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Palaeoclimatic Studies of the Late Quaternary Sediments from Chirakkara, Kollam District, Kerala, India

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ABSTRACT

The Quaternary period is considered one of the most eventful periods of all geologic periods. The present study intends to understand the paleo-environmental conditions that prevailed in the southern part of the Kerala State, India, during the Late Quaternary period. The present study aims to understand the climatic variability of the Holocene epoch in the Chirakkara region, the easternmost part of Polachira wetland, Kollam district, South Kerala, by using granulometric data and geochemical proxies. A core of 2.5 m in length has been collected from the study area, and both textural and TOC/TN analyses were carried out. The variation in grain size is attributed to the variations in the energy level of the transporting medium and turn to the climatic conditions, especially rainfall. The sediments encountered in the core are dominated by sand-sized particles indicating dynamic high energy conditions and high precipitation events. The ternary plot of the sediment samples also suggests violent environmental conditions during the deposition of the sediments. The predominance of low values of TOC/TN ratio found at both ends of the core indicates an autochthonous source for organic carbon, possibly due to the aggravated aquatic phytoplankton activity, and increased lake bioproduction, and/or decline in the delivery of organic matter from the terrestrial environment. High values of the TOC/TN ratio noted at the middle portion of the core at depths from 120 cm to 210 cm indicate the allochthonous source for the organic carbon. Among allochthonous sources, the C3-type plant is dominant, indicating a cool and wet climate. At the same time, the extremely high TOC/TN values at 170 cm core depth indicate a short period of hot and sunny climatic conditions. The analysis of the granulometric data and organic matter proxies suggest that the study area has experienced wet climatic conditions with occasional dry spells during the Late Quaternary Period.

INTRODUCTION

Understanding the climatic variations of the recent past is highly essential for drawing comprehensive plans for protecting mother Earth. Paleoclimatic evidence preserved in geologic materials gives indirect indications of the past climatic conditions. Different proxies such as sedimentological, micropaleontological, and geochemical imprints are embedded in the Quaternary sediments (Chappell 1974, Fairbanks 1989, Charles et al. 1996, Naidu & Malmgren 1999, Thamban et al. 2001, Pandarinath et al. 2007). Various methods were suggested by many workers for the reconstruction of Quaternary paleoclimatic conditions (Bradley 1999, Mirecki et al. 1995, Slowey et al. 2002, Ishimura et al. 2012). Many studies relate the sea-level changes on the west coast of India to the climatic conditions of the Quaternary Period (Gupta 1972, Nair & Hashimi 1980, Kale & Rajaguru 1985, Baskaran et al. 1989, Somayajulu 1990, Shankar & Karbassi 1992, Hashimi et al. 1995, Pandarinath et al. 1998). The response of the river system along the west coast of India to the climatic changes during the Late Quaternary Period has been studied by Mishra et al. (2003). Padmalal et al. (2012) conducted a study on India's fragile coast with special reference to Late Quaternary environmental dynamics. It is believed that the sea-level fluctuations after the Last Glacial Maximum of the Quaternary Period have resulted in the deposition of sediments along the Kerala coast during the later stage of the Quaternary (Thamban et al. 2001, Pandarinath et al. 2007, Shankar & Karbassi 1992, Hashimi et al. 1995). There were few attempts earlier to study the quaternary sediments found along the coastal belt of Kerala, where the focus was mainly on the sedimentological and textural parameters (Nair 1996, Samsuddin 1986, Rao et al. 2010, Padmalal et al. 2014, Vishnu Mohan 2015). The present study aims to reconstruct the Quaternary climatic conditions of the Kollam region, Kerala State, based on sedimentological and geochemical analysis.

STUDY AREA

A core sample has been collected from the Chirakkara region, the easternmost part of the Polachira wetland, Kollam district, South Kerala. Polachira is a wetland spread over an area of 600 hectares of sprawling land and at an altitude of 5 m above sea level, located in the Kollam District. Polachira wetland is a partially water-logged marshy basin. The wetland encircles the Paravur estuary of the Ithikkara River. It is a unique eco-geo system. As a result of the biodiversity and abundance of fish and mussels within the wetland, Polachira is a favorite destination for migratory birds too.

