Journal of Geointerface, Vol. 3, No. 2, December 2024, pp. 93–102 e-ISSN: 2583-6900

Holocene coastal wetland evolution in a tropical ecosystem: Sedimentary archives from South Kerala, India

Divya Murali [1,*], Rajesh Reghunath[1], Shitha Kannichankandy[1], Ravi Bhushan[2], K. Anoop Krishnan[3]

[1] *Department of Geology, University of Kerala, Karyavattom Campus, Trivandrum 695581, India*
[2] *PRL-AMS Lab, Physical Research Laboratory, Ahmedabad, Gujarat, India*
[3] *National Centre for Earth Science Studies, Trivandrum, India*

ABSTRACT

This study focuses on the Late Holocene evolution of Ashtamudi Lake, utilizing a multiproxy analysis of borehole samples from Munroe Island in the Ashtamudi floodplain. Granulometric analysis reveals rapid shifts in sedimentary environments throughout the core, except at depths of 2–7 m and 14.5–18 m. High TOC/TN ratios in the Munroe Island core suggest an allochthonous source of organic carbon, while the predominance of C3 plants over C4 plants indicates a generally cool and wet climate with occasional hot and sunny intervals. Conversely, low TOC/TN ratios at depths of 3.5, 4.5, 5, 13, and 21 m suggest episodes of aquatic phytoplankton activity, basin eutrophication, and brief periods of intense rainfall leading to nutrient influx. The presence of estuarine and marine molluscan shells at depths of 8 m and 21–26 m suggests a transition from a regression phase to normal marine conditions in the lower core, followed by marine transgression between 21–22.5 m, and regression thereafter. AMS radiocarbon dating at depths of 8.5 m and 23 m yielded ages of 2385 ± 39 years BP and 3702 ± 39 years BP, respectively, confirming a Late Holocene timeline. The occurrence of estuarine and marine fossil shells, coupled with geochemical and geochronological data, indicates that the coastal floodplains of Ashtamudi Lake evolved during the Late Holocene through a series of marine transgression-regression events and associated environmental changes.

ARTICLE HISTORY

Received 2 November 2024
Revised 25 November 2024
Accepted 29 November 2024

https://doi.org/10.5281/zenodo.14264382

KEYWORDS

Late Holocene Period
TOC/TN ratio
Radiocarbon dating
Wetland system
Ashtamudi Lake
Munroe Island

1. Introduction

Kerala, located along the southwestern coast of India, is notably renowned for its ample wetlands on the Indian subcontinent (Nayar and Nayar, 1997). Most of Kerala's wetlands are predominantly brackish, with a few freshwater wetlands thought to have formed during the Holocene period and they represent a pivotal geomorphic unit that holds the socioeconomic facets of the state. The wetlands in Kerala are disseminated along the coastal plains, spanning from Kollam to Kodungallur. This coastal stretch encompasses prominent wetlands such as Vembanad Lagoon, Kayamkulam Lagoon, Ashtamudi Estuary and Sasthamkotta Lake. As stated by Thrivikramji et al. (2007) and Nair et al. (2010), these major wetlands have evolved throughout the Holocene. The Vembanad Lake, Ashtamudi Lake, and Sasthamkotta Lake have been designated as Ramsar sites sup-

*Corresponding author. Email: divyasooraj89@gmail.com (DM), rajeshgeologist@gmail.com (RR), shithapremraj96@gmail.com (SK), bhushan@prl.res.in (RB), sree.anoop@ncess.gov.in (KAK)

