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USE OF ^{210}Pb DATING TO IDENTIFY RECENT SEDIMENTATION IN MUTHUPET LAGOON, PALK STRAIT, SOUTH EAST COAST OF INDIA

Muthumanickam JAYAPRAKASH[1*], Veeramalai GOPAL[1], Loganathan GIRIDHARAN[2], Puliyankurichi Mookan VELMURUGAN[3], Linto ALLAPATT[4] & Manfred FRECHEN[4]

[1]Department of Applied Geology, University of Madras, Chennai 600 025, India, e-mail: veegopaal@gmail.com
[2] Department of Geology and Mining, Chennai 600 032, India
[3]Centre for Earth and Atmospheric Science, Sathyabama University, Chennai 600 119, India
[4]Leibniz Institute for Applied Geophysics (LIAG), Stilleweg 2, 30655 Hannover, Germany

Abstract: The sediment accumulation rates and geochronology of the lagoon sediments were studied from Muthupet, SECI. Accumulation rate was determined by applying a constant rate of supply model (CRS) to the measured $^{210}Pb_{excess}$ profile. The main objective of this study is to evaluate the age and rate of accumulation of sediments using short-lived radionuclides. Core sampling was carried out at two sites Core 1 and 2 where the samples were taken upto 150 and 175 cm depth respectively, at an interval of 2.5 cm. The age and sedimentation rate of the cores (C1 and C2) were estimated using the depth distribution of radionuclides ^{137}Cs, ^{210}Pb and ^{228}Ra determined by high resolution gamma spectrometry on frozen dry samples. The ^{210}Pb activity profile in C1 and C2 has a maximum value in few layers beneath the surface sediment. Bottom sediments of C1 (77.5-80 cm) and C2 (117.5-120 cm) depth were dated as the years of 1881 and 1880 respectively. There are two distinct correlations/variations between depth and sediment dates in C1 and C2 from top to the bottom. C1 shows a deflection at peak around 30 cm depth whilst C2 shows maxima at 100 cm depth. Both the cores demonstrate higher values near the surface and tail down to the bottom of the cores.

Key words: ^{210}Pb, CRS Mode, Age of Sedimentation, Rate of Sedimentation, Lagoon Sediments

1. INTRODUCTION

Tracking the history of natural events is essential due to global environmental change; it is clear that in many places the period of ultimate impact and most histrionic alteration lies within the last 150 years (Oldfield & Appleby, 1984; Appleby & Oldfield, 1992; Appleby, 1997, 2008). Many aspects of this impact can be reconstructed by sediments in coastal areas, which can be regarded as good archives of environmental processes and their effects, for environmental evolution can be recorded well in a relatively stable sedimentary environment (Oldfield, 1977). Therefore, the study of core sediments in coastal areas has excessive prominence to the understanding of the interface between human activities and natural marine systems. In addition, the instituting of a comprehensive and precise sequence of events for core sediments, in other words, the estimation of sedimentation rate, is of significant importance to develop a scale of insight into environmental processes. Over the past few decades, dating of lake sediments using unsupported ^{210}Pb activity profiles has become a standard technique for the determination of a recent (100-150 years) sedimentary geochronologies and this method can provide valuable information on sediment mixing and sediment accumulation rates (Baskaran & Naidu, 1995; O'Reilly et al., 2011). Determination of sediment accumulation rates is important for understanding of geochemical processes in surface sediments, especially the origin of particulate matter and estimating the flux of organic carbon to the bottom sediments (Turner & Delrome, 1996).

Within this view, the goal of the research is to separate out the natural changes that have occurred in the system from the anthropogenically induced changes. Accurate age models are essential to attribute biotic change observed in sediment cores to specific environmental or climatic causes and to evaluate the influences of natural vs. anthropogenic factors on critical ecosystems. This method has been adopted and functional in several case studies around in the world (Gharibreza et al., 2013; Alhajji et al., 2013; Jose & Gregg, 2014). The aim of this study is to use a constant rate supply (CRS) model in determining the age and sediment accumulation rates with time and depth. The sediment cores from Muthupet Lagoon were used to discuss in detail for the applicability of this model in the determination of age and rate of sedimentation.