A core of 2.5 m in length has been collected from the study area at the latitude of 8°8’ 42″N and a longitude of 76°43’ 22.8″ E (Fig. 1). The Study area receives an average of about 2555 mm of rainfall annually. The major source of rainfall is the southwest monsoon from June to September which contributes nearly 55% of the total rainfall of the year. The northeast monsoon season from October to December contributes about 24% and the remaining 21% is received from January to May as pre-monsoon showers. Out of the total 119 rainy days, 70 rainy days occur in the southwest monsoon season.

MATERIALS AND METHODS

The recovered core has been subsampled at every 5 cm and preserved for further laboratory analyses. The textural analysis of sediment samples was conducted by following standard methods such as sieving (Ingram 1971) and pipetting (Galehouse 1971). Total Nitrogen (TN) and Total Organic Carbon (TOC) in the core samples were measured using a CHN analyzer (Elementar Vario EL CUBE).

RESULTS AND DISCUSSION

Grain Size

The grain size depends on the type of environmental setting, transporting agent, length and time during transport, and depositional conditions. Hence, it acquires remarkable usefulness as an environmental proxy (McManus 1988, Stanley-Wood & Lines 1992). The variation in grain size can be attributed to the energy level, the velocity of water, and in turn the climatic conditions, especially rainfall (Pettijohn 1957). Clay size particles indicate lower energy levels and low-intensity rainfall patterns or a calm environment. During high precipitation events, the energy level of the transporting medium increases. As a result, the sediments being deposited will move to the coarser end, such as gravel, sand, etc. (Pettijohn 1957). The details of the downcore variation of the grain size parameters of the present study are summed up in Table1.

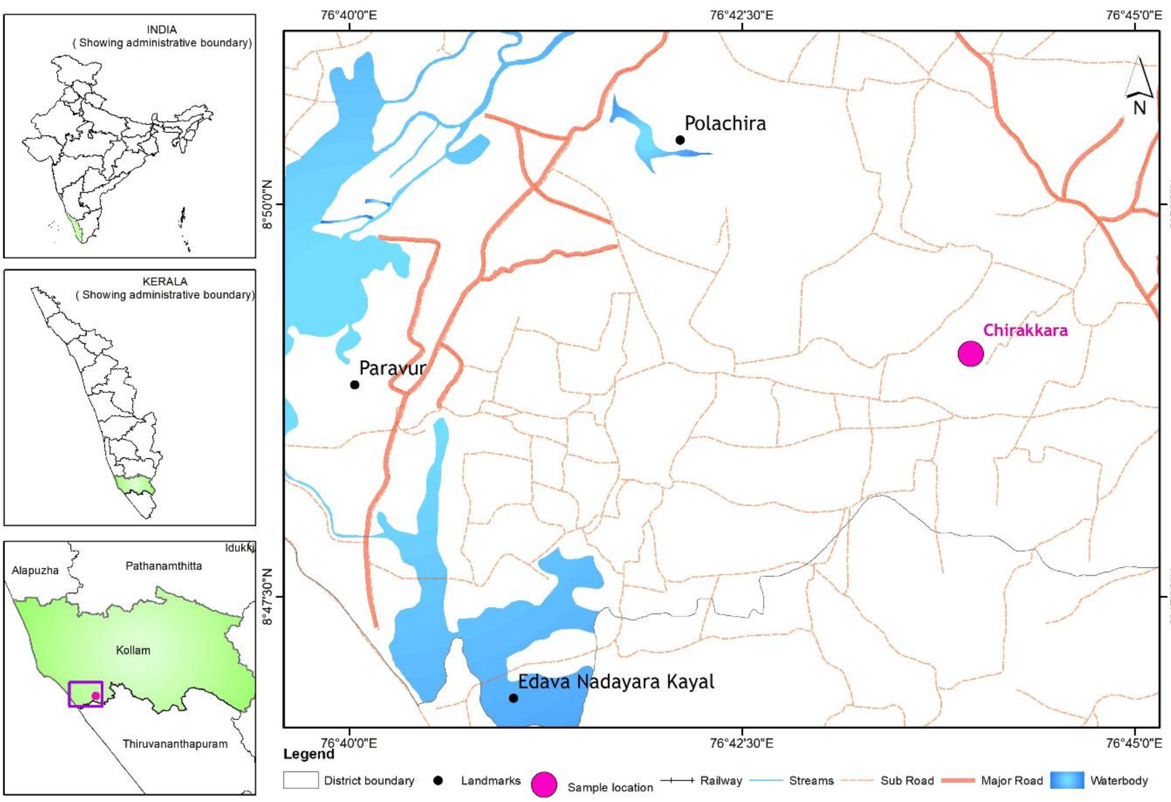

Fig. 1: Map of the study area.

