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APPLICATION OF ENVIRONMENTAL MAGNETISM IN RECONSTRUCTION OF PALEOENVIRONMENT IN MANGROVE SEDIMENTS: A CASE STUDY OF MUMBAI, MAHARASHTRA, INDIA

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ABSTRACT

Mineral magnetic variations are a function of environmental change because of which it can be used towards elucidation of a diversity of problems, including the mangroves. The mineral magnetic technique, in the present attempt, is applied on consolidated and unconsolidated sedimentary samples from mangrove depositional environment that includes freshwater as well as marine influenced sediments. Various mineral magnetic parameters and their ratios are harnessed to ascertain likely composition and grain size of the magnetic mineral assemblage. The high resolution data generated in the present study revealed climatic and oxidation-reduction conditions. The magnetic observatory inclination values were correlated with sediment inclination values to arrive at a robust age-depth model.

Keywords: Environmental, Mineral magnetic, Sediments, Mangroves

INTRODUCTION

Mangroves are coastal and riverside plants that thrive at interfaces between land and sea in the tropics and subtropics (Chow, 2018). Mangroves are a complex web of coastal ecosystem since it being transitional zone between continent and sea. This zone is influenced by land-sea-atmosphere dynamics and undergoes interplay of local hydrology, geology, tidal ingress-regress, geomorphology, ecology and the quantum of freshwater addition (Blasco, 1984; Selvam, 2003). The mangrove cover across India is ~ 487,100 ha (Nayak and Bahuguna, 2001). Mangroves are trapping zones of fine-grained sediments that may contain spores and pollen. The intricate pattern and complex nature of their root system makes it an efficient trapping zone allowing to study these sediments for quaternary climate change signals involving sea level change and monsoonal fluctuations. Monsoonal intensification or weakening has a direct bearing on the erosional and weathering capacity of the local surface and substrate geology. The rate of subsidence of the low lying areas containing estuaries and lagoons turns into marshes.

Mangrove forests are one of the most productive and bio diverse wetlands on Earth, and also the most threatened habitats. They are likely disappearing quickly than inland tropical rainforests. Growing in the inter-tidal areas and estuary mouths between land and sea, mangroves provide critical habitat for a diverse marine and terrestrial flora and fauna (Kumaran *et al*., 2004). Healthy mangrove forests are key to a healthy marine ecology. The mangrove dominated marine estuary emit less carbon di-oxide (Akhand *et al*., 2016). Mangroves are marine tidal forests and they are most luxuriant around the mouths of large rivers and in sheltered bays and are found mainly in tropical countries where annual rainfall is fairly high (Kumaran *et al*., 2004). Mangrove plants, trees, shrubs, ferns and palms are found in the tropics and sub-tropics on riverbanks and along coastlines, being unusually adapted to anaerobic conditions of both salt and fresh water environments. These plants have adapted to muddy, shifting, saline conditions. They produce stilt roots, which project above the mud and water in order to absorb oxygen. Mangrove plants form communities which help to stabilize banks and coastlines (Thom, 1984) and become home to many types of animals. However, in many areas of the world, mangrove deforestation is contributing to fisheries declines, degradation of clean water supplies and salinization of coastal soils, erosion, and land subsidence, as well as the release of carbon dioxide into the atmosphere. In fact, mangrove forests fix more carbon dioxide per unit area than phytoplankton in tropical oceans. Mangrove forests once covered ¾ of the coastlines of tropical and sub-tropical countries. Today less than 50% remain, and of this remaining forest, over 50% is degraded and not in good form. Many factors contribute to mangrove forest loss, including the charcoal and timber industries, urban growth pressures, and mounting pollution problems.

In India, mangroves occur on the West Coast, on the East Coast and on Andaman and Nicobar Islands, but in many places they are highly degraded. According to the Government of India (1987), India lost 40% of its mangrove area in the last century. The National Remote Sensing Agency (NRSA) recorded a decline of 7000 ha of mangroves in India within the six-year period from 1975 to 1981. In Andaman and Nicobar Islands about 22,400 ha of mangroves were lost between 1987 and 1997.