2. ENVIRONMENTAL SATUS OF THE STUDY AREA

Muthupet lagoon is located at 10°20’N and 79°32’E of South India, covering an area of 68.03 sq. km, which is mainly covered by creeks (Krithika et al., 2008). The rivers which contribute to these mangroves are highly seasonal and freshwater input into the system is directly dependent on rainfall. Muthupet lagoon, situated at the southernmost end of the Cauvery delta in Palk Strait, is part of the Muthupet mangroves and is connected to the Bay of Bengal in the north and the Gulf of Mannar and the Indian Ocean in the south (Fig. 1).

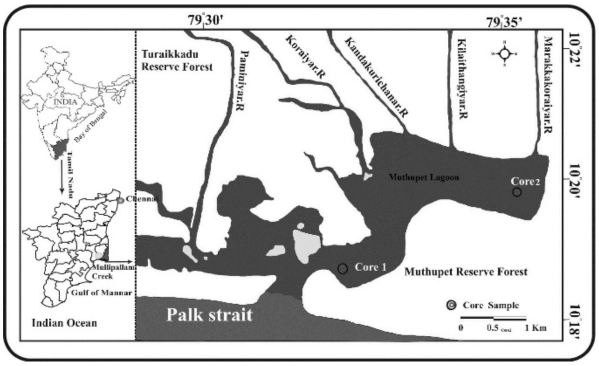

Figure1. Location map of the study area

Certain areas in Muthupet lagoon and mud flats on its northern flank are prone to floods during the monsoon season. The Muthupet wetland system is fed by minor rivers Paminiyar, Koraiyar, Kandanku-richanar, Kilaithuangiyar and Marakkakoraiyar, and these rivers form a part of the tributaries of River Cauvery (Ramachandran et al., 1998). In this lagoon, 10% of the area is covered by thick forest and 20% of the wetland is submerged under water and the tidal amplitude varies from 0.4 to 1 m (Selvam, 2003). Freshwater input into Muthupet lagoon is limited to the northeast monsoon period and the lagoon is very shallow in many places, except at its mouth; it rarely exceeds 7 m (Rao et al., 2013).

Tidal creeks connecting the mangroves are limited, and the pathways for water and material exchange are well defined in Muthupet lagoon. The dominant species in the Muthupet mangrove wetland are Avicennia marina (95%) and the rest are Acanthus ilicifolius, Aegiceras corniculatum, Excoecaria agallocha and Rhizopora mucronta (Selvam, 2003).

3. METHODOLOGY

The present study was carried out on sediment core samples (C1 and C2) collected during April 2009. The site was selected as it is an area adjoining the draining sites for minor rivers. Fresh water flow is observed here during the monsoon periods and there is a tidal influence of the adjacent coastal region. PVC coring tube (6.3 cm inner diameter and 2.5 m length) pre-cleaned with acid was used for the collection of samples. The overall lengths of the cores (C1 and C2) obtained were 150 and 175 cm, respectively, and sub-samples were made at 2.5 cm intervals. The radiometrical data presented in this study have not been corrected for compaction, as it is likely to be uniform along the length of the core (eg. Clark et al., 1998). Textural analysis (sand, silt and clay) distribution was performed using the procedure of Ingram 1970.

The sedimentation rates for the cores (C1 and C2) were estimated by using the depth distribution of radionuclides ^{137}Cs, ^{210}Pb and ^{228}Ra determined by gamma spectrometry on frozen dry samples. ^{137}Cs in the atmosphere derives from nuclear bomb tests that were started in 1954. The released ^{137}Cs activity peaked in 1963. The natural radionuclide ^{210}Pb has a half-life of 22.3 y and thus allows dating of sediments to an age of about 100-150 y. It requires the distinction between supported ^{210}Pb produced in situ by decay of ^{226}Ra, measured via gamma emissions of ^{214}Pb, and unsupported $^{210}Pb_{excess}$ and ^{214}Pb (Dukat & Kuehl, 1995).

Analysis for radioisotopes (^{210}Pb, ^{214}Pb, and ^{137}Cs) was made by direct gamma spectroscopy using a low background gamma spectrometer (Ametek ORTEC and Canberra Eurisys) with a high-purity germanium (HPGe) well-detector having lower detection limits for ^{210}Pb, ^{137}Cs and ^{226}Ra measurements. The radiometric dating was carried out in the Leibniz Institute of Applied Geophysics, Hannover, Germany. High-Purity Germanium detector is a semiconductor particle detector. HPGe detectors have high energy resolution so they are used where we need to identify gammas of energy near to each other (differing by say 1.5 KeV). These detectors behave differently for different energy gamma-rays and they are most efficient in a particular energy range only. Germanium detectors are semiconductor diodes having a p-i-n structure in which the intrinsic (i) region is sensitive to ionizing radiation, particularly X-rays and Gamma rays. These detectors directly collect the charges produced when the semiconductor material is ionized by the ionizing radiations.

