank of the Champa Canal

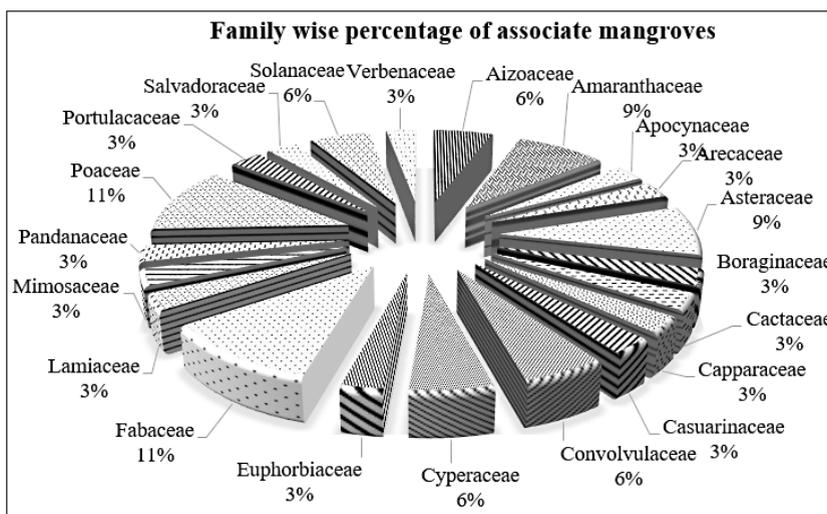


Fig. 4: Family-wise percentage of mangrove associates recorded along the bank of the Champa Canal

Water Quality Parameters

The water quality in the Champa Canal exhibited distinct seasonal and spatial variations. Air temperature fluctuated between 27.6°C and 31.1°C, whilst surface water temperature ranged from 23.1°C to 32.6°C, reaching its peak during the PreM period. The pH values reached a maximum of 8.9 in Z-I and a minimum of 6.3 in Z-III. Dissolved oxygen varied

from 3.5 to 6.5 ppm, with elevated values during the MoS season. Electrical conductivity and total dissolved solids were maximal in Z-I, signifying elevated salinity. Additional indicators, including alkalinity, BOD, TSS, nitrite, nitrate, and phosphate, exhibited variability, with the majority of values rising during the MoS as a result of runoff and freshwater influx (Table 3).

Table 3: Physico-chemical parameters (Mean±SD) of the Champa Canal water across the three study zones

Parameters	Pre-monsoon (PreM)			Monsoon (MoS)			Post-monsoon (PoM)		
	Z-I	Z-II	Z-III	Z-I	Z-II	Z-III	Z-I	Z-II	Z-III
AT(°C)	31.08 ±1.19	30.15 ±1.27	30.20 ±1.28	28.89 ±2.10	28.77 ±2.19	29.09 ±2.21	28.02 ±1.31	27.75 ±1.29	27.62 ±1.44
WT(°C)	30.43 ±1.82	31.1± 1.71	30.53 ±1.49	29.17 ±1.37	29.49 ±1.41	29.31 ±1.3	27.01 ±1.16	26.77 ±1.31	26.31 ±1.2
pH	8.34 ±0.21	8.08± 0.17	7.98± 0.19	7.86 ±0.41	7.5± 0.3	7.42± 0.29	8.01± 0.15	7.59± 0.09	7.11 ±0.17
TA (ppm)	206.7 8±5.28	182.91 ±4.52	151.1 ±4.14	180.3 ±6.12	161.29 ±5.09	139.49 ±4.97	192.3 ±4.46	169.31 ±4.9	141.0 5±5.01
Salinity (‰)	18.9 ±0.1	11.4 ± 0.35	4.9± 0.26	16.28 ±0.34	9.72± 0.22	2.17± 0.2	18.3± 0.3	10.09 ±0.18	3.3± 0.21
DO (ppm)	4.31 ±1.63	4.17± 1.38	3.48± 1.03	5.24 ±1.49	5.31± 1.38	5.1± 1.51	5.05 ±1.7	4.86± 1.52	3.55± 1.18
EC (µS/cm)	25,650. 33 ±50	17,80 6.5 ±	8,035. 25±79	20,32 7.14±	15,29 3.11±	7,124. 09 ±72	22,12 3.01±	15,297. 7±72	8,091. 3± 61
	1.08	739.0	8.201.9	620.01	710.15	8.26	471.1	9.02	2.0

