CHAPTER 6

SEDIMENT ACCRETION RATES IN
PICHAVARAM MANGROVES

6.1 INTRODUCTION

A key issue that has affected mangrove ecosystem in the past 200 years is sedimentation (Panayotou 2002). A knowledge by which sediments have been accumulating in mangroves is clearly of fundamental importance to the understanding of the anthropogenic fluxes of heavy metals and organic pollutants into the sediments (Krauss et al 2003). One of the important functions of mangroves to environment is to provide a mechanism for trapping sediment and thus the mangrove forests are believed to be an important sink for suspended sediments (Woodroffe 1992; Wolanski 1995; Furukawa et al 1997). The mechanisms of sediment transport in mangrove waters are mostly based on hydrodynamic processes rather than biological (Smoak and Patchineelam 1999) and the hydrodynamic process includes the asymmetry of tidal currents and shear-induced destruction of flocs (Wolanski et al 1995). Pichavaram mangroves receive pollutants and sediments via multiple inputs. With reduced freshwater inputs into the mangroves in recent times, the rates of sedimentation could have also been altered significantly. Furthermore, there has been no previous study available on the process of sedimentation which is a very crucial estimate for mangrove sustenance and thus forms a basis of the present study.
6.2 \( ^{210}\text{Pb} \) DATING FOR ESTUARINE SEDIMENTS

Before discussing the results obtained in this study, it would be relevant to have a basic understanding of the principle of \( ^{210}\text{Pb} \) dating and the mathematical model used to calculate the rates of sediment accretion. The most widely used method for dating sediments deposited over the last 100 to 150 years in marine or lacustrine environments is based on the examination of \( ^{210}\text{Pb} \) profiles (Appleby and Oldfield 1978).

Core chronologies using \( ^{210}\text{Pb} \) analysis was first suggested in 1963 by Goldberg and was first applied to lake sediments by Krishnaswamy et al (1971). It has been applied successfully to sediments from lagoons, estuaries and coastal environments with sedimentation rates ranging from millimeters to centimeters per year. Lake, lagoon and estuarine sediments are favorable for the use of the \( ^{210}\text{Pb} \) dating method as \( ^{210}\text{Pb} \) is concentrated in a stratified manner and then decays at a known rate (Oldfield and Appleby 1984).

\( ^{210}\text{Pb} \) may reach these sediments in two forms:

- A ‘supported’ component derived directly from eroded soil in the estuary’s catchments. ‘Supported’ \( ^{210}\text{Pb} \) has not been in the atmosphere and emanates from its parent isotope \( ^{226}\text{Ra} \), which is present in the eroded sediment (Hakanson and Jansson 1983).
- An ‘unsupported’ (or excess) component from the atmosphere deposited either directly onto the estuarine surface or deposited within the estuary’s catchment and reaching the estuary via the drainage network (Oldfield and Appleby 1984).
To determine dates using $^{210}\text{Pb}$ both total $^{210}\text{Pb}$ and ‘supported’ $^{210}\text{Pb}$ activity must be established (Packwood 1999). Total $^{210}\text{Pb}$ activity is therefore determined indirectly by measurement of its beta-emitting daughter nuclide, $^{210}\text{Bi}$. Measurement of $^{226}\text{Ra}$ activity will provide an adequate figure of ‘supported’ $^{210}\text{Pb}$, as these two elements are assumed to be in equilibrium (Gale et al 1995). Subtracting of ‘supported’ $^{210}\text{Pb}$ from total $^{210}\text{Pb}$ will determine ‘unsupported’ $^{210}\text{Pb}$ (Hakanson and Jansson 1983). The $^{210}\text{Pb}$ dating method depends on there having been a steady supply of ‘unsupported’ $^{210}\text{Pb}$ delivered to the study area over the time. The $^{210}\text{Pb}$ accumulates in the sediment, buried and decays at a known rate. By measuring $^{210}\text{Pb}$ activity at the surface of a core sample taken from the estuary bed and at regular intervals through the core, a chronology for the core can be established (Packwood 1999).