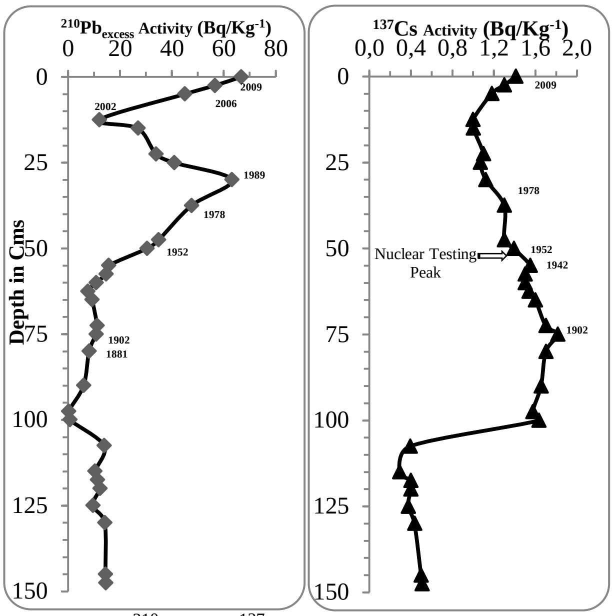

Figure 2. ^{210}Pb and ^{137}Cs activity curve for the core 1, Muthupet Lagoon

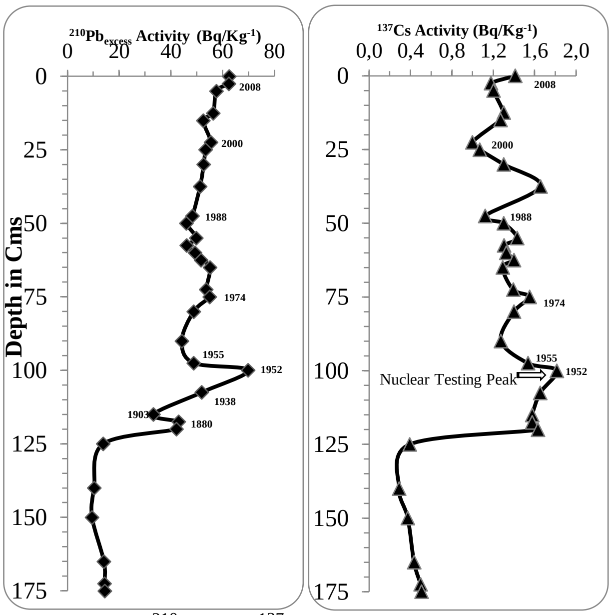

Figure 3. ^{210}Pb and ^{137}Cs activity curve for core 2, Muthupet Lagoon

High Purity Germanium (HPGe) is the only radiation detection technology that provides sufficient information to accurately and reliably identify radionuclides from their passive gamma ray emissions. HPGe detectors have a 20-30 times improvement in resolution as compared to that of Sodium Iodide (NaI) detectors. The major characteristics of the HPGe detector are high atomic number, low impurity concentration (large depletion depth), low ionizing energy required to produce an electron-hole pair, high conductivity, compact size, first time response, high resolution and relative simplicity of operation. HPGe Detector with Lead Shield is used to measure the specific gamma radiation of radionuclides from various types of samples. Shielding minimizes the background radiation which enables better identification of the peaks in acquired spectrum by reducing Compton continuum. Shielding improves the sensitivity of the detector.

Measurement of ^{210}Pb is an established method for the dating of recent (up to 120 years old) nearshore sediments of relatively high sediment accumulation rate. The accuracy of the radiometric procedure was evaluated in an independent experiment by checking the activity of determining radionuclide ^{210}Pb in two standard reference materials produced by the International Atomic Energy Agency: IAEA-368 and IAEA 300 marine sediments. The obtained activity concentrations for certified radionuclide ^{210}Pb were close to the reported values with deviations of < 5 %. The method is based on the measurement of ‘excess’ ^{210}Pb activity which is incorporated into the accumulating sediment from atmospheric fallout. The total ^{210}Pb activity in the accumulating sediment is the sum of this excess activity and the supported ^{210}Pb (caused by decay of ^{238}U series radionuclides in the sediment itself). A full description of the dating method has been given by Appleby & Oldfield (1992). $^{210}Pb_{excess}$ activity profiles for the two cores are shown in Fig. 2 and 3”. Sedimentation rates were determined according to the CRS model of ^{210}Pb dating (Appleby & Oldfield, 1992). Changes in the slope of the profile may have caused by the varying accumulation rate or sediment source, or bioturbation and physical mixing.