BOD (ppm)	1.73± 0.22	1.91± 0.3	8±0.26	1.95 ±0.2	2.18± 0.25	2.36± 0.31	2.04± 0.29	2.58± 0.32	2.94± 0.25
TDS (ppm)	23,72 0.14±	18,48 2.51±	16,092 .25±62	21,92 0.39±	15,092 .14±1,6	14,43 8.65±1,	23,133 .17±76	17,62 7.76±6	15,421 .92±51
TSS (ppm)	736.73 115.25 ±16.83	539.21 84.44± 18.35	1.17 79.35± 19.27	989.87 232.5± 22.85	57.92 176.43 ±25.74	072.24 165.24± 20.96	7.04 144.5± 19.02	20.34 131.74± 15.21	1.08 130.17 ±14.08
Nitrite (ppm)	0.09± 0.03	0.14± 0.05	0.18± 0.03	0.41 ± 0.14	0.38± 0.16	0.43± 0.15	0.2±0 .08	0.19± 0.03	0.3±0. 06
Nitrate (ppm)	0.16 ±0.08	0.2±0 .05	0.28± 0.06	0.44 ± 0.15	0.46± 0.13	0.58± 0.21	0.34± 0.13	0.3± 0.1	0.39± 0.13
Phosphate (ppm)	0.15 ± 0.09	0.16± 0.08	0.16± 0.1	0.37 ±0.2	0.43± 0.19	0.5±0 .14	0.25± 0.13	0.31± 0.16	0.36± 0.15

AT=Atmosphere Temperature; WT=Water Temperature; TA=Total Alkalinity; DO=Dissolved Oxygen; EC=Electrical conductivity; BOD= Biological Oxygen Demand; TDS=Total Dissolved Solids; TSS=Total Suspended Solids

Soil Quality Parameters

Soil parameters across the three zones showed noticeable seasonal variations. Soil pH remained relatively stable, ranging from 5.95 to 6.68, with slightly higher values during the MoS. Electrical conductivity varied between 1.53 and 3.97 dS/m, peaking in Z-I during the PoM season. Available

nitrogen content ranged from 156.44 to 230.22 kg/ha, with the highest values found in Z-I, likely due to organic matter accumulation. Phosphorus content ranged from 18.4 to 24.1 kg/ha, and potassium varied between 213.38 and 368.89 kg/ha, both being highest in mangrove-dominated Z-I (Table 4).

Table 4: Physico-chemical parameters of mangrove soil along the bank of Champa Canal across the three study zones

Parameters	Pre-monsoon (PreM)			Monsoon (MoS)			Post-monsoon (PoM)		
	Z-I	Z-II	Z-III	Z-I	Z-II	Z-III	Z-I	Z-II	Z-III
Soil pH	6.21 ± 0.12	5.95 ±0.09	6.14± 0.08	6.68± 0.17	6.1± 0.14	6.57 ±0.2	6.2± 0.16	6.0± 0.11	6.6± 0.19
EC (dS m ⁻¹)	3.14 ±0.43	2.95 ±0.36	2.57± 0.33	2.03 ±0.27	1.84± 0.25	1.53 ±0.2	3.97 ±0.61	3.05± 0.42	3.09 ± 0.4
Nitrogen (kg/ha)	209.24 ±31.04	194.61 ± 29.26	172.16 ±25.19	183.1 ±27.52	178.19 ±26.08	156.44± 23.15	230.22 ±34.15	206.46 ±30.9	182.14 ±27.63
Phosphorus (kg/ha)	21.32 ±3.09	19.14 ±2.68	18.72 ±2.16	24.1 ±3.6	23.66 ±3.32	20.58 ±3.1	21.2 ±3.05	22.58 ±3.13	18.4± 2.14
Potassium (kg/ha)	291.78 ±35.04	209.4 ±27.2	213.38 ±28.07	368.89 ±47.12	267.72 ±34.26	234.65 ±30.59	302.01 ±29.39	235.13± 28.26	226.24 ±26.5

EC=Electrical conductivity

Tidal variance

The tidal pattern along the Champa Canal was found to be meso-tidal and semi-diurnal, with spring tides ranging from 2.6 to 5.5 meters and neap tides from

0.2 to 2.3 meters. The highest spring tide occurred in October 2024, while the lowest was recorded in March and April. Neap tides peaked in September and reached their minimum in March (Figure 5).