The materials residing in mangroves are of transported and those created *in situ.* Material flux takes place in the hydrosphere, the atmosphere and the cryosphere, the most important agents being rivers, ocean currents, ground water, wind, rain, snow, glaciers, ice sheets and icebergs. For the most part, the transported material itself exists in granular or particulate form, typically in the size range 10-100 mm.; Depending on the ambient conditions, these mineral grains may suffer some chemical change such as oxidation during transport and deposition, but by and large, they are passive and inert. However, once they are deposited, many chemical changes may occur. Indeed, some grains may entirely disappear while others may be created. This is particularly so in soils, that is the pedosphere, which harbor a complex interplay of chemical, physical and biological activity. Magnetic minerals occur more or less universally; iron being one of the most common elements in the Earth's crust. They may be present in minor amounts, less than 1% usually, but they are easily, rapidly and non-destructively detected. The soils and sediments of mangroves ecosystem are highly productive environments characterised by high organic matter contents (Sarker *et al*., 2020). The palynological and sedimentological results of Cauvery River delta reveal a monsoonal circulation and a climatic shift from warm and humid with strengthened monsoon to dry and arid (Srivastava *et al*., 2013).

Environmental magnetism deals with understanding the presence of magnetic minerals in different domains and the influence they have on the morphological and chemical characteristics of magnetic minerals in the natural and cultural environments (Thompson and Oldfield, 1986). With modern equipments, it is experimentally easy to detect useful magnetic signals from environmental materials such as soils and various sediments even if magnetic component makes up less than a thousandth of whole sample. Magnetism thus provides a tracer of environmental conditions. To make use of this tracer, however, knowledge of magnetic substances involved and of their relevant magnetic properties is required. Furthermore, some understanding of techniques used is necessary if the possibilities and limitations of the subject are to be properly appreciated (King *et al*., 1983; King, 1983; Creer and Tucholke, 1982; Lund and Banerjee, 1985). For detailed investigation of key or representative samples, it is often highly desirable to resort to a range of additional measurements, like for example, recording the variation of susceptibility and remanence with temperature. The derived magnetic parameters are continuous functions and hence are substantially data based presenting great scope for the use of different quantitative techniques.

The samples collected from the mangroves may contain biogenic magnetite. However, at present there is no completely reliable method for discriminating between biogenic and abiogenic magnetite and determining the relative importance of the two mechanisms (Stolz *et al*., 1990; Chang and Kirschvink, 1989; Sparks *et al*., 1990). The aim of present study is to investigate present and past environmental or climatic conditions at Mumbai.

2. Depositional Environments under Investigation

A plethora of Indian sedimentary basins is under investigation to understand environmental and climatic changes by harnessing mineral magnetism for a complete perception of the sources and processes of these changes. Mineral magnetic measurements have been performed on core and hand specimens collected from Airoli, Mumbai, Maharashtra (India) encompassing depositional environments of varying type and provenance.

Area Distribution of Mangroves in India (Thousand ha)

State/Union Territory	Govt. of India, 1987	Govt. of India, 1997	Govt. of India, 2017
West Bengal (Subdarbans)	420	212.3	211.4
Andaman and Nicobar Islands	119	96.6	61.7
Maharashtra	33	12.4	30.4
Gujarat	26	99.1	114
Andhra Pradesh	20	38.3	40.4
Tamil Nadu	15	2.1	4.9
Orrisa	15	21.1	24.3
Karnatak	6	0.3	1.0
Goa	20	0.5	2.6
Kerala	Sparse	NIL	0.9
Total	674	482.7	491.6