In the present work, the sand content varies from 33.39 % to 91.42 %, and that of silt varies from 7.77% to 64.5%. All samples are characterized by a very low amount of clay particles, i.e., 0.45 % to 2.33 %. Both sand and silt content fluctuate drastically along the core length. The downcore variation of clay also shows an irregular variation (Fig. 2). The higher content of sand-sized particles indicates dynamic high energy conditions and high precipitation events.

The sediment classification scheme proposed by Picard (1971) also clearly reveals the dominance of sandy texture over the entire core length (Fig. 3). The upper portions of the core, up to a depth of 200cm are characterized by the alternative occurrence of sandy silt and silty sand sediments. The lower portions are dominated by sand-sized sediments. The sediment type sandy mud is present at a depth of 63 cm only.

The demarcation of diverse environments from granulometric studies can be done because particle distribution is tremendously reactive to the environment of deposition (Mason & Folk 1958, Friedman 1961, 1967, Griffiths 1962, Stapor & Tanner 1975, Nordstrom 1977, Goldberg 1980, Sly et al. 1982, Seralathan 1988, Padmalal 1992, Badarudeen 1997, Mohan 2000). The sediments that are laid down in different depositional environments, should have peculiar particle size distributions due to their differential erosion, transportation, and deposition (Lario et al. 2002). The hydrodynamic condition of deposition can be understood by using a ternary diagram proposed by Pejrup (1988) which mostly characterizes an aggregated fine fraction and a non-aggregated coarse fraction. The ternary diagram put forth by Pejrup (1988) has been applied in the core samples collected from Chirakkara to decipher the hydrodynamic dynamic condition of deposition that existed at that time. All samples fall in category IV of the ternary diagram (Fig. 4) indicating the dominance of violent environmental conditions during the deposition of the sediments.

Total Nitrogen and Total Organic Carbon Percentage

Total organic carbon (TOC) and total nitrogen (TN) values of sediments can be used to unravel the palaeo-climatic conditions, since their ratios (TOC/TN) can differentiate marine and terrestrial sources of organic matter, the environment of deposition, etc. Total organic carbon and total nitrogen

Table 1: Down core variation of grain size parameters of the core samples.

Sample Number	Depth [cm]	Sand [%]	Clay [%]	Silt [%]	Sediment Type by Picard (1971)	Depositional environment after Pejrup (1988)
CK 1	53	42.34	2.33	55.33	Sandy silt	IV
CK 3	63	50.18	0.97	48.85	Sandy mud	IV
CK 5	73	74.82	0.48	24.7	Sand	IV
CK 6	78	80.61	0.55	18.84	Sand	IV
CK 7	83	78.04	0.45	21.51	Sand	IV
CK 9	90	62.52	1.92	35.56	Silty sand	IV
CK 11	100	68.17	0.57	31.26	Silty sand	IV
CK 13	110	62.67	0.73	36.6	Silty sand	IV
CK 15	120	54.76	0.84	44.4	Silty sand	IV
CK 17	130	36.05	1.30	62.65	Sandy silt	IV
CK 18	135	42.22	1.47	56.31	Sandy silt	IV
CK 19	140	45.55	1.40	53.05	Sandy silt	IV
CK 20	145	56.15	1.39	42.46	Silty sand	IV
CK 23	160	38.89	1.37	59.74	Sandy silt	IV
CK 25	170	33.39	2.11	64.5	Sandy silt	IV
CK 31	200	72.53	1.16	26.31	Silty sand	IV
CK 33	210	79.37	0.77	19.86	Sand	IV
CK 35	220	88.43	0.58	10.99	Sand	IV
CK 36	225	91.42	0.81	7.77	Sand	IV
CK 39	240	89.79	0.60	9.61	Sand	IV
CK 41	250	87.79	0.57	11.64	Sand	IV