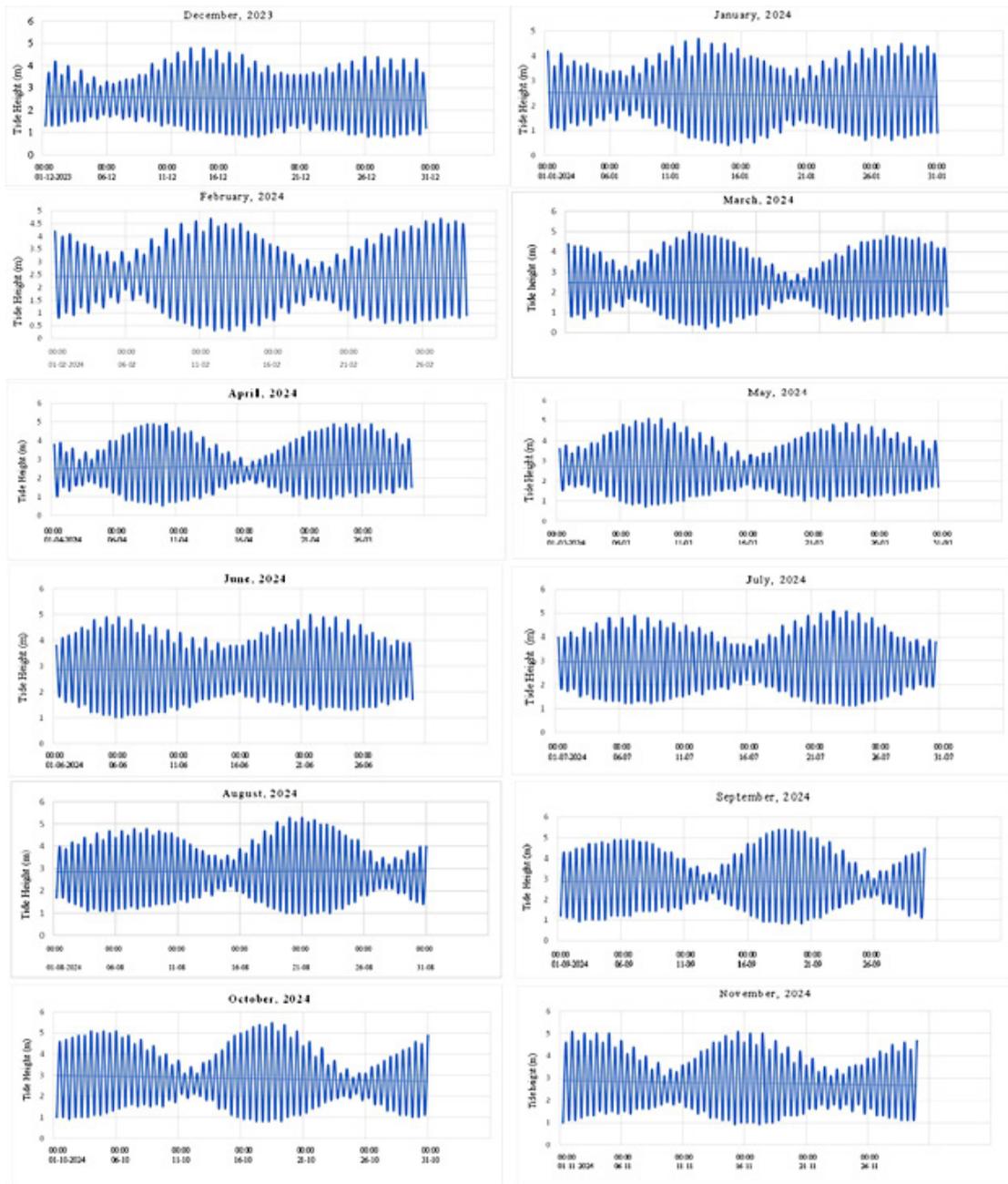


Fig. 5: Monthly tidal variations along the bank of the Champa Canal during the study period

Discussion

Mangrove Diversity

In a previous study, a total of 37 true mangrove species and mangrove associates were listed along the Digha-Junput coastline.¹³ A thorough investigation in

the Purba Medinipur district identified 23 angiospermic species, comprising 9 true mangrove species and 14 mangrove associates.¹⁶ In the same district, 20 mangrove associates from 15 families were found.¹⁷ This coastal region harboured 42 tidal vegetation

species, including 6 true mangrove species and 36 mangrove associates.¹⁸ A recent study in the Champa Canal area of the Ramnagar-I block, Purba Medinipur district, discovered 3 true mangrove species and 8 associate mangroves.¹⁹ The brackish water area of the Champa Canal was categorised into three distinct zones (Z-I, Z-II, Z-III) according to salinity levels and the presence of tidal vegetation. Z-I is situated closest to the Bay of Bengal and is characterised by the presence of true mangroves and halophytic vegetation, resulting from significant salinity intrusion and tidal effects. Salinity intrusion in estuarine mangrove zones demonstrates both seasonal and spatial variability, as observed in the Krishnapatnam Coast and Paravoor mangrove ecosystems of India.^{35,36} In the Z-I zone, six true mangrove species dominate: *Acanthus ilicifolius*, *Avicennia alba*, *Avicennia marina*, *Avicennia officinalis*, *Derris trifoliata*, and *Excoecaria agallocha*. Additionally, four species, namely *Aegiceras corniculatum*, *Bruguiera gymnorrhiza*, *Ceriops decandra*, and *Sonneratia apetala*, are commonly found in this area. In Z-I, 34 out of 35 mangrove associates are present. Of these, 10 are classified as abundant, 16 as common, 7 as rarely available, and 1 as extremely rare. Species including *Suaeda maritima*, *Suaeda monoica*, *Heliotropium curassavicum*, *Guilandina bonduc*, *Clerodendrum inerme*, *Myriostachya wightiana*, and *Azima tetracantha* are prominent associates along the canal bank of Z-I. *Leersia hexandra* was absent in Z-I.