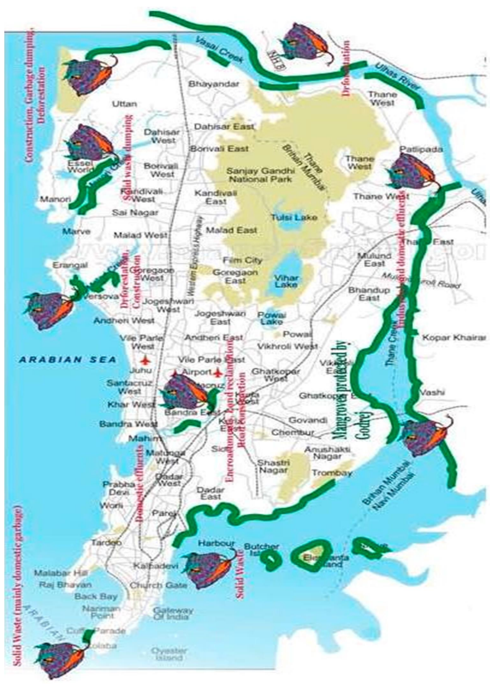

Fig. 1- Mangrove map of Mumbai
(www.mapsofindia.com)

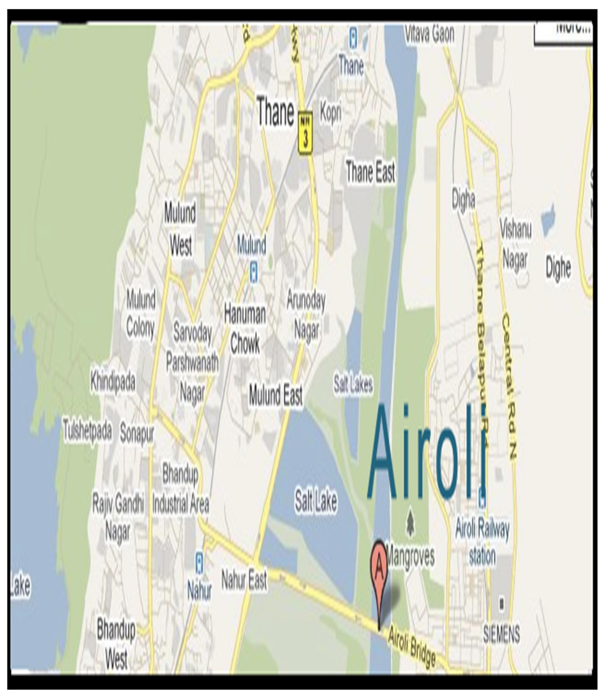

Fig.2- Map of Airoli
(www.navimumbaionline.in)

3. METHODOLOGY

3.1 Sampling

Sedimentary cores were excavated from mangrove sedimentary terrain of Airoli, Navi

Mumbai, Maharashtra. Two sedimentary profiles were collected from adjacent localities. Oriented samples were collected using soil corer. The azimuths of the profiles were found to be 270˚W. The oriented samples were transferred into 10 mm plastic sample bottles. For paleomagnetism measurements, the direction of north was marked on the oriented sample bottles (Tarling, 1983), and for environmental magnetism measurements, unoriented samples were used. The orientd and unoriented samples were collected from same level so that mineral magnetic and paleomagentic parameters could be analyzed for same level.

The samples used in environmental magnetism measurements were prepared by drying the soil samples in porcelain containers in an electric oven for about 72 hr. The samples are heated at temperature range of 40˚C and not more than that. The dried samples are later on powdered and then weighed and filled in the 10 mm plastic sample bottles. After the soil is powdered it was wrapped in a thin nonmagnetic polyethylene film. This is to prevent any movement of the sample particles while the measurements are on.

The paleomagnetic samples from mangroves are usually wet samples. The orientation of plastic bottles is noted and marked on the top and bottom after they are inserted into the sediment. Plastic film lines the inner part of the bottle so as to hold the sample in place. It is seen through our sampling that during the time interval from collection to measurement the sample may get dehydrated and there is a tendency for the sample to get disoriented inside the bottle thus leading to error in measurements. To avoid this, a tissue was placed inside the bottle before placing the lid so that the sample remains tighten in place. The directions were marked on the bottom of the bottle rather than on the lid as there is a probability for the lid to be rearranged during the course of measurements. A total number of 40 samples from a soil profile at an interval of 5 cm are subsampled and packed.

3.2 Instrumentation

The experiments involved the calculation of NRM measurements in the oriented samples for which the Molspin MINISPIN Spinner was used. The oriented samples were also subjected to the various demagnetizing fields in the ASC Scientific D2000 AF demagnetizer (0.2 Tesla), for various demagnetizing fields.