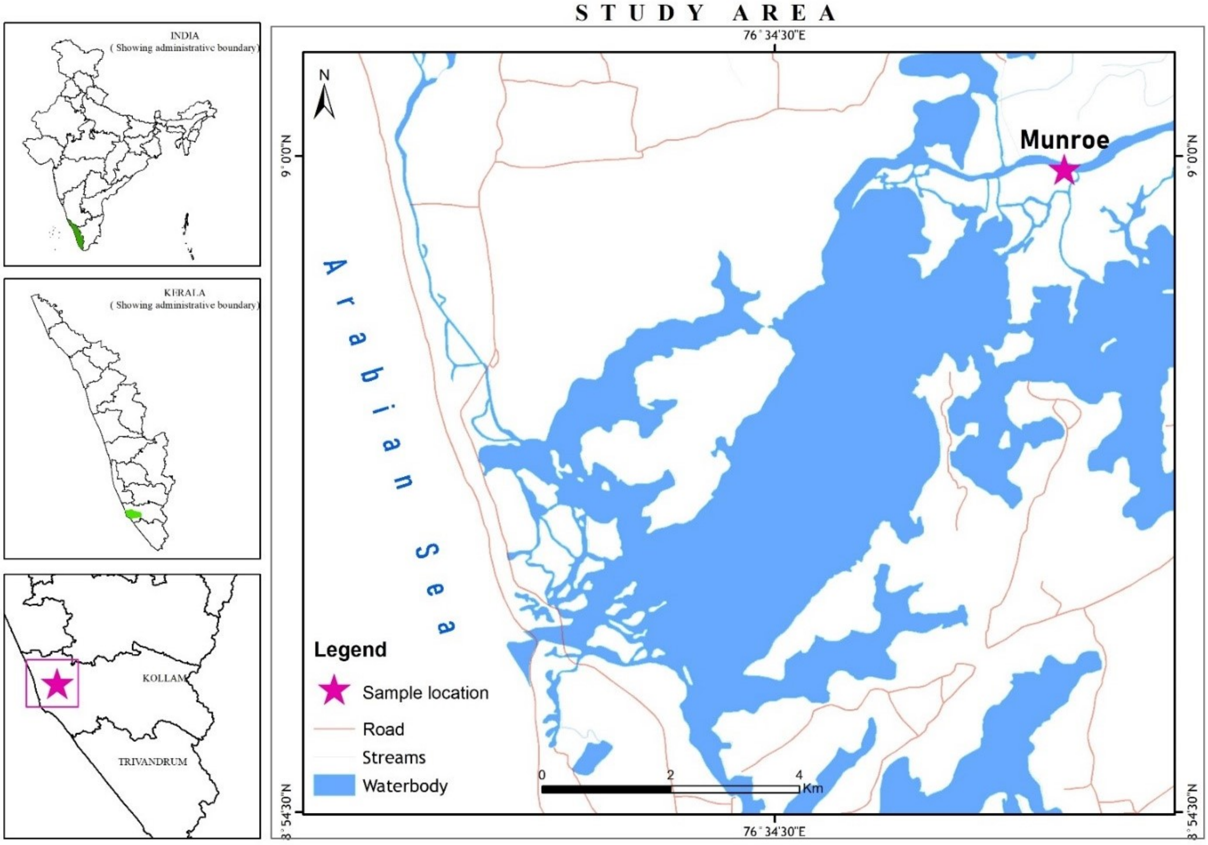

Fig. 1. Map of the study area showing the location of borehole sampling.

porting the hydrodynamic balance for the economic preferment of the region. The formation of wetlands involves an intricate interplay of biological, hydrological, geochemical, and geomorphic factors. The interplay of sea level fluctuations, climate variations, and anthropogenic activities has substantially altered these wetlands, leading to significant shrinkage, particularly during the Late Holocene period (Padmalal et al., 2011, 2014a). Coastal wetlands, arising from intricate land-sea interactions, serve as critical transitional landforms and their significance lies in acting as repositories for sediments and organic matter, capturing the historical imprints of sea-level fluctuations within diverse sedimentary archives. Previous research has examined the geological evolution of the coastal wetlands in south Kerala and explored the influence of climate and sea level on their formation. The studies by Padmalal et al. (2014a,b), Kumaran et al. (2014), Kumaran et al. (2018), Maya et al. (2017) and Banerji et al. (2021) have employed sedimentological, palynological, and geochronological analyses of sediments to investigate these aspects. In this study, different climate proxies are used to address the Late Holocene evolution of Ashtamudi Lake. Additionally, the palaeontological and TOC/TN ratio results of sediment cores are employed. Besides, the study aims to explore the evolutionary history of the Ashtamudi coastal wetland by the application of granulometric, palaeontologic, geochemical and geochronological study of core sediments.

2. Study area

In the present study the sediment records for the inquisition have been acquired through rotary drilling in the selected location in Munroe Island located in the floodplains of Ashtamudi wetland and is bounded between latitude 8°57′27.61″N and longitude 76°38′1.53″E (Fig. 1). Munroe Island is a group of islands comprising of eight medium-sized and a few tiny islands located in the backwaters of the famous Ashtamudi Lake in Kerala, south India. The Munroe Island of Kollam district was formed as a result of the sediment depositional process by river Kallada and Ashtamudi Lake indicating a lacustrine origin. The Munroe Islands are composed of newly formed alluvium brought up by combined riverine and marine sedimentation of Quaternary origin. Tertiary sediments belonging to Warkalli and Quilon Formations underlie the Quaternary sediments.