Zone-II exhibits moderate mangrove diversity alongside various vegetation types, attributed to the reduction of salinity and tidal influences as one moves inland. The location extends from the west side of Chowddomile Bridge to the bank of the Madhabpur canal. A total of 9 true mangrove species are recorded from Z-II. Among these, two species (*Acanthus ilicifolius*, *Excoecaria agallocha*) are abundant, three species (*Avicennia alba*, *Avicennia officinalis*, *Derris trifoliata*) are common, and four species (*Aegiceras corniculatum*, *Avicennia marina*, *Bruguiera gymnorrhiza*, *Ceriops decandra*) are rarely available. A total of 33 associate mangroves were documented in Zone-II. *Calotropis gigantea* and *Cynodon dactylon* are prevalent in this zone, with approximately 21 species being common and 10 species occurring rarely. *Suaeda nudiflora* and *Casuarina equisetifolia* were absent in Z-II.

Zone-III demonstrates the least mangrove diversity, primarily due to the predominance of freshwater flow and reduced salinity levels. The location is situated between Sabitrapur and the Paniparul Syphon bridge. The Champa Canal exhibits brackish water characteristics from Shankarpur Mohana to the Paniparul syphon.¹⁵ In Z-III, four mangrove species are identified: *Acanthus ilicifolius* and *Excoecaria agallocha* are common, while *Avicennia officinalis* and *Derris trifoliata* are rarely found. *Aegiceras corniculatum*, *Avicennia alba*, *Avicennia marina*, *Bruguiera gymnorrhiza*, and *Ceriops decandra* were absent in Z-III. *Sonneratia apetala* was not present in Z-II and Z-III. A total of 28 mangrove associates are present along the canal bank. The *Calotropis gigantea* shrub, *Cyperus rotundus*, and *Cynodon dactylon* herbs are prevalent in this zone. Certain exclusive mangrove associates, such as *Sesuvium portulacastrum*, *Suaeda maritima*, *Suaeda nudiflora*, *Ipomoea pes-caprae*, and *Portulaca oleracea*, are absent in this zone. *Suaeda monoica* and *Clerodendrum inerme* are notably rare species. *Guilandina bonduc*, *Acacia nilotica*, *Pandanus odoratissimus*, and *Solanum trilobatum* are prevalent species in this zone.

Within the true mangrove families, Acanthaceae accounts for 40%, while Rhizophoraceae represents 20%, and Primulaceae, Fabaceae, Euphorbiaceae, and Lythraceae each provide around 10%. The associate mangrove families Fabaceae and Poaceae each account for 11%. Both Amaranthaceae and Asteraceae contribute 9% each. Each family, including Aizoaceae, Convolvulaceae, Cyperaceae, and Solanaceae, contributes 6%. The remaining 13 mangrove associates contribute 3% each.

Species previously documented, such as *Heritiera fomes*, *Derris scandens*, *Rhizophora mucronata*, and *Hibiscus tiliaceus*,^{13,16,18} along the Purba Medinipur Coast, were absent in the current study. While presently recorded exclusive mangrove associates, such as *Suaeda maritima* and other related species, were absent in prior studies conducted in this region. Alien plants can proliferate swiftly due to the mobility of society and the deliberate transport of ornamental and forage species.³⁷ According to a report, a total of 173 IAPS were introduced in India.³⁷ Six invasive alien plant species (*Chromolaena odorata*, *Parthenium*

hysterophorus, *Opuntia dillenii*, *Prosopis juliflora*, *Solanum sisymbriifolium*, *Lantana camara*) were identified in the study area. Their presence in this area is prevalent and increasing rapidly, posing a significant threat to the native biodiversity of the region. Among the recorded mangrove associates, 11 species are classified as NeMS, adapted to the tidal

plain of Champa Canal as tidal vegetation. Among the 11 recorded NeMS, 5 are classified as IAPS-NeMS (excluding *Prosopis juliflora*), while the remaining 6 species are identified as native NeMS: *Calotropis gigantea*, *Phoenix sylvestris*, *Capparis zeylanica*, *Casuarina equisetifolia*, *Euphorbia lactea*, and *Neptunia oleracea* (Plate A and B).