In case of the mineral magnetism studies the AGICO KLY4S Kappabridge was used for mineral susceptibility measurements. ARM measurements for intensity of 0.05mT were also carried out on the unoriented samples using the ASC Scientific D2000 AF demagnetizer. IRM measurements were carried out using a combination of the Molspin pulse magnetizer and Molspin spinner.

4. ANALYSIS

4.1 Site Location

The geographic location of the sampling site is 19˚10’41” N, 72˚59’48” at Airoli a suburban of

Navi Mumbai, Maharashtra state in India. The total length of the excavated core is around 2 m. The site is situated adjacent to the mangrove forests which cover the banks of the Thane Creek. The site was selected as it was previously under the mangrove cover and had been cleaned for the construction of the MIDC Tech Park. It is interesting to observe that the area is situated on the banks of the Thane Creek which is connected to the sea, and hence is subjected to the transgressions of the sea. The Parsik Hills, Kharegon, Kalwa is situated near by to the East of the creek; these hills are almost barren and hence is a probable source of input into the creek. All these sediments seem to be entrapped in the rigid root framework of the mangroves.

A steel plant of Mukand Iron & Steel is also situated to the North-east of the location. This is believed to be functional in 1980, which may act as a temporal marker to our soil horizon. The pollution input form this plant acts as a marker, in the soil profile, from 1980 onwards.

4.2 Environmental Magnetic Parameters

The concept of using magnetic properties as proxy parameters and correlation tool in a geoscientific context was put forward in the late 1970s mostly by Oldfield and his coworkers; the article in Science (Thompson *et al*., 1980) is often considered as the formal definition of "environmental magnetism" as a subdiscipline. The magnetic parameters of reduction diagenesis is discussed in several research papers (Karlin 1990, Leslie *et al*., 1990, Bloemendal *et al*., 1989, King *et al*., 1991). The summary of these research papers is, (1) a marked decrease in indicators of magnetic concentration (e.g., susceptibility, ARM and SIRM); (2) changes in indicators of magnetic particle size (e.g. ARM/Sus, SIRM/Sus, SIRM/ARM) indicate a larger magnetic particle size; and (3) changes in indicators of magnetic mineralogy indicate increased concentrations of canted antiferromagnetic minerals, e.g. hematite and goethite and lower concentrations of magnetite (Bloemendal *et al*., 1989, Bloemendal *et al*., 1992). Comparison of the ratio ARM/SIRM with the frequency dependence of susceptibility (Maher and Taylor, 1988) resolves the problem of poor discrimination. Simultaneous matching of magnetics data is a non-trivial exercise (Martinson *et al*. 1987). Variations in the mineral magnetic parameters Susceptibility, ARM and SIRM primarily reflect variations in the concentration of magnetic minerals in natural materials (Robinson, 1986; Bloemendal *et al*., 1988). Variations in the interparametric ratios, ARM/Sus, SIRM/Sus, SIRM/ARM primarily reflect variations in the particle size of the magnetic mineral assemblage in natural materials. The ratio SIRM/ARM varies directly with magnetic particle size whereas ARM/Sus and SIRM/Sus vary inversely with magnetic particle size (Robinson, 1986; Bloemendal *et al*., 1988; Maher and Taylor, 1988). In addition interparametric ratios (e.g. HIRM) can be calculated utilizing forward IRM values and back IRM values. For example, the parameter HIRM or hard IRM is a measure of the concentration of high coercivity magnetic minerals i.e. hematite and goethite in a material (Robinson, 1986; Bloemendal , 1988; Thompson and Oldfield, 1986). The parameter S-ratio is measure of proportion of higher coercivity magnetic minerals to lower coercivity magnetic minerals in a material. Values of S-ratio of about 1.0 indicate a high proportion of magnetite, whereas lower values indicate an increasing proportion of hematite and goethite (Robinson, 1986; Bloemendal *et al*., 1988; Thompson and Oldfield, 1986, Maher., and Thompson, 1999). Kent (1982) first demonstrated the strong correlation between variations in magnetic susceptibility and IRM from marine sediments.