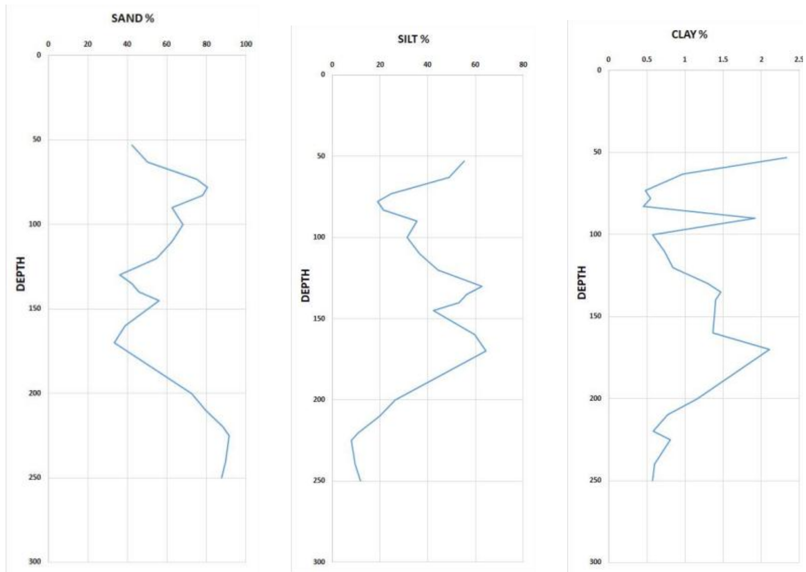

Fig. 2: Down core variation of sand, silt, and clay particles of the study area.

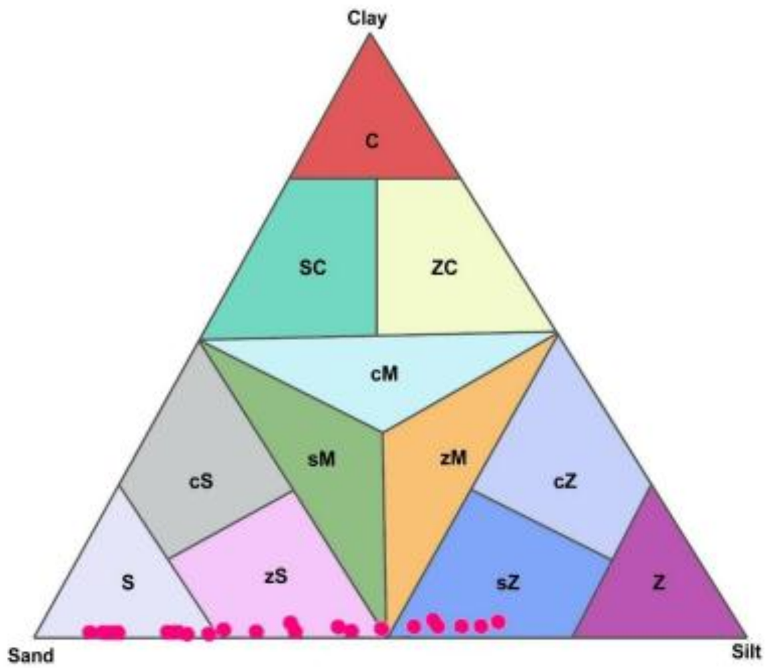

Fig. 3: Sediment type derived from Picard (1971).

content ratios have been used widely as biomarkers for the reconstruction of the depositional environments and to trace the environmental changes of the past (Dean 1999,1974, Avramidis et al. 2013, 2014, Badejo et al. 2014, Aasif Lone et al. 2018). Organic matter deposited in lakes has two principal sources: aquatic phytoplankton living in the lake (autochthonous) and terrestrial plants growing in the catchment (allochthonous) (Meyers 1990). Aquatic phytoplankton contains relatively abundant proteins that are rich in organic nitrogen, and therefore the autochthonous organic matter is characterized by low TOC/TN ratios, between 4 and 10 (Meyers 1990). Terrestrial vascular plants are dominated by lignin and cellulose that are poor in nitrogen, and thus allochthonous organic matter has high TOC/TN ratios of 20