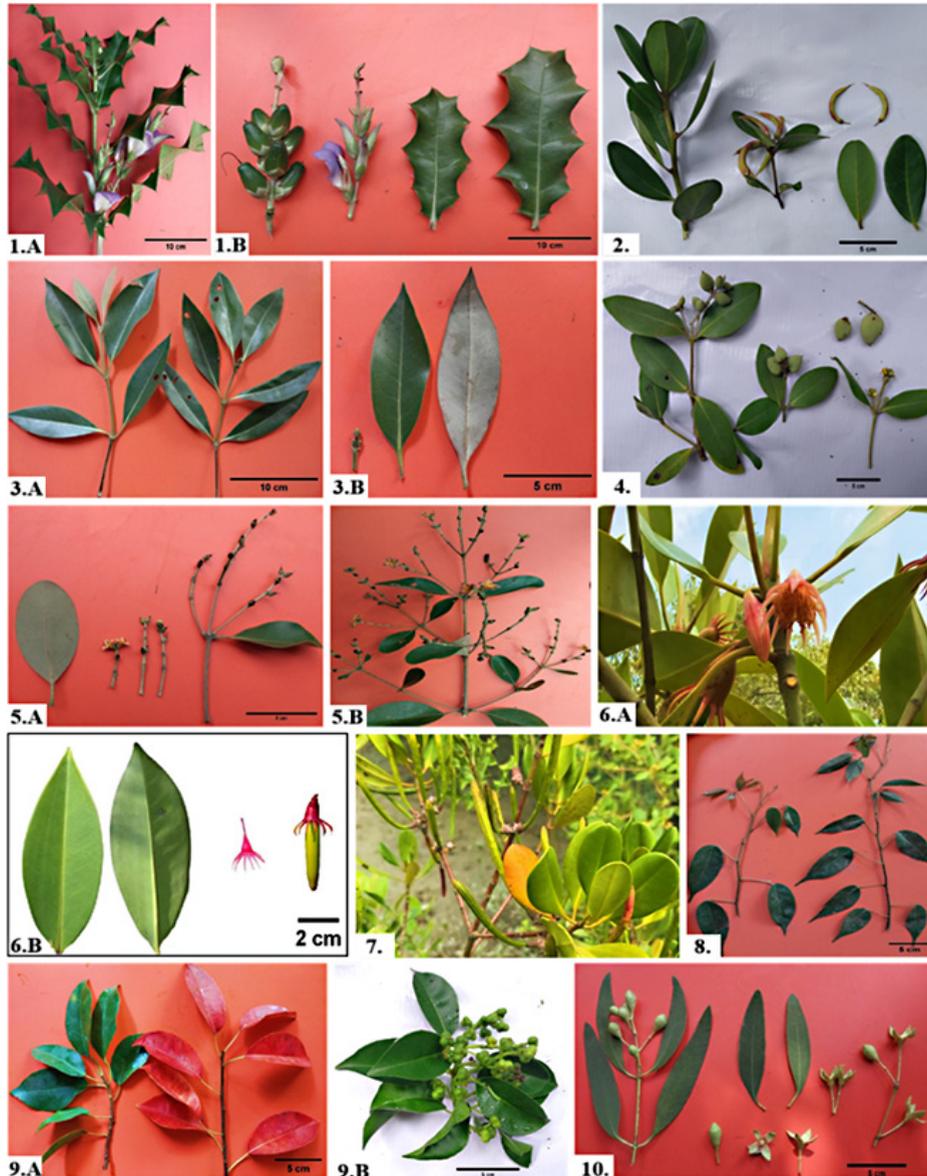


Plate A. True Mangroves found along the bank of the Champa Canal: 1) *Acanthus ilicifolius*, 2) *Aegiceras corniculatum*, 3) *Avicennia alba*, 4) *Avicennia marina*, 5) *Avicennia officinalis*, 6) *Bruguiera gymnorrhiza*, 7) *Ceriops decandra*, 8) *Derris trifoliata*, 9) *Excoecaria agallocha*, 10) *Sonneratia apetala*