3. Materials and methods

The core has been collected up to a depth of 28 m from the ground surface and has been subsampled at every 50 cm and kept for further laboratory analyses. The granulometric analysis of sediment samples has been carried out by following the standard methods (Ingram, 1971) and pipetting (Galehouse, 1971). The sediment types were identified by following Flemming's Ternary Diagram (Flemming, 2000). Total Nitrogen (TN) and Total Organic Carbon (TOC) in the core samples were measured using a CHNS analyzer (Elementar Vario EL CUBE). To estimate the organic carbon, the inorganic carbon was removed by decarbonization of the sediment sample with 0.5N HCl. The mega fossil shells in the core sediments were identified. For radiocarbon dating, two samples were taken from different depth intervals and graphitized following the procedures published in Bhushan et al. (2019a,b). The radiocarbon measurement of samples was done using 1 mv AMS (Auris) at the Geoscience Division, Physical Research Laboratory, Ahmedabad, India.

4. Results

4.1. Granulometric analysis

In the Munroe Island core, the sand content varies from 32.66% to 94.81%, and that of silt varies from 4.84% to 66.51%. All samples have a low clay percentage (0.14% to 1.22%), except those at 8.5 and 27 m of depth, where it is 7.58% and 24.62% respectively (Table 1).

Both sand and silt content fluctuate drastically along the full core length. The down core variation of clay shows only two peaks at 8.5 m and 27 m depth (Fig. 2). In Munroe Island core the prevalent sediment type is slightly silty sand, followed by slightly clayey sand and extremely silty sandy mud. The other sediment types encountered in the core such as silty sand, very silty sandy mud and clayey sand are represented by only one sample each and they are present at 9 m, 12.5 m and 27 m depths respectively (Fig. 3 and 4).

The ternary diagram put forth by Pejrup (1988) has been applied to the core samples collected from the study area to understand the hydrodynamic conditions. Except for one sample at a core depth of 27 m, all samples fall in category IV of the ternary diagram, indicating the extreme dominance of violent environments during the deposition of the sediments. The sample at a core depth of 27 m falls in category II of the diagram, indicating a relatively calm environment during deposition (Fig. 5).

4.2. Geochemical analysis (TOC/TN ratio)

In the Munroe Island core samples, the TN values range from 0.02% to 3.79%, and that of TOC ranges from 0.436% to 9.361%. The TOC/TN values range from 0.968% to 51.25% (Table 2).

The down core variation pattern of TN, TOC, and TOC/TN varies drastically (Fig. 6). Munroe island core is characterized by relatively high values of TOC/TN ratio suggesting an allochthonous source for organic carbon, where C3 type plants dominate over the C4 type indicating a cool and wet climate. The C4 type plants dominate only at a few depths, such as 6.5 m, 9.5 m, 10.5 m, 17 m, and 23 m indicating a hot and sunny environment (Meyers, 1994). Low TOC/TN ratio values are recorded at specific depths such as 3.5 m, 4.5 m, 5 m, 13 m, and 21 m indicating aquatic phytoplankton activity at these depths (Meyers, 1994; Tyson, 1995).

4.3. Palaeontological analysis

Megafossil shells of pelecypods and gastropods were recovered from the Munroe Island core (Fig. 7). Among the fossil shells, the pelecypod *villorita,* which is recovered at 8 mm, and 25–26 m core depths, indicates typical estuarine conditions at these depths. The species *villorita* is present in the slightly clayey sand and slightly silty sand. Another pelecypod namely *Anomalodiscus squamosus,* recovered from a core depth of 22.5 m in extremely silty sandy mud, suggests marine condition. The gastropod shells, *Pirenella cingulate* and *Nassarius jacksonianus* from the core depth of 21 m in extremely silty sandy mud also indicate the marine environment.

4.4. Radiocarbon dating

The AMS radiocarbon dating has been done for sediment samples at two levels. Table 3 gives the radiocarbon dates of the present study. The samples at 8.5 m and 23 m core depth of Munroe island core are dated as 2385 ± 39 yrs BP and 3702 ± 39 yrs BP, respectively indicating Late Holocene age.

Table 1. Textural aspects of core sediments.