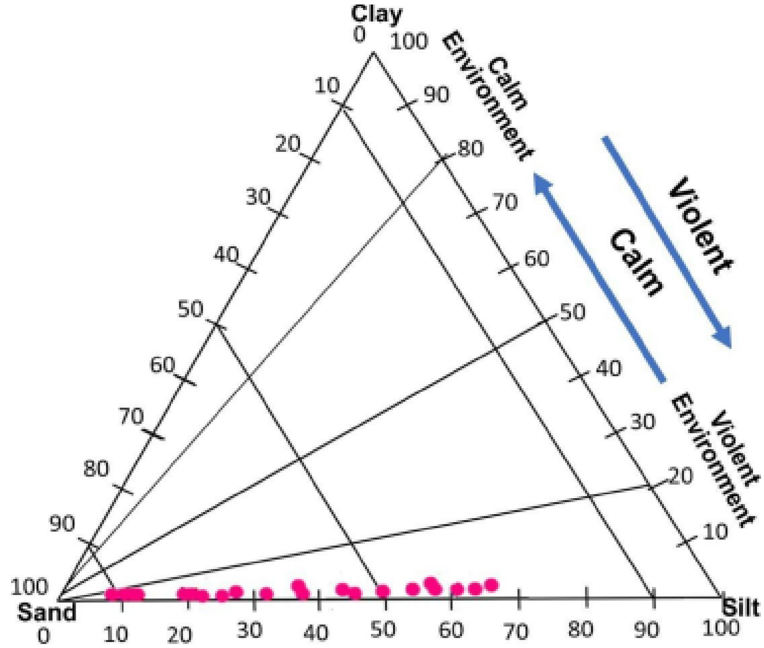

Fig. 4: Ternary plot of Pejrup (1988) showing the depositional environment.

and greater (Meyers 1990). Among the terrestrial plants' C3 vascular plants, which indicate cool & wet environments, has TOC/TN ratios around 12 and over (Tyson 1995), whereas, terrestrial C4 grasses, which indicate hot & sunny environment typically have TOC/TC ratios above 30 (Meyers 1994). In the present study, the TN values range from 0.05 to 0.40%, and that of the TOC ranges from 0.44 to 9.14%. The TOC/TN values range from 5.461 to 30.466% (Table 2).

The downcore variation pattern of both TOC and TN shows an irregular behavior, and that of TOC/TN shows a peak at the middle portion of the core (Fig 5). The upper and lower portion of the core is characterized by extremely low values of TOC/TN ratio, which indicates an autochthonous source for organic carbon, possibly due to aquatic phytoplankton activity and decline in the delivery of organic matter from the terrestrial environment and increased lake bioproduction. High values of the TOC/TN ratio present at the middle portion of the core depths, ie., from 120 cm to 210 cm indicate the allochthonous source for the organic carbon. Among allochthonous source, the C3 type plant dominate which indicates a cool and wet climate, whereas, the extreme high TOC/TN values at 170 cm core depth indicate hot and sunny climatic conditions. The extreme high ratios at these depths also indicate intense fluvial activity which may be due to neo-tectonic activities or due to high precipitation events, as indicated by the granulometric analysis. On the west coast of India, the climate was arid around 11 kyrs BP (Hashimi & Nair 1986, Sarkar et al. 1990) and changed to

Table 2: Down core variation of TOC, TN, and TOC/TN.

Sample-Number	Core depth[cm]	TOC[%]	TN[%]	TOC/TN
CK 1	53	4.08	0.40	10.2
CK 3	63	1.57	0.20	7.85
CK 5	73	0.60	0.14	4.286
CK 6	78	0.69	0.12	5.75
CK 7	83	0.44	0.08	5.5
CK 9	90	0.49	0.05	9.8
CK 11	100	0.65	0.10	6.5
CK 13	110	0.52	0.08	6.5
CK 15	120	0.64	0.05	12.8
CK 17	130	2.37	0.16	14.812
CK 18	135	4.29	0.20	21.45
CK 19	140	1.98	0.16	12.375
CK 20	145	0.91	0.14	6.5
CK 23	160	2.78	0.24	11.583
CK 25	170	9.14	0.30	30.466
CK 31	200	6.61	0.26	25.423
CK 33	210	2.48	0.17	14.588
CK 35	220	0.80	0.13	6.154
CK 36	230	0.71	0.13	5.461
CK 39	240	1.0	0.13	7.692
CK 41	250	1.09	0.13	8.385