In the present study $^{210}\text{Pb}$ radionuclide was used as a tracer to establish sediment accumulation rates in Pichavaram mangrove ecosystem. Similar dates have been made in the mangrove sediments of Mexico (Lynch et al 1989), Sepitiba Bay, Brazil (Joseph and Patchineelam 1999; Marques Jr et al 2006) indicating that $^{210}\text{Pb}$ measurement is an efficient technique to determine the rates of sedimentation in mangroves.

### 6.3 SEDIMENT ACCRETION RATE MODEL

For the present study a simple mathematical treatment is used to calculate sediment accumulation following Joshi and Ku (1979).

Provided that the sedimentation rate, $S$ (cm$^2$ yr$^{-1}$) and the activity of the $^{210}\text{Pb}_{\text{excess}}$ added to the surface sediments, $C_o$, $C$ (dpm g$^{-1}$) are constant in time the distribution of excess $^{210}\text{Pb}$ in undisturbed sediments is governed by the relationship
\[ \ln C = \frac{\lambda}{S} D + \ln C_0 \]

where \( C_0, C \) - activities of excess \(^{210}\)Pb at the surface and depth \( D \), respectively.

\( \lambda \) - Radioactive decay constant for \(^{210}\)Pb (0.693/22.26 yr\(^{-1}\)).

\( S \) - Sedimentation rate.

6.4 SEDIMENT ACCRETION RATES IN PICHAVARAM

The use of \(^{210}\)Pb radionuclide in the measure of accretion rates is highly dependant on the assumptions and models used to interpret the data. The accuracy of rates depends on the ability to correct for and/or minimize the potential errors encountered in the process of collecting and analyzing these cores. The following factors need to be considered:

1. Errors in collection of the core, such as disturbance of the natural distribution of the sediments.

2. Errors associated with biotic and/or abiotic disturbance of the radionuclide profiles prior to removal for analysis such as compaction, migration, mixing and/or bioturbation of the radionuclide in the sediment.

3. Errors encountered following removal of the core, such as sectioning, accuracy of the instrumentation and validity of underlying assumptions (Nixon 1980; Davis et al. 1984; Oldfield and Appleby 1984; Casey et al. 1986; Sharma et al. 1987). All these aspects need to be addressed to resolve whether \(^{210}\)Pb excess technique is an accurate representation of accretion in mangrove forests.
6.4.1 Compaction

In all five sediment cores taken in Pichavaram mangroves, handling errors were assumed to be minimal. In general, the natural processes occurring within each core, such as compaction and sediment mixing, complicate radionuclide data interpretations. Failure to account for compaction and sediment mixing can result in overestimating the accretion rate (Nittrouer 1979). Compaction during extraction of the core was minimized by using wide diameter (10 cm), thin-walled PVC tubes and care was taken in sectioning each core. Instrument counting errors for $^{210}\text{Pb}$ averaged ±2% to ±5% of the measured value owing to the use of a high efficiency detector. Therefore, correction for $^{210}\text{Pb}$ profile for consolidation of the sediments with depth is very important. A generally accepted rule is that compaction is more prevalent in sediments with lower bulk density due to higher organic content (Busch and Keller 1982).

6.4.2 Accretion Rates

Five sediment cores (10 cm diameter) were collected by inserting a PVC core tube into the sediment during low tide soon after monsoon (January 2005) based on mangrove zonation. Five depositional sites were chosen for sampling (Table 6.1): (i) Avicennia zone (CR1), (ii) Mixed vegetation zone (CR), (iii) Rhizophora zone (CR3), (iv) Unvegetated zone (drainage point of Uppanar canal) (CR5) and (v) Avicennia Zone (CR6). The measured activity of total $^{210}\text{Pb}$ varies from 1.6 to 2.3 dpm g$^{-1}$ (Table 6.2). The total activity of both $^{210}\text{Pb}$ and $^{226}\text{Ra}$ appears to decrease with depth (Figure 6.1). However, the decrease is irregular at the top 20 cm layers in CR and CR5 due to physical mixing and bioturbation. The measured $^{226}\text{Ra}$ activities were subtracted from total $^{210}\text{Pb}$ activity to obtain the excess or unsupported $^{210}\text{Pb}$ ($^{210}\text{Pb}_{xs}$) activity. This assumes that $^{222}\text{Rn}$, the parent nuclide of $^{210}\text{Pb}$, is in secular equilibrium with $^{226}\text{Ra}$. 
Table 6.1 Sediment accretion rates and vegetation type in Pichavaram mangroves