Sample no	Depth (m)	Sand (%)	Clay (%)	Silt (%)	Sediment type (after Flemming, 2000)
MN1	1	82.05	0.34	17.6	Slightly silty sand
MN2	1.5	43.91	0.33	55.75	Extremely silty sandy mud
MN3	2.5	86.2	0.44	13.35	Slightly silty sand
MN4	3	94.81	0.35	4.84	Slightly silty sand
MN5	3.5	91.6	0.44	7.96	Slightly silty sand
MN6	4	88.69	0.44	10.87	Slightly silty sand
MN7	4.5	93.94	0.33	5.73	Slightly silty sand
MN8	5	94.67	0.41	4.93	Slightly silty sand
MN9	5.5	91.64	0.4	7.96	Slightly silty sand
MN10	6	92.13	0.46	7.42	Slightly silty sand
MN11	6.5	91.09	0.25	8.66	Slightly silty sand
MN12	7	71.27	0.37	28.36	Slightly clayey sand
MN13	7.5	89.16	0.39	10.44	Slightly silty sand
MN14	8	58	0.64	41.36	Slightly clayey sand
MN15	8.5	37.58	7.58	54.84	Extremely silty sandy mud
MN16	9	60.84	0.3	38.86	Silty sand
MN17	9.5	81.68	0.33	17.99	Slightly silty sand
MN18	10	39.51	0.93	59.56	Extremely silty sandy mud
MN19	10.5	70.82	0.39	28.79	Slightly clayey sand
MN20	11	75.49	0.36	24.15	Slightly silty sand
MN21	11.5	60.83	0.41	38.76	Slightly clayey sand
MN22	12	90.42	0.42	9.17	Slightly silty sand
MN23	12.5	32.66	0.82	66.51	Very silty sandy mud
MN24	13	94.01	0.14	5.85	Slightly silty sand
MN25	13.5	71.9	0.35	27.75	Slightly clayey sand
MN26	14	73.67	0.4	25.93	Slightly clayey sand
MN27	14.5	40.61	1.02	58.38	Extremely silty sandy mud
MN28	15	57.27	1.22	41.51	Slightly clayey sand
MN29	15.5	68.11	1.02	30.88	Slightly clayey sand
MN30	16	60.86	1.11	38.03	Slightly clayey sand
MN31	16.5	51.45	0.91	47.64	Slightly clayey sand
MN32	17	59.12	0.57	40.31	Slightly clayey sand
MN33	17.5	60.59	0.44	38.97	Slightly clayey sand
MN34	18	75.59	0.32	24.09	Slightly silty sand
MN4	18.5	70.11	0.41	29.48	Slightly clayey sand
MN36	19	74.15	0.72	25.13	Slightly silty sand
MN37	19.5	85.18	0.51	14.31	Slightly silty sand
MN38	20	41.49	0.53	57.98	Extremely silty sandy mud
MN39	20.5	41.59	0.67	57.75	Extremely silty sandy mud
MN40	21	45.69	0.3	54.01	Extremely silty sandy mud
MN41	21.5	89.32	0.62	10.06	Slightly silty sand
MN42	22	76.1	0.43	23.48	Slightly silty sand
MN43	22.5	46.27	0.51	53.22	Extremely silty sandy mud
MN45	23	45.07	0.35	54.58	Extremely silty sandy mud
MN46	23.5	83.63	0.29	16.08	Slightly silty sand
MN47	24	65.9	0.5	33.6	Slightly clayey sand
MN48	24.5	66.12	0.6	33.28	Slightly clayey sand
MN49	25	70.6	0.52	28.88	Slightly clayey sand
MN50	25.5	82.87	0.35	16.78	Slightly silty sand
MN51	26	65.58	0.39	34.04	Slightly clayey sand
MN52	26.5	33.95	0.73	65.33	Extremely silty sandy mud
MN53	27	60.73	24.62	14.66	Clayey sand
MN54	27.5	47.38	0.7	51.92	Extremely silty sandy mud
MN55	28	47.57	0.36	52.07	Extremely silty sandy mud

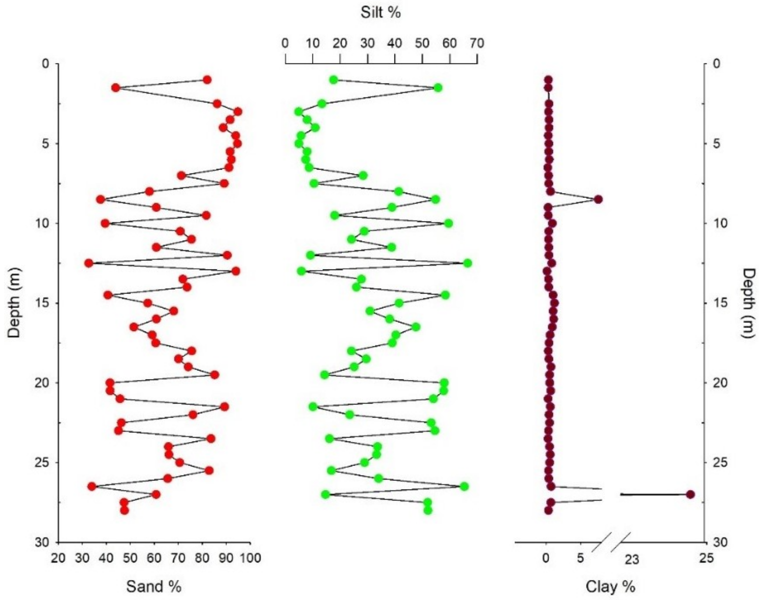

Fig. 2. Down core variation of sand, clay and silt particles of the core samples.