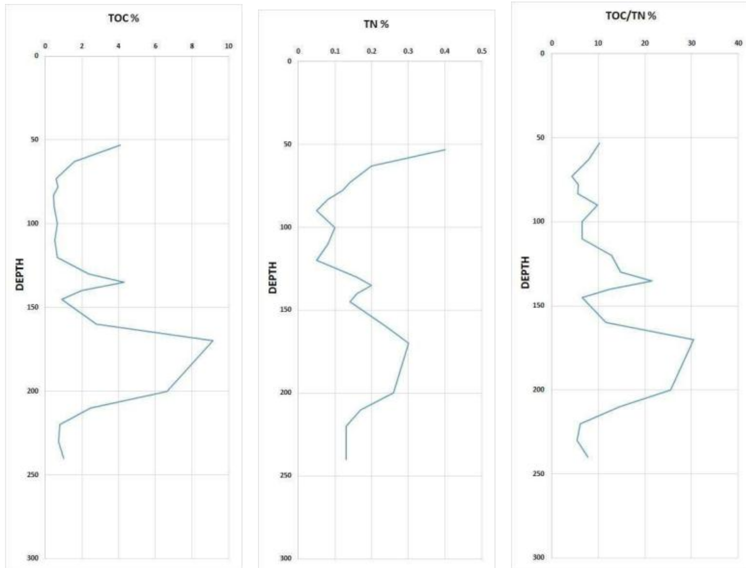

Fig. 5: Downcore variation of TOC, TN, and TOC/TN values.

warm and humid around 10 kyrs BP. Thereafter, the monsoon showers got intensified and remained so up to 7 kyrs BP (Nair & Hashimi 1980).

CONCLUSION

The sediment analysis of the core sample recovered from the Polachira wetland at Kollam district, Kerala State, India, reveals that the study area had witnessed high precipitation conditions with occasional dry or hot and sunny climatic conditions in the recent past. The highly fluctuating as well as the higher content of sand-size particles indicates intermittent high energy conditions and high precipitation events. The ternary plot (Pejrup 1988) indicates violent environmental conditions during the deposition of these sediments. The upper and lower portions of the core are characterized by extremely low values of TOC/TN ratio, indicating an autochthonous source for organic carbon, possibly due to aquatic phytoplankton activity (Meyers 1990). It further indicates a state of limited delivery of organic matter from the terrestrial environment and increased lake bioproduction. High values of the TOC/TN ratio present at the middle portion of the core depths from 120 cm to 210 cm indicate the allochthonous source for the organic carbon. Among the allochthonous sources, the C3 type plant dominates indicating a cool and wet climate (Tyson 1995). The extremely high TOC/TN values noted at 170 cm core depth indicate hot and sunny climatic conditions. The granulometric analysis and the TOC/TN ratio values of the sediments suggest a state of overall cool and wet climatic conditions with occasional dry or hot and sunny environmental conditions during the later Quaternary period.

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REFERENCES

Avramidis, P., Geraga, M., Lazarova, M. and Kontopoulos, N. 2013, Holocene record of environmental changes and palaeoclimatic implications in Alykes Lagoon, Zakynthos Island, western Greece, Mediterranean Sea. Quaternary International, 293: 184-195.

Avramidis, P., Iliopoulos, G., Panagiotaras, D., Papoulis, D., Lambropoulou, P., Kontopoulos, N. and Christanis, K. 2014. Tracking Mid-to Late Holocene depositional environments by applying sedimentological, palaeontological and geochemical proxies, Amvrakikos coastal lagoon sediments, Western Greece, Mediterranean Sea. Quaternary International, 332: 19-36.

Badarudeen, A. and Sajan, K. 1997. Sedimentology And Geochemistiiy of Some Selected Mangrove Ecosystems of Kerala, Southwest Coast of India (Doctoral dissertation, Cochin University of Science And Technology).