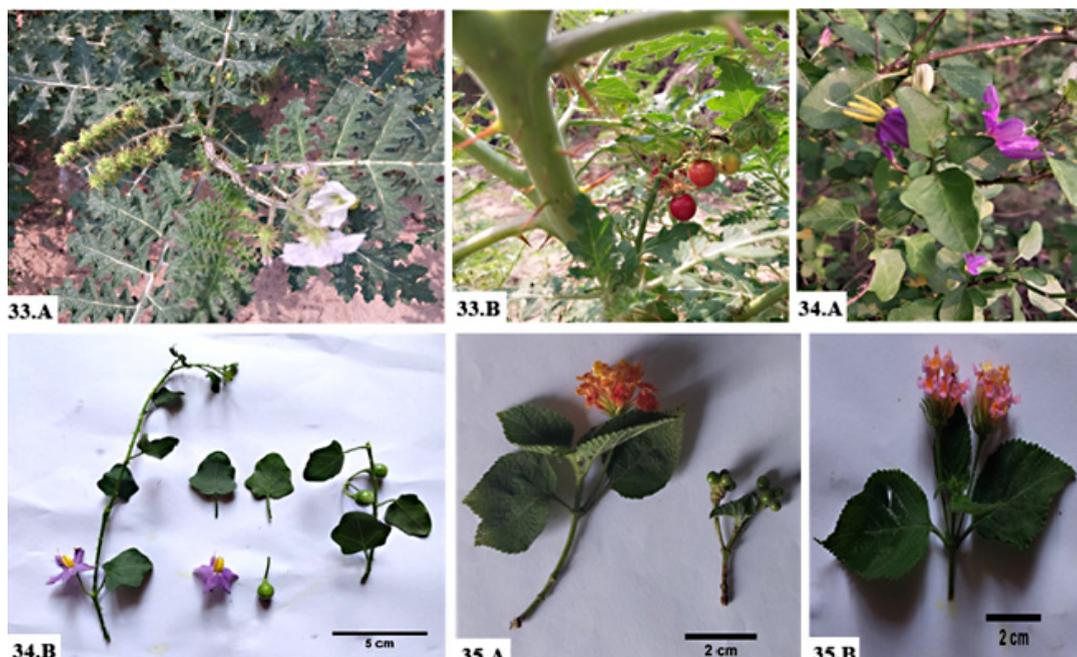


Plate B. Mangrove associates found along the bank of the Champa Canal: 1) *Sesuvium portulacastrum*, 2) *Trianthema portulacastrum*, 3) *Suaeda maritima*, 4) *Suaeda monoica*, 5) *Suaeda nudiflora*, 6) *Calotropis gigantea*, 7) *Phoenix sylvestris*, 8) *Pluchea indica*, 9) *Chromolaena odorata*, 10) *Parthenium hysterophorus*, 11) *Heliotropium curassavicum*, 12) *Opuntia dillenii*, 13) *Capparis zeylanica*, 14) *Casuarina equisetifolia*, 15) *Ipomoea pes caprae*, 16) *Ipomoea sagittifolia*, 17) *Cyperus rotundus*, 18) *Fimbristylis ferruginea*, 19) *Euphorbia lactea*, 20) *Guilandina bonduc*, 21) *Neptunia oleracea*, 22) *Prosopis juliflora*, 23) *Rothia indica*, 24) *Clerodendrum inerme*, 25) *Acacia nilotica*, 26) *Pandanus odoratissimus*, 27) *Cynodon dactylon*, 28) *Leersia hexandra*, 29) *Myriostachya wightiana*, 30) *Porteresia coarctata*, 31) *Portulaca oleracea*, 32) *Azima tetraacantha*, 33) *Solanum sisymbriifolium*, 34) *Solanum trilobatum*, 35) *Lantana camara*

Water Quality Parameters

Air temperature ranged from 27.62°C (PoM) to 31.08°C (PreM). Air temperature peaks during PreM and reaches its lowest point during MoS, while PoM exhibits moderate temperature variation. In the mangroves of Kundapur temperature ranged from 24°C to 29°C,³⁸ while temperature ranged from 25.4°C to 31.2°C in the Krishnapatnam mangroves.³⁵ Surface water temperature varied between 23.1°C (PoM) and 32.6°C (PreM) in Z-II. All zones exhibited comparable trends with analogous seasonal variations. Surface water temperature is highest in PreM (Z-II) and lowest in PoM (Z-III). Surface water temperature is primarily influenced by photoperiod intensity, atmospheric temperature, evaporation, insolation, freshwater influx, and cooling, in addition to the ebb and flow from adjacent neritic waters.³⁶

The pH reached its maximum in Z-I during the PreM season at 8.9, while it was at its minimum in Z-III during PoM at 6.3. The pH of Z-I was consistently higher across all seasons compared to the other two zones. Z-I represents the integrated bay and estuarine regions. This indicates a combined variation in pH, while the other two zones reflect a typical estuarine pH resulting from the mixing of fresh and marine water.³⁹

Seasonal analysis of dissolved oxygen demonstrated an inverse correlation with temperature and salinity. Temperature and salinity are recognised factors influencing the solubility of oxygen in seawater.⁴⁰ The current investigation observed elevated DO values during the Mos across all three zones and diminished values during PreM. Dissolved oxygen levels varied from 3.48 ppm to 5.31 ppm in the Champa

Canal mangrove region. During PreM and PoM, dissolved oxygen (DO) levels were elevated in Z-I (4.31 ppm in PreM and 5.05 ppm in PoM) due to significant turbulence and mixing from tidal action in Z-I, with the desiccation of Z-III resulting from the absence of lotic waters from the Dubda Basin and various anthropogenic activities. The minimum dissolved oxygen (DO) level was observed in Z-III (3.48 ppm) during the PreM phase. The elevated levels seen on the opposite side during MoS DO in Z-II (6.5 ppm) may be attributed to substantial rainfall and freshwater flow from the upstream region. Different researchers obtained analogous results.^{41,42} The dissolved oxygen levels in the Paravoor mangrove ecosystem of Kerala ranged from 3.8 ppm to 5.2 ppm,³⁶ whereas a fluctuation was noted in DO from 2.4 ppm to 5.0 ppm in the Pichavaram mangroves of Tamil Nadu.⁴³

The alkalinity of the water sample ranged from 139.49 ppm to 206.78 ppm. The peak alkalinity was seen in Z-I during the PreM, whereas the minimum was noted in Z-III during the MoS. Z-I exhibited relatively elevated levels during all three seasons, while Z-II demonstrated a moderate value. The elevated alkalinity levels in the Z-I may be attributed to its proximity to the Bay of Bengal and the presence of abundant mangrove vegetation in these areas. The elevated pH levels at the downstream stations result from the amalgamation of saltwater with estuarine waters and the photosynthetic activity of mangroves, which consumes CO₂, thereby altering the balance towards increased alkalinity.⁴⁴