<table>
<thead>
<tr>
<th>Core code</th>
<th>Location</th>
<th>Vegetation type</th>
<th>Sedimentation rates (mm yr⁻¹)</th>
<th>Remarks</th>
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<tbody>
<tr>
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<td>Minpallam</td>
<td>Avicennia zone</td>
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<td>Dense rooted zone</td>
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<td>CR</td>
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<td>Rhizophora zone</td>
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<td>CR5</td>
<td>Drainage point of Uppanar canal</td>
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<td>CR6</td>
<td>TTDC</td>
<td>Avicennia zone</td>
<td>2.5</td>
<td>Less tidal inundation area</td>
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Table 6.2  The measured activity of $^{210}$Pb excess (dpm g$^{-1}$) in sediment cores

<table>
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<tr>
<th>Depth (cm)</th>
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<th>CR3</th>
<th>CR5</th>
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<td>0.39</td>
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</table>
Figure 6.1 Vertical distribution of $^{210}$Pb activity in the sediment cores

In an ideal core, the excess $^{210}$Pb activity would exponentially decrease with depth. The core CR1 collected at the Avicennia zone show irregular and highly disturbed surface layers due to the presence of dense roots in the upper 20 cm of the sediment (Purvaja et al 2004). Although the core CR5 collected at the unvegetated zone, it is characterized by bioturbating organisms such as crabs and polychaete worms and anthropogenic disturbances due to constant movement of fishing boats. The $^{210}$Pb excess activity, plotted against depth is given in Figure 6.3. The $^{210}$Pb excess profile decrease monotonically with depth and therefore a slope was drawn to calculate accretion rates. The overall trend in the $^{210}$Pb excess profiles suggests more or less constant rates of sediment accumulation in Pichavaram mangroves. The sediment accretion rates for five sediment cores were presented in the Table 6.2. The sedimentation rates in Pichavaram show an
increase towards the estuary (Figure 6.2). Table 6.4 compares sedimentation rates with other estuarine and mangrove ecosystems worldwide.

![Variation in sediment accretion in different coring sites](image)

**Figure 6.2** Variation in sediment accretion in different coring sites

The calculation of the least squares of regression indicates a good correlation between $^{210}$Pb excess activity and depth in all cores, with an exception of core CR3. The high accumulation rate were observed both 3.0 mm yr$^{-1}$ (Coleroon estuary) and 2.9 mm yr$^{-1}$ (Uppanar canal), which are the two major entry and exit points of the estuary respectively. Apart from this, the higher accretion rate was due to frequent exposure to tidal inundation and also resulted from flocculation under high saline conditions. Sediment at this site seemed to remain as slurry for a longer period compared to the back mangrove region. This statement is supported by Reed (1989), who postulated that the process of sediment deposition and sedimentation preferentially occur in the slurry zone. Lynch et al (1989) determined accumulation rates using $^{210}$Pb excess in mangroves of Florida and Mexico to range from 1.0 to 4.4 mm yr$^{-1}$. Recently Krauss et al (2003) determined sedimentation rates of Micronesian mangrove forests which are ranged between 7.7 to 11 mm yr$^{-1}$. 
Therefore, the sediment accumulation rates calculated in the present study are within the same range as for salt marshes and other mangrove ecosystems.

Figure 6.3  Excess $^{210}$Pb activity profile in sediment cores
6.4.3 Mixing

Mixing in the upper sediment layers induced by biological activity or physical stirring by bottom currents can have a significant impact on the measured profiles of trace metals and radionuclides (Benninger et al. 1979; Santschi et al. 1984). Mixing increases the immediate capacity of the subsurface sediments for pollutants and radionuclides by constantly diluting the concentrations of surface sediments with uncontaminated subsurface particles. Therefore, information on the magnitude and the vertical extent of mixing is important for the estimation of net sedimentation rate and for the proper interpretation of historical records of substances introduced to the sediments. Under such conditions particles deposited to the soil surface is quickly mixed to the base of the surface layer, where the actual burial process begins. $^{210}$Pb can be useful in observing this phenomenon due to the continual input of the radionuclide to the soil surface (Lynch et al. 1989). Indication of a surface mixing zone is usually revealed by a homogenous layer of activity (Guinasso and Schink 1975; Nittrouer et al. 1979).