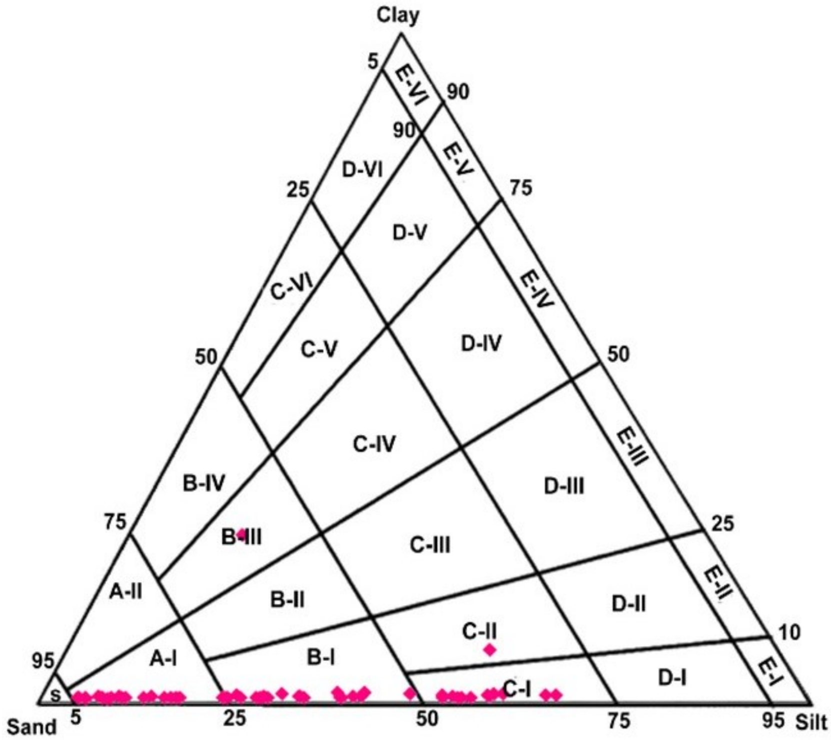

Fig. 3. Sediment types of the core (after Flemming, 2000).

5. Discussion

The downcore variation of sediment types in Munroe Island core indicates rapid short-term profound shifts in the climatic conditions and associated eustatic changes all along the core except at two depth ranges such as 2 to 7 m and 14.5 to 18 m. In the present study, the hydrodynamic conditions of the past environment are understood by using the ternary diagram proposed by Pejrup (1988). In the ternary diagram, all samples except one belong to category IV indicating the prevalence of violent environmental conditions during the deposition of the sediments. The sample from the Munroe Island borehole at a depth of 27 m falls in category II, suggesting a relatively calm environmental condition during the deposition (Fig. 5).

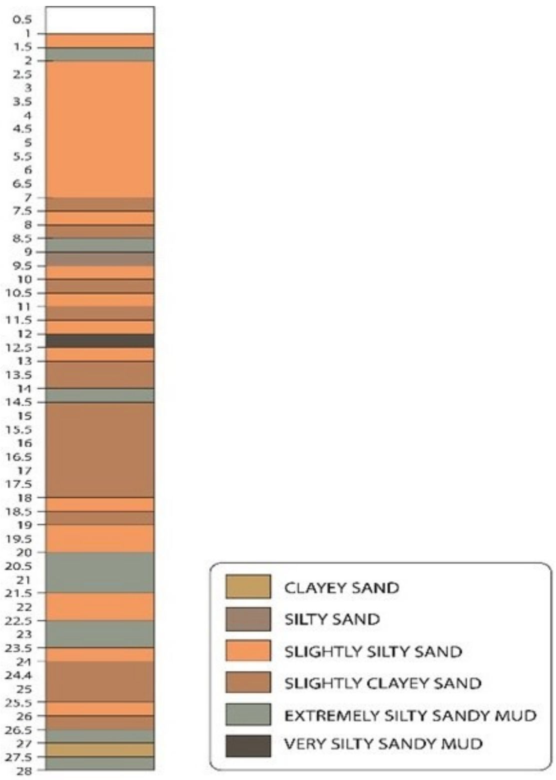

Fig. 4. Litholog of the core based on Flemming's Classification (2000).