Badejo, A.O., Choi, B.H., Cho, H.G., Yi, H.I. and Shin, K.H. 2014. Paleoenvironmental reconstruction of the last 15,000 cal yr BP via Yellow Sea sediments using biomarkers and isotopic composition of organic matter. Clim. Past Discuss. 10: 1527-1565.

Baskaran, M. and Chakrabarti, A. 1989. Biogenic faecal pellet mounds in Quaternary miliolites of Saurashtra, India. Palaeogeography, Paleoclimatology, Paleoecology, 73(3-4): 311-315.

Bradley, R.S. 1999. Paleoclimatology: Reconstructing Climates of the Quaternary, Academic Press, San Diego.

Chappell, J. 1974. Geology of coral terraces, Huon Peninsula, New Guinea: a study of Quaternary tectonic movements and sea-level changes. Geological Society of America Bulletin, 85: 553-570.

Dean, W. E. 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition; comparison with other methods. Journal of Sedimentary Research, 44(1): 242-248.

Dean, W. E. 1999. The carbon cycle and biogeochemical dynamics in lake sediments. Journal of Paleolimnology, 21(4): 375-393.

Fairbanks, R. G. 1989. A 17,000 year glacio-eustatic sea level record: Influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. Nature, 342: 637-642.

Friedman, G. M. 1967. Dynamic processes and statistical parameters compared for size frequency distribution of beach and river sands. Journal of Sedimentary Research, 37(2): 327-354.

Galehouse, J. S. 1971. Sedimentation analysis. Procedures in Sedimentary Petrology, 69-94.

Griffiths, D. H., King, R. F. and Rees, A. I. 1962. The relevance of magnetic measurements on some fine grained silts to the study of their depositional process. Sedimentology, 1(2): 134-144.

Gupta, S. K. 1972. Chronology of the raised beaches and inland coral reefs of the Saurashtra coast. The Journal of Geology, 80(3): 357-361.

Hashimi, N. H. and Nair, R. R. 1986. Climatic aridity over India 11,000 years ago: Evidence from feldspar distribution in shelf sediments. Palaeogeography, Palaeoclimatology, Palaeoecology, 53: 305-319.

Hashimi, N.H., Nigam, R., Nair, R.R. and Rajagopalan, G. 1995. Holocene sea-level fluctuations on western Indian Continental margin: An update. J. Geol. Soc. India, 46: 157-162.

Ingram, F. S. 1971. Sieve analysis. In: Procedures in Sedimentary Petrology, ed. R. E. Carver, pp. 49-68. Wiley/Interscience, New York.

Ishimura, T., Tsunogai, U., Hasegawa, S., Nakagawa, F., Oi, T., Kitazato, H. and Toyofuku, T. 2012. Variation in stable carbon and oxygen isotopes of individual benthic foraminifera: tracers for quantifying the vital effect. Biogeosciences Discussions, 9(5).

Kale, V.S. and Rajaguru, S.N. 1985. Neogene and Quaternary transgressional and regressional history of the west coast of India- An overview. Bull. Deccan College Res. Inst., 44: 153-165.

Lario, J., Spencer, C., Plater, A. J., Zazo, C., Goy, J. L. and Dabrio, C. J. 2002. Particle size characterisation of Holocene back-barrier sequences from North Atlantic coasts (SW Spain and SE England). Geomorphology, 42(1-2): 25-42.

Lone, A. M., Shah, R. A., Achyuthan, H. and Fousiya, A. A. 2018. Geochemistry, spatial distribution and environmental risk assessment of the surface sediments: Anchar Lake, Kashmir Valley, India. Environmental earth sciences, 77(3): 1-20.

Mason, C. C. and Folk, R. L. 1958. Differentiation of beach, dune, and aeolian flat environments by size analysis, Mustang Island, Texas. Journal of Sedimentary Research, 28(2): 211-226.

Meyers, P.A. and Ishiwatari, R. 1993. Lacustrine organic geochemistry- An overview of indicators of OM sources and diagenesis in lake sediments. Org. Geochem., 7: 867-900.

Meyers, P.A. 1994. Preservation of elemental and isotopic source identification of sedimentary organic matter. Chem. Geol., 114: 289-302.

McManus, J. 1988. Grain size determination and interpretation. Techniques in sedimentology, 63-85.