Electric conductivity (EC) serves as a measure of the concentration of dissolved salts in water. This is also characterised by the quantity of ions, both positive and negative, present in water, as well as the capacity of water to conduct an electrical current. This serves as an important measure of the salinity and overall salt concentration in a water sample.³⁵ The electrical conductivity ranged from 7,124.09 μ S/cm to 25,650.33 μ S/cm during the study period. The observed higher and lower conductivity values during the PreM and MoS seasons may be attributed to the reduction in freshwater flow and increased evaporation rates, and vice versa. The current results align with the research conducted in the Sunderban mangroves,⁴⁵ as well as in Bhitarkanika Mangrove.⁴⁶

The BOD values in this study varied from 1.73 to 2.94 ppm over the three seasons, with elevated BOD levels noted during the monsoon and post-monsoon seasons, attributed to the microbial oxygen demand for decomposing suspended organic matter.⁴⁷ The elevated BOD and reduced DO levels recorded at Z-III may be ascribed to anthropogenic activity in that area. Pristine rivers typically exhibit a 5-day BOD of less than 1 ppm, whereas highly contaminated rivers display BOD values ranging from 2 to 8 ppm.⁴⁸ The current estuary segment of the Champa Canal is thus unfavourable regarding organic load and nitrogen levels. This represents the potential pollution risk from current agricultural and industrial operations in this region.

The total dissolved solids (TDS) range from 14,438.65 ppm to 23,720.14 ppm, signifying water pollution primarily resulting from the confluence of seawater and river water.⁴⁹ Total Dissolved Solids (TDS) is typically linked to inorganic salts, and there exists a strong correlation between TDS and conductivity. While there is no universally applicable precise quantitative correlation between TDS and conductivity, elevated conductivity suggests high TDS.⁴¹ A study reported that the TDS levels in Sunderban mangrove regions varied from 7,200 to 12,900 ppm.⁴⁵ TDS value ranged from 10,000 ppm to 30,000 ppm in the Bhitarkanika Mangrove.⁴⁶ The total suspended solids (TSS) level during this present study period ranged from 79.35 ppm to 232.5 ppm. The elevated TSS values during the MoS and immediate PoM seasons, in contrast to the summer season, may be ascribed to rainfall, turbulent conditions, and the influx of dislocated fine earth materials from the catchment area via runoff into the mangrove ecosystem.³⁵ A study recorded TSS ranged from 0.7 g/L to 3 g/L in Krishnapatnam Coastal mangroves.³⁵

Nitrite in mangroves is a crucial element of the nitrogen cycle and contributes to different ecological processes. The concentration is affected by the system's oxidation or reduction conditions. Nitrite concentrations can impact the richness and variety of microbial communities, thereby influencing other creatures within the mangrove ecosystem.³⁶ In the current investigation, nitrite levels varied from 0.09 ppm to 0.43 ppm. Peak nitrite concentrations were

observed during MoS. Z-III exhibited the highest value, maybe attributable to anthropogenic activity in the region and the introduction of organic load from upstream sources. Nitrite concentrations observed between 0.04 and 0.87 μM in the western mangroves of Kachchh-Gujarat.⁵⁰ Nitrates are an essential nitrogen source that affects plant growth and the overall productivity of mangroves.³⁶ The nitrate concentration in the study area ranged from 0.16 ppm to 0.58 ppm. In the Bhitarkanika mangrove nitrate concentrations varied from 0.349 ppm to 1.067 ppm.⁴⁶ The maximum nitrate value was identified during PreM. Phosphate content varied between 0.15 and 0.5 ppm. Elevated phosphate levels were recorded during the MoS, while reduced levels were noted during PreM. The elevated values recorded during the MoS season may be ascribed to runoff from agricultural and aquaculture areas.³⁵ The phosphate concentration varied from 0.55 ppm to 2.59 ppm in Mahanadi mangrove ecosystem.⁴¹

Soil Quality Parameters

The mean salinity of Z-I was recorded at 18.9 ppt in the PreM, 16.28 ppt in the MoS season, and 18.3 ppt in the PoM. The highest salinity observed was 18.9 ppt during the PreM period. The salinity of water in Z-II varied between 9.72 and 11.4 ppt. The maximum salinity observed was 11.4 ppt during the PreM period, whereas the minimum recorded was 9.72 ppt during the MoS season. The water salinity in Z-III ranged from 2.17 ppt (MoS) to 4.9 ppt (PreM). A study indicated that salinity in the Krishnapatnam Coastal mangrove region of Andhra Pradesh ranged from 21 ppt to 33 ppt, with higher levels noted in summer and lower levels during the monsoon, due to rainfall and freshwater inflow from the land.³⁵ The salinity values observed in the Paravoor mangrove ecosystem study in Kerala ranged from 15.8 ppt to 48.31 ppt.³⁶