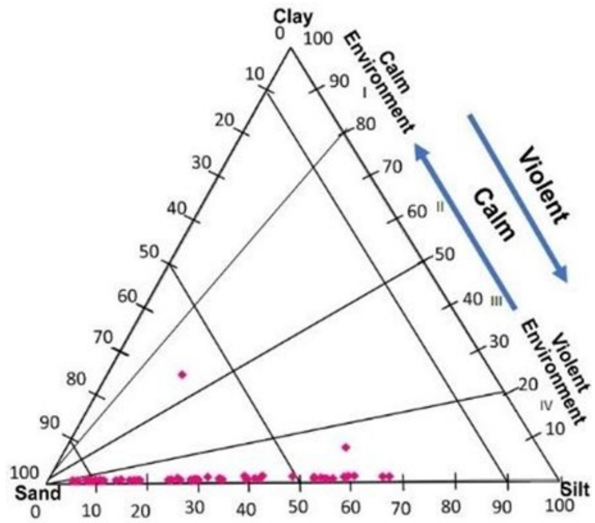

Fig. 5. Ternary plot of Pejrup (1988) showing the depositional environment of the study area.

The TOC/TN ratios of Munroe Island core are characterized by high values, attributing an allochthonous source of organic carbon. The dominance of the C3-type plants over C4-type plants indicates the predominance of a cool and wet climate over the entire period with occasional hot and sunny periods in between. It can be further stated that the nutrient regime and net sedimentary inputs from land sources have fluctuated many times owing to the shifts in precipitation patterns and climate. The low values of TOC/TN ratio seen at 3.5, 4.5, 5, 13 and 21 m indicate autochthonous source and the presence of aquatic phytoplanktons and short episodes of very high spells of rainfall and the rapid influx of nutrients to the basin. Estuarine and marine molluscan shells present at core depths 8 m and 21–26 m in the Munroe Island core indicate later stages of the regression phase to normal marine conditions at the lower portion of the core and marine transgression conditions in between 21 m and 22.5 m core depth and a

Table 2. Geochemical aspects of core sediments.

SAMPLE NO	DEPTH (M)	TN (%)	TOC (%)	TOC/TN (%)
MN1	1	0.02	0.436	21.800
MN2	1.5	0.1	2.566	25.660
MN3	2.5	0.07	1.619	23.129
MN4	3	0.06	0.763	12.717
MN5	3.5	0.06	0.715	11.917
MN6	4	0.04	0.54	13.500
MN7	4.5	0.06	0.492	8.200
MN8	5	0.82	0.794	0.968
MN9	5.5	0.05	0.706	14.120
MN10	6	0.08	1.434	17.925
MN11	6.5	0.02	1.025	51.250
MN12	7	0.14	3.372	24.086
MN13	7.5	0.03	0.545	18.167
MN14	8	0.21	5.787	27.557
MN15	8.5	0.35	9.361	26.746
MN16	9	0.23	6.108	26.557
MN17	9.5	0.16	5.443	34.019
MN18	10	0.2	5.868	29.340
MN19	10.5	0.06	4.801	30.006
MN20	11	0.23	4.648	20.209
MN21	11.5	0.22	4.51	20.500
MN22	12	0.29	4.837	16.679
MN23	12.5	0.26	4.493	17.281
MN24	13	3.79	3.738	0.986
MN25	13.5	0.28	4.787	17.096
MN26	14	0.26	4.719	18.150
MN27	14.5	0.27	4.987	18.470
MN28	15	0.2	5.527	27.635
MN29	15.5	0.24	4.683	19.513
MN30	16	0.16	4.186	26.163
MN31	16.5	0.25	3.74	14.960
MN32	17	0.14	5.255	37.536
MN33	17.5	0.21	3.994	19.019
MN34	18	0.17	2.84	16.706
MN35	18.5	0.23	3.096	13.461
MN36	19	0.18	4.002	22.233
MN37	19.5	0.25	5.094	20.376
MN38	20	0.22	3.045	13.841
MN39	20.5	0.26	6.188	23.800
MN40	21	0.27	3.147	11.656
MN41	21.5	0.31	5.971	19.261
MN42	22	0.26	6.248	24.031
MN43	22.5	0.21	5.229	24.900
MN45	23	0.26	8.142	31.315
MN46	23.5	0.26	4.386	16.869
MN47	24	0.25	4.831	19.324
MN48	24.5	0.28	6.193	22.118
MN49	25	0.24	6.727	28.029
MN50	25.5	0.29	6.216	21.434
MN51	26	0.26	7.2	27.692
MN52	26.5	0.22	4.963	22.559
MN53	27	0.24	6.48	27.000
MN54	27.5	0.2	4.833	24.165
MN55	28	0.2	5.811	29.055