Apart from bioturbation and physical mixing, the other major factor for a highly disturbed upper sediment layers could be due to the Indian Ocean tsunami on 24th December 2004. Mangroves in Pichavaram have acted as first line defense during this event by largely reducing the intensity of the tsunami waves. However, the sediments have undergone extensive reworking and resuspension causing severe disturbance to the surface sediments. The Coleroon estuary (CR) has been a major point of entry of tsunami waves, widening the mouth of the Coleroon River into the Bay of Bengal (Figure 6.4). It is the resuspension and reworking of sediment that has considerably altered the rates of sedimentation in Pichavaram mangroves. Inundation by successive tsunami waves has caused reworking in the top 30 cm of the sediment in the Coleroon estuary (CR) and generally decreases as we progress towards land wide.
To summarize, the vertical distribution of excess $^{210}\text{Pb}$ was measured in five sediment cores from Pichavaram mangroves which clearly indicate that geochronology of the sediments of Pichavaram mangroves could be dated successfully using the $^{210}\text{Pb}$ method. The sediment accretion rates range from 2.5 to 3.0 mm yr$^{-1}$ and show an increase towards estuary. The highest accumulation rate was measured in CR (Coleroon estuary), which is most likely due to the sediments have undergone extensive reworking and resuspension causing severe disturbance to the surface sediments after the Asian tsunami, December 2004 and frequent exposure of the estuary to tidal activities. The lowest rate of sediment accumulation was measured at the back mangrove area (CR6), which characterized with poor inundation of both river and sea water. The sediment accumulation rates for Pichavaram mangroves

Figure 6.4  Satellite imageries before and after Tsunami showing the extent of opening to various inlets of Pichavaram mangrove areas. (Source: NRSA, India)
falls within ranges of the most published data reported in various estuaries and mangroves worldwide (Table 6.3). From the above results, it is clear that the geochronology of the sediments of Pichavaram mangroves is well enough using the $^{210}\text{Pb}$ method.

**Table 6.3** Comparison of sediment accretion rates from Pichavaram mangroves with some published values from various estuarine and mangrove sediments

<table>
<thead>
<tr>
<th>Location</th>
<th>Method</th>
<th>Accretion rates (mm yr$^{-1}$)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pichavaram mangroves</td>
<td>$^{210}\text{Pb}$</td>
<td>2.5–3.0</td>
<td>Present study</td>
</tr>
<tr>
<td>Chesapeake Bay</td>
<td>$^{210}\text{Pb}$</td>
<td>1.7–3.6</td>
<td>Stevenson et al (1985)</td>
</tr>
<tr>
<td>Mexico, mangroves</td>
<td>$^{210}\text{Pb}$ and $^{137}\text{Cs}$</td>
<td>3.0</td>
<td>Lynch et al. (1989)</td>
</tr>
<tr>
<td>Sepetiba Bay mangroves</td>
<td>$^{210}\text{Pb}$, $^{234}\text{Th}$ and $^{7}\text{Be}$</td>
<td>1.1 – 1.8</td>
<td>Joseph and Patchineelam (1999)</td>
</tr>
<tr>
<td>Sabine-Neches estuary</td>
<td>$^{210}\text{Pb}$ and $^{137}\text{Cs}$</td>
<td>1.0-11.4</td>
<td>Ravichandaran et al (1994)</td>
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<td>2.6–4.2</td>
<td>Romen et al (1997)</td>
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<td>Ramesh et al (1988)</td>
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<td>3.4</td>
<td>Subramanian and Mohanachandran (1997)</td>
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<td>Tamirabarani Estuary</td>
<td>$^{210}\text{Pb}$</td>
<td>11</td>
<td>Ramesh et al (2002)</td>
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