4. RESULTS AND DISCUSSION

4.1. Sediment Features

The collected core sediments are generally greyish homogeneous clay or silty clay indicating a low energy environment. In core 1, at the depth of 120 to 125 cm, thick layers of shell materials are observed, which indicate it is derived from a high energy environment. In the case of core 2, this layer is observed at the depth of 80 to 85 cm. Changes in the slope of the profile may be caused by the varying accumulation rate or sediment source, or bioturbation and physical mixing. Slope depends upon the grain size and wave energy which are themselves interdependent. Major factors governing the slope includes wave height, wave period/length and grain size of the particles. Physical mixing and circulation occurs in estuarine environments. Mixing and circulation types include stratified, partially mixed, and well mixed. Various conditions of sedimentation occur when river flow and tide strength varies. At the interface between the fresh- and saltwater layers, shear forces allow variable mixing between the two depending upon the conditions. One of the significant outcome of the mixing is the sedimentation and slope formation. According to Håkanson & Jansson (2002) the accumulation of sediments occurs without disturbances in area of the bottom with slopes less than 4°, whereas sediment focusing with varied intensity occurs in the range 4°-14°. In the case of slopes greater than 14° accumulation practically does not occur.

4.2. Temporal variation in sedimentation rates Derived from ^{210}Pb method

The results obtained from the calculation using a CRS model for the ages and accumulation rates in C1 and C2 are tabulated in Table 1 and Table 2 respectively. Sediment accumulation rates of core 1 obtained is shown in Table 1 and range from 0.37 to 10.57 mm year^{-1}. The sedimentation rate has experienced an increase with time, from the minimum value 120 years ago to the maximum value at the present time. Downcore diagram of sedimentation rate illustrates a sudden accretion at the depth of 12.5 cm. The CRS model of age determination shows that the depth corresponds to the year 2002/4, which clearly indicates the occurrence of tsunami on the coastal zone of Tamil Nadu during this period (Srinivasalu et al., 2006). In the case of core 2, the change in the rate of sedimentation up to 30 cm from the surface is not significant, but observed to be high in the range of 4.88 to 6.11 mm year^{-1}, with a mean of 5.59 mm year^{-1}. Below 30 cm in the core, a steady decrease in the rate of sedimentation has been observed (Fig. 4). The high rate of recent sedimentation may be attributed to the rainfall, fast urbanization in the catchment area, including land use changes such as construction activities that would induce the increase of sediment discharge (Siakeu et al., 2004; Pérez et al., 2010). Variation in the rate of sedimentation may be due to the difference in slope between the cores and the competition between erosional and sedimentation activities. Moreover, distribution and sedimentary processes in a lagoon depend on the water-inflow velocity, gravitational forces and other factors such as bottom slope (Sly, 1978).

Apparently, the accumulation rates in core 2 are twice as that of core 1, since core 2 was collected from near onshore in the lagoon, whereas core 1 was taken from near offshore (deep water of the lagoon, near the bay). There will be a strong dependence on the contributions of the river basin in times of spates, being the area of greatest sedimentation rate in the bay due to the fluvial confluence and tidal regime.