Mirecki, J. E., Wehmiller, J. F. and Skinner, A. F. 1995. Geochronology of Quaternary coastal plain deposits, southeastern Virginia, USA. Journal of Coastal Research, 1135-1144.

Naidu, P. D. and Malmgren, B. A. 1999. Quaternary carbonate record from the equatorial Indian Ocean and its relationship with productivity changes. Marine Geology, 161(1): 49-62.

Nair, K. K. 1996. Geomorphology and evolution of the coastal plain of Kerala. Geological survey of India, Special Publication, (40): 83-94.

Nair, R. R. and Hashimi, N. H. 1980. Holocene climatic inference from the sediments of the western continental shelf. Proceedings of Indian Academy of Sciences, 89: 299-315.

Nordstrom, K. F. 1977. The use of grain size statistics to distinguish between high-and moderate-energy beach environments. Journal of Sedimentary Research, 47(3): 1287-1294.

Padmalal, D. 1992. Mineralogy and geochemistry of the sediments of Muvattupuzha river and central Vembanad estuary, Kerala, India. PhD thesis, Cochin University of Science and Technology, Kochi, pp. 122.

Padmalal, D., Kumaran, K. P. N., Nair, K. M., Ruta B. Limaye, Vishnu Mohan, S., Baijulal, B. and Anooja S. 2014. Consequences of sea level and climate changes on the morphodynamics of a tropical coastal lagoon during Holocene: An evolutionary model. Quaternary International, 333: 156-172.

Pandarinath, K., Narayana, A. C. and Yadava, M. G. 1998. Radiocarbon dated sedimentation record up to 2 ka BP on the inner continental shelf off Mangalore, south-west coast of India. Current Science, 730-732.

Pandarinath, K., Subramanya, K. R., Yadava, M. G. and Verma, S. P. 2007. Late Quaternary sedimentation records on the continental slope of SW coast of India - Implication for provenance, depositional and palaeomonsoonal conditions. Journal of Geological Society of India, 69: 1285-1292.

Picard, M. D. 1971. Classification of fine-grained sedimentary rocks. Journal of Sedimentary Research, 41(1): 179-195.

Pejrup, M. 1988. The triangular diagram used for classification of estuarine sediments: a new approach. Tide-influenced sedimentary environments and facies. Reidel, Dordrecht, pp. 289-300.

Pettijohn, F. J. 1957. Paleocurrents of Lake Superior Precambrian quartzite. Geological Society of America Bulletin, 68(4): 469-480.

Samsuddin, M. 1986. Textural differentiation of the foreshore and breaker zone sediments on the northern Kerala coast, India. Sedimentary Geology, 46: 135-145.

Sarkar, A., Ramesh, R., Bhattacharyya, S. K. and Rajagopalan, G. 1990. Oxygen Isotope evidence for a stronger winter monsoon current during the last glaciation. Nature, 343: 549-551.

Seralathan, P and Shajan, K. P. 1998. Studies on late quaternary sediments and sea level changes of the Central Kerala coast, India (Doctoral dissertation, Marine Geology and Geophysics, School of Marine Sciences).

Shankar, R. and Karbassi, A. R. 1992. Sedimentological evidence for a palaeobeach off Mangalore, west coast of India. Journal-Geological Society of India, 40: 241-241.

Slowey, N. C., Wilber, R. J., Haddad, G. A. and Henderson, G. M. 2002. Glacial-to-Holocene sedimentation on the western slope of Great Bahama Bank. Marine Geology, 185(1-2): 165-176.

Sly, P. G., Thomas, R. L. and Pelletier, B. R. 1982. Comparison of sediment energy-texture relationships in marine and lacustrine environments. Hydrobiologia, 91(1): 71-84.

Stanley-Wood, N. G. and Lines, R. W. (Eds.). 2007. Particle Size Analysis. Royal Society of Chemistry.

Stapor, F. W. and Tanner, W. F. 1975. Hydrodynamic implications of beach, beach ridge and dune grain size studies. Journal of Sedimentary Research, 45(4): 926-931.

Thamban, M., Rao, V. P., Schneider, R. R. and Grootes, P. M. 2001. Glacial to Holocene fluctuations in hydrography and productivity along the southwestern continental margin of India. Palaeogeography, Palaeoclimatology, Palaeoecology, 165: 113-127.

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