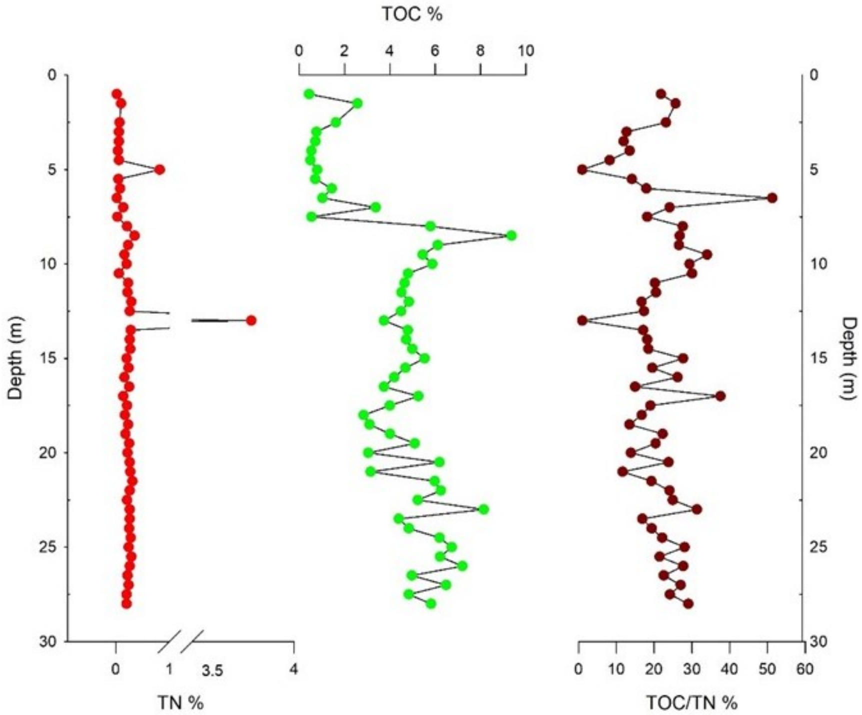

Fig. 6. Down core variation of TN, TOC and TOC/TN values.

Table 3. Details of the radiocarbon dates of core samples from the study area.

Sample ID	LAB ID	Radiocarbon Age (years)	Calibrated Age Range (1 Sigma) years BP	Median Age
MN - 8.5 m	AURIS-04764	2385 ± 39	2348–2464	2420
MN - 23 m	AURIS-04763	3702 ± 39	3982–4138	4040

Calibration is done by Calib 8.2; IntCal20.

regression thereafter.

The coastal lowlands of Kerala are characterized by the signatures of Early Holocene monsoon strengthening, marine transgression accompanied by consequent weakening of monsoon and sea level regression (Padmalal et al., 2014b; Banerji et al., 2021). As per the geochemical data generated in the present study during the Late Holocene period the study region is dominated by wet and cool climatic conditions with intermittent hot and sunny environments which further suggest the shifts in monsoon pattern. The palaeontological analysis indicates transgression-regression events in the study region and the current structure of the Ashtamudi wetland formed by the interplay of these climate and sea-level fluctuations during the Late Holocene.

6. Conclusion

The intricate interplay between rising sea levels, river sedimentation and climatic variations brought on by monsoonal shifts have resulted in the Late Holocene evolution of coastal wetlands in Kerala. These elements moulded the coastal landscapes over millennia, creating the distinctive and critically important wetland systems that exist today. Understanding the ecological, hydrological, and socioeconomic roles of the Ashtamudi wetland requires an awareness of its evolutionary history. Insights from its past can guide effective conservation, climate adaptation, and sustainable development strategies, ensuring the wetland continues to support both biodiversity and local livelihoods for future generations. The primary goal of this study is to examine how Ashtamudi Lake evolved during the Late Holocene. To accomplish the above, multiproxy analyses of borehole samples taken from Munroe Island in the Ashtamudi floodplain are being conducted and the findings suggest that the current structure of Ashtamudi wetland formed by the interplay of these climate and sea-level fluctuations during the Late Holocene.

Fig. 7. Mega fossil shells of Munroe Island core, a: *Villorita*, b: *Anomalodiscus squamosus*, c: *Nassarius jacksonianus*, d: *Pirenella cingulate*.

ACKNOWLEDGEMENTS

Facilities provided in the Department of Geology, University of Kerala are gratefully acknowledged. We are grateful for the laboratory facilities provided by the Central Laboratory for Instrumentation and Facilitation (CLIF), University of Kerala and the National Centre for Earth Science Studies, Trivandrum. The State Planning Board of the Government of Kerala provided project funds to support the study and is also acknowledged. The research fellowship from the University of Kerala is gratefully acknowledged by the first author.

References

Banerji, U.S., Shaji, J., Arulbalaji, P., Maya, K., Mohan, S.V., Dabhi, A.J., Padmalal, D., 2021. Mid-late Holocene evolutionary history and climate reconstruction of Vellayani Lake, South India. *Quaternary International* 599, 72–94. https://doi.org/10.1016/j.quaint.2021.03.018.