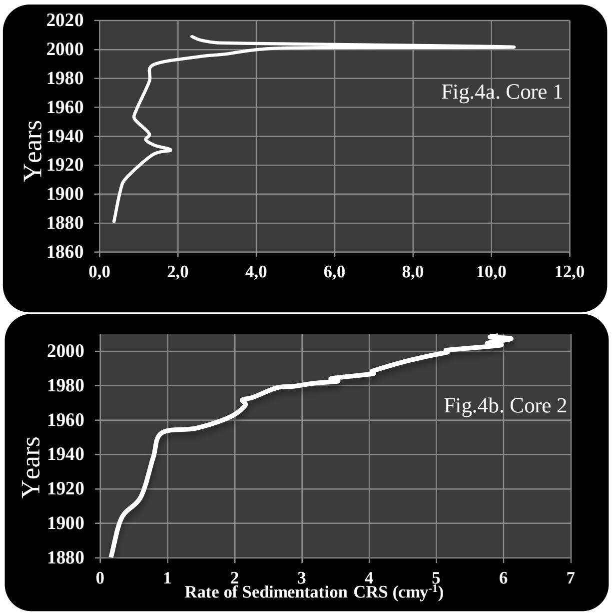

Figure 4 a & b. Sediment Accumulation rate for core 1 & 2 Muthupet Lagoon

As shown in figures 3 and 4, the profiles of excess ^{210}Pb generally show a non-linear and non-monotonic decrease with depth. Meanwhile, depressed activities of excess ^{210}Pb can be found in the upper layers of both cores. Provided the depressed near-surface activities are caused by the mixing effect, the suspected mixing thickness does not exceed 15% of the total thickness of the excess ^{210}Pb profile. As demonstrated by Appleby & Oldfield (1978), the depressed near-surface activities may be associated with accelerated sedimentation rate. Therefore, the mixing effect is not taken into account in this work.

The supported ^{210}Pb of C1 and C2 shows significant variations with depth. Exponential decrease in the downcore profiles was not observed in both the cores; as a result, the sedimentation rates are not constant with time.

Table 1. Determination of age and rate of sedimentation using constant rate of supply model (CRS) in core 1

S.No	Depth in Cms (x)	Activity (Bq/kg)			$^{210}Pb_{excess}$	uncertainty	Age CRS	AGE	Rate of Sedimentation CRS (Cmy^{-1})
		^{210}Pb	^{214}Pb	^{137}Cs	C	^{210}Pb		year	
1	0	80.92	14.27	1.41	66.66	3.193	0.4	2009	2.35
2	2.5	70.77	14.22	1.3	56.55	3.149	2.6	2006	2.6
3	5	59.27	14.34	1.18	44.94	3.307	4.4	2005	3.09
4	12.5	25.52	13.52	1	12	3.105	7.3	2002	10.57
5	15	40.34	13.44	1	26.91	3.730	8	2001	4.6
6	22.5	47.63	13.72	1.1	33.91	3.537	12.1	1997	3.22
7	25	54.23	13.34	1.07	40.89	5.375	14	1995	2.52
8	30	77.38	14.29	1.12	63.1	3.743	19.6	1989	1.37
9	37.5	63.23	15.66	1.3	47.57	4.592	31.2	1978	1.27
10	47.5	49.76	14.85	1.3	34.91	7.811	50.9	1958	0.93
11	50	43.84	13.39	1.39	30.46	2.904	56.8	1952	0.89
12	55	29.22	13.6	1.55	15.62	2.575	67	1942	1.26
13	57.5	27.65	12.98	1.5	14.67	3.535	71.3	1938	1.18
14	60	23.62	12.84	1.5	10.78	2.337	75.3	1934	1.41
15	62.5	20.4	12.79	1.54	7.61	2.221	78.5	1930	1.81
16	65	22.79	13.57	1.6	9.22	2.075	81.8	1927	1.35
17	72.5	24.92	13.73	1.7	11.19	2.712	98.2	1911	0.67
18	75	25.73	14.96	1.81	10.77	3.416	107.1	1902	0.53
19	80	22.5	14.4	1.7	8.1	2.147	127.9	1881	0.37
20	90	16.4	10.42	1.65	5.99	2.847			

Table 2. Determination of age and rate of sedimentation using constant rate of supply model (CRS) in core 2