The primary determinant of mangrove sediment is soil pH, which varied from 5.95 (Z-II during PreM) to 6.68 (Z-I during MoS). Throughout the study period, soil pH remained consistent across the three seasons, showing no significant variation. However, a relatively elevated pH value was noted during MoS compared to PreM and PoM. The elevated pH levels observed during the rainy season can be attributed to the influx of rainwater.⁵¹ pH ranged from 7.4 to 8.2 for mangrove soils in the Indian Sunderbans.⁵²

Electrical conductivity ranged from 1.53 dS m^{-1} in Z-III during MoS to 3.97 dS m^{-1} in Z-I during PoM. The current study recorded higher values during the PoM season and minimal values during the MoS season. The electrical conductivity of a soil solution increases with higher ion concentration.⁵³ High soil conductivity results from the infiltration of seawater during high tides, water evaporation, and the capillary rise of groundwater during low tides.⁵⁴

This study reports that the available nitrogen ranges from 156.44 to 230.22 kg/ha. The maximum value was recorded during PoM in Z-I, whereas the minimum value was noted during MoS in Z-III. In Z-I, a high nitrogen value was observed due to the trapping of detritus by finer particles, leading to a significant increase in bacterial population, which subsequently contributed to elevated nitrogen levels. This behaviour was attributed to the elevated organic carbon content in these soils.⁵² A nearly identical situation was observed regarding phosphorus content. The soil in Z-I, dominated by mangroves, demonstrated a higher availability of phosphorus compared to Z-II and Z-III. Soil phosphorus content varied from 24.1 kg/ha in Z-I during the MoS to 18.4 kg/ha in Z-III during the PoM. The observed low phosphate levels following monsoon seasons can be attributed to restricted freshwater flow, increased salinity, and phosphate consumption by phytoplankton. Fine sediments in muddy areas exhibit a higher efficiency in phosphorus adsorption compared to coarse-grained sediments. This likely explains the abundant growth of mangroves in muddy environments.⁵⁵ The potassium content in soil ranged from 213.38 kg/ha in Z-III during PreM to 368.89 kg/ha in Z-I during MoS. No significant variation in phosphorus content was observed across all seasons. The average soil potassium values ranged from 117.43 kg/ha in the MoS season to 537.63 kg/ha in the MoS season in the Kundapura mangroves of Karnataka.⁵⁶

Tidal Variance

The tide serves as the primary controlling factor in estuarine hydrodynamic processes, facilitating the advection and dispersion of fluvial materials in coastal water bodies and resulting in significant alterations to the nearby beaches and the bottom topography of the estuarine region.⁵⁷ The range of spring tides is between 2.6 and 5.5 meters, while

the range of neap tides was from 0.2 to 2.3 meters. The peak spring tide height was recorded in October 2024, while the minimum occurred in March and April 2024. The peak neap tide height was recorded in September 2024, while the minimum was noted in March 2024.

The tidal pattern along this coast is predominantly meso-tidal and semi-diurnal. The tides cause seawater intrusion in the sanctuary, leading to a brackish salinity regime essential for the survival of vegetation and animals, including mangroves. Tidal changes significantly influence sedimentation patterns and nutrient distribution in estuarine mangrove regions, hence sustaining their rich biodiversity.⁵⁸ The seasonal variations in the tidal range were examined in the Bhitarkanika Mangrove where spring tide ranged 3.1–3.7 meters, while the neap tide range was 0.6–1.4 meters.⁵⁷

Conclusion

The current work shows that the Champa Canal preserves rather great diversity of mangroves and related species, mostly formed by salinity gradients, soil conditions, and tidal dynamics. Increased salinity and tidal effects have improved species richness and ecological complexity in Zone-I; diversity is much reduced in Zone-III, freshwater dominated. The acquired data distinctly demonstrate the significant impact of hydrological and edaphic factors on mangrove distribution. This method underscores the significance of targeted conservation efforts grounded in site-specific biological dynamics. Respond promptly to oversee and control invasive species, restore compromised ecosystems, and curtail extensive human activities. The findings offer crucial insights for the management of sustainable estuaries and considerably enhance existing understanding of regional mangrove conservation.

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Conflict of Interest

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Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Permission to Reproduce Material from other Sources

Not Applicable

Author Contributions

- **Avik Bhanja:** Conceptualization, Methodology, Writing – Original Draft, Sampling, Data Collection, Analysis.
- **Pijush Payra:** Conceptualization, Analysis, Sampling, Writing – Review & Editing.
- **Indrajit Sau:** Analysis, Review & Editing.
- **Sandip Makur:** Field Support, Data Curation.
- **Dishani Biswas:** Literature Review, Visualization.
- **Tapas Bhunia:** Data Curation, Literature Review.
- **Nibedita Sinha:** Formatting, Referencing.

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