Bhushan, R., Yadava, M.G., Shah, M.S., Raj, H., 2019a. Performance of 1 MV AMS Facility (AURIS) at PRL, Ahmedabad. *Nuclear Instruments of Methods in Physics Research: Section B – Beam Interactions with Materials and Atoms* 439, 76–79. https://doi.org/10.1016/j.nimb.2018.12.003.

Bhushan, R., Yadava, M.G., Shah, M.S., Banerji, U.S., Raj, H., Shah, C., Dabhi, A.J., 2019b. First results from PRL Accelerator Mass Spectrometer. *Current Science* 116, 361–363.

Flemming, B.W., 2000. A revised textural classification of gravel-free muddy sediments on the basis of ternary diagrams. *Continental Shelf Research* 20, 1125–1137. https://doi.org/10.1016/S0278-4343(00)00015-7.

Galehouse, J.S., 1971. Sedimentation analysis, in: Carver, R.E. (Ed.), Procedures in Sedimentary Petrology, p. 69–94.

Ingram, R.L., 1971. Sieve analysis, in: Carver, R.E. (Ed.), Procedures in Sedimentary Petrology, p. 49–67.

Kumaran, K.P.N., Padmalal, D., Limaye, R.B., Mohan, S.V., 2018. Signatures of Holocene hydrological processes from sedimentary archives in Southwestern India: case studies from Wetlands of Kerala Coast. *J. Geol. Soc. India* 92(5), 596–606. https://doi.org/10.1007/s12594-018-1073-9.

Kumaran, N.K., Padmalal, D., Nair, M.K., Limaye, R.B., Guleria, J.S., Srivastava, R., Shukla, A., 2014. Vegetation response and landscape dynamics of Indian Summer Monsoon variations during Holocene: An eco-geomorphological appraisal of tropical evergreen forest subfossil logs. *Plos One* 9(4), 93596. https://doi.org/10.1371/journal.pone.0093596.

Maya, K., Vishnu Mohan, S., Limaye, R.B., Padmalal, D., Kumaran, K.P.N., 2017. Geomorphic response to sea level and climate changes during Late Quaternary in a humid tropical coastline: Terrain evolution model from Southwest India. *Plos One* 2(5), 0176775. https://doi.org/10.1371/journal.pone.0176775.

Meyers, P.A., 1994. Preservation of elemental and isotopic source identification of sedimentary organic matter. *Chem. Geol* 114, 289–302. https://doi.org/10.1016/0009-2541(94)90059-0.

Nair, K.M., Padmalal, D., Kumaran, K.P.N., Sreeja, R., Limaye, R.B., Srinivas, R., 2010. Late Quaternary evolution of Ashtamudi, Sasthamkotta lake systems of Kerala, south west India. *J. Asian Earth Sci* 37, 361–372. https://doi.org/10.1016/j.jseaes.2009.09.004.

Nayar, S., Nayar, N.M., 1997. Wetlands, in: Thampi, K.B., Nayar, N.M., Nayar, C.S. (Eds.), The Natural Resources of Kerala. WWF State Office, Trivandrum, Kerala.

Padmalal, D., Kumaran, K.P.N., Nair, K.M., Limaye, R.B., Mohan, S.V., Baijulal, B., Anooja, S., 2014a. Consequences of sea level and climate changes on the morphodynamics of a tropical coastal lagoon during Holocene: An evolutionary model. *Quaternary Int* 333, 156–172. https://doi.org/10.1016/j.quaint.2013.12.018.

Padmalal, D., Kumaran, K.P.N., Limaye, Ruta.B., Baburaj, B., Vishnu Mohan, S., Maya, K., 2014b. Effect of Holocene climate and sea level changes on landform evolution and human habitation: Central Kerala, India. *Quaternary Int* 325, 162–178. https://doi.org/10.1016/j.quaint.2013.12.032.

Padmalal, D., Kumaran, K.P.N., Nair, K.M., Baijulal, B., Limaye, R.B., Mohan, S.V., 2011. Evolution of the coastal wetland systems of SW India during the Holocene: evidence from marine and terrestrial archives of Kollam coast, Kerala. *Quaternary Int* 237(1-2), 123–139. https://doi.org/10.1016/j.quaint.2010.12.021.

Pejrup, M., 1988. *The triangular diagram used for classification of estuarine sediments: a new approach. Tide-influenced Sedimentary Evironments and Facies.* Reidel, Dordrecht.

Thrivikramji, K.P., Joseph, S., Narayana, A.C., 2007. Coastal wetlands of Kerala: origin and evolution, in: Proc. Kerala Environment Congress, p. 36–48.

Tyson, R.V., 1995. *Sedimentary Organic Matter: Organic Facies and Palynofacies.* Chapman and Hall, London.