S.No	Depth in Cms (x)	Activity (Bq/kg)			$^{210}Pb_{excess}$	uncertainty	Age CRS	AGE	Rate of Sedimentation CRS (cmy^{-1})
		^{210}Pb	^{214}Pb	^{137}Cs	C	^{210}Pb		year	
1	0	76.83	14.26	1.41	62.57	3.221	0.2	2009	5.924
2	2.5	75.01	12.61	1.18	62.4	3.029	0.9	2008	5.804
3	5	70.9	12.8	1.2	57.6	3.589	1.8	2007	6.113
4	12.5	69.2	13.2	1.3	56.3	3.129	4.5	2005	5.758
5	15	66.29	13.75	1.27	52.54	2.912	5.6	2003	5.954
6	22.5	68.9	13.36	1	55.54	2.461	8.5	2000	5.145
7	25	67.69	14.24	1.07	53.45	2.389	9.6	1999	5.168
8	30	65.2	13.8	1.3	52.7	2.643	11.9	1997	4.888
9	37.5	64.73	13.47	1.66	51.27	2.665	15.4	1994	4.502
10	47.5	62	13.73	1.12	48.27	2.221	20.8	1988	4.043
11	50	60.28	14.28	1.3	46	2.314	22.2	1987	4.064
12	55	64.25	14.46	1.43	49.8	1.945	25	1984	3.438
13	57.5	60.63	14.5	1.3	46.13	2.451	26.5	1982	3.537
14	60	62.16	12.79	1.33	49.37	1.863	27.7	1981	3.188
15	62.5	64.8	13.1	1.4	51.7	2.321	29.5	1979	2.876
16	65	68.52	13.36	1.29	55.17	2.541	30.4	1979	2.625
17	72.5	66.9	13.25	1.39	53.65	2.242	35.8	1973	2.275
18	75	68.37	13.42	1.55	54.95	1.845	37.4	1972	2.115
19	80	62.2	13.4	1.4	48.8	1.685	40.6	1968	2.157
20	90	57.73	13.54	1.27	44.2	1.984	47.5	1962	1.922
21	97.5	62.95	14.18	1.54	48.77	2.214	53.8	1955	1.431
22	100	87.7	17.83	1.81	69.88	2.562	56.6	1952	0.916
23	107.5	67.54	15.65	1.65	51.89	3.124	71	1938	0.788
24	115	47.92	14.65	1.58	33.27	2.875	93.8	1915	0.604
25	117.5	56.37	13.31	1.58	43.06	1.954	106	1903	0.319
26	120	55.82	13.73	1.63	42.09	2.456	128.9	1880	0.16
27	125	13.88	14.01	0.39	13.88	2.543			

Due to this circumstance, the sediment age and accumulation rates are determined by the most widely used CRS model Sanchez et al., (1999). The constant initial concentration (CIC) model could not be applied because of the nonexponential form and the behaviour of the ^{210}Pb profile. The excess ^{210}Pb activity profile in C1 and C2 has maximum value in a few layers beneath the surface sediment. Bottom sediments of core 1 (77.5-80 cm depth) and core 2 (117.5-120 cm depth) were dated as the years of 1881 and 1880, respectively. There are two distinct correlations/variations between depth and sediment dates in cores 1 and 2 from top to the bottom. Core 1 shows a deflection, i.e., A peak around 30 cm depth whilst core 2 shows maxima at 100 cm depth. Both the cores demonstrate higher values near the surface and tail down to the bottom of the cores. ^{137}Cs results also correlated well with ^{210}Pb activity results. Downcore profile variation at the depths of 80 and 120 cm in cores 1 and 2, demonstrate the substratum records of the volcanic event that occurred at Krakatoa in Indonesia (Berninghausen, 1966; Rastogi & Jaiswal, 2006). Volcanic activity usually provides coarse clastic sediments in large quantities over short span of time. The coarse clastic sediments is texturally and compositionally immature and the composition may be peculiar and sometimes unique. Due to the eruption of sediments in large quantities, the atmospheric fall out will be high in and around the region. In some cases, due to wind action and high level of jet stream movements in the troposphere, the erupted sediments are carried over a long distance and get deposited.

5. CONCLUSIONS

The study demonstrates the application of radiochronological methods in the determination of age and rate of sedimentation in the Muthupet Lagoon sediment. The present study has confirmed the ability of the ^{210}Pb dating method to provide reliable chronologies in lagoon sediment sequences.

- Of the various models available for the geochronological calculations, it is illustrated that the CRS model is more suitable for the determination of age and accumulation rates of sediment, subsequently this model can determine the accumulation rates which vary with depth as well as time (year).
- It is clear that the CRS model can be used for analyzing the concentration of unsupported ^{210}Pb in sediment cores for determining the age and accumulation rates of sediment.
- The excess ^{210}Pb seems to originate primarily from atmospheric fallout, but a further inventory of the ^{210}Pb distribution over the lake bottom must be made to properly assess the significance of other sources.
- Combining radionuclide dating methods with detailed sedimentological investigations allows sedimentary events to be correlated with well-documented high energy events.
- The sediment accumulation rates using the CRS model for Muthupet Lagoon range from 0.37 to 10.57 mm year^{-1} and from 0.16 to 6.11 mm year^{-1} in the two cores.
- The comprehensive characterization of the sediments using radiometric and sedimentological methods made it possible to better understand and judiciously interpret the radionuclide profiles.

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