5. RESULTS AND DISCUSSION

The magnetic susceptibility values are low and invariant at the bottom from 180 cm to ~135 cm (Fig. 3), which is seen to increase abruptly at about 130 cm and then goes back to the bottom low values that have moderate amplitude. From ~90 cm upwards the susceptibility values are seen to be on the rise till the very top of the core. The XFD% is quite low indicating low presence of SP grains (Fig. 3), which can be further confirmed by ARM values (Fig. 3), which are quite low and without any variation at the bottom of the core. From 100 cm onwards it is seen to increase till about 60 cm and then fall generally till about 25 cm, above which it is low and invariant. SIRM indicates the presence of all the remanence carrying minerals and is quite similar to the magnetic susceptibility curve. The soft IRM and hard IRM values (Fig. 3) indicate the magnetic minerals have reached saturation at very low fields. This indicates the prevalence of magnetite in the samples. S-ratio is a discriminant between the ferrimagnetic and antiferromagnetic minerals. There is a distinct change in the mineralogy at around 100 cm. Below this depth the ratio is low and above high indicating change in the type of mineralogy. At the bottom are the magnetic minerals that may have changed their mineral phase. The diagenetic changes must have brought about changes to the magnetic mineralogy. The magnetic minerals at the top of the core could be magnetite. The ones at the bottom could be maghaemite since the magnetite has transformed to this magnetic phase. The SIRM/MS (Fig. 4) reveals the same. The quantum of magnetic minerals is either less at the bottom or that it has changed diagenetically. ARM/MS ratio (Fig. 4) reveals the values are controlled more by the type of mineral than the grain size.

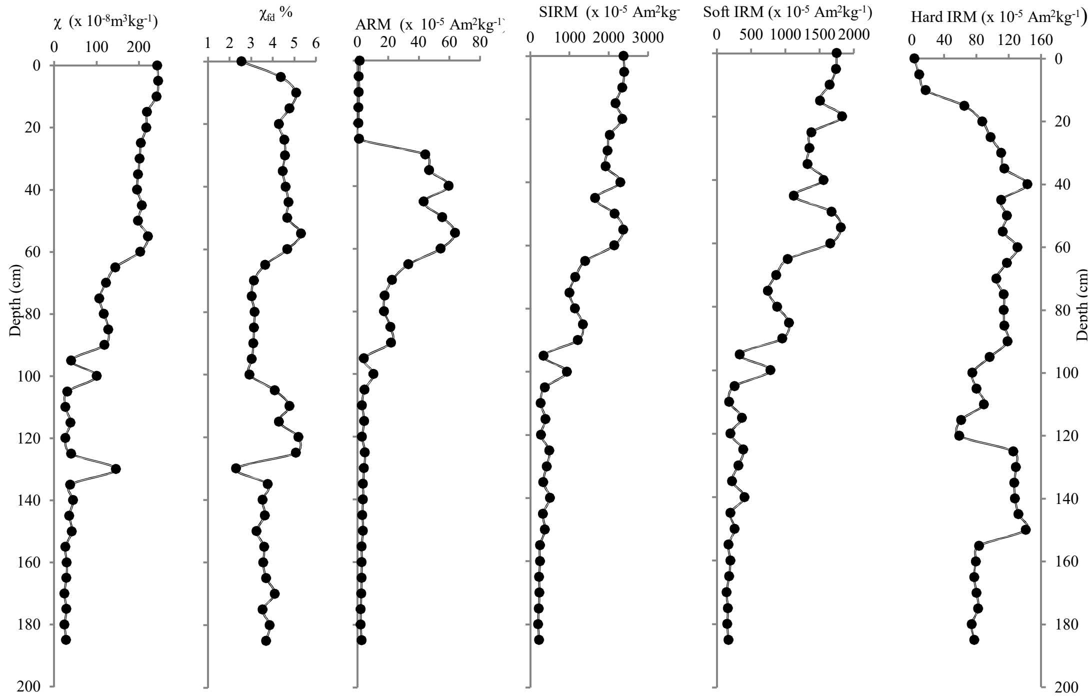

Fig.3. Variation in mineral magnetic parameters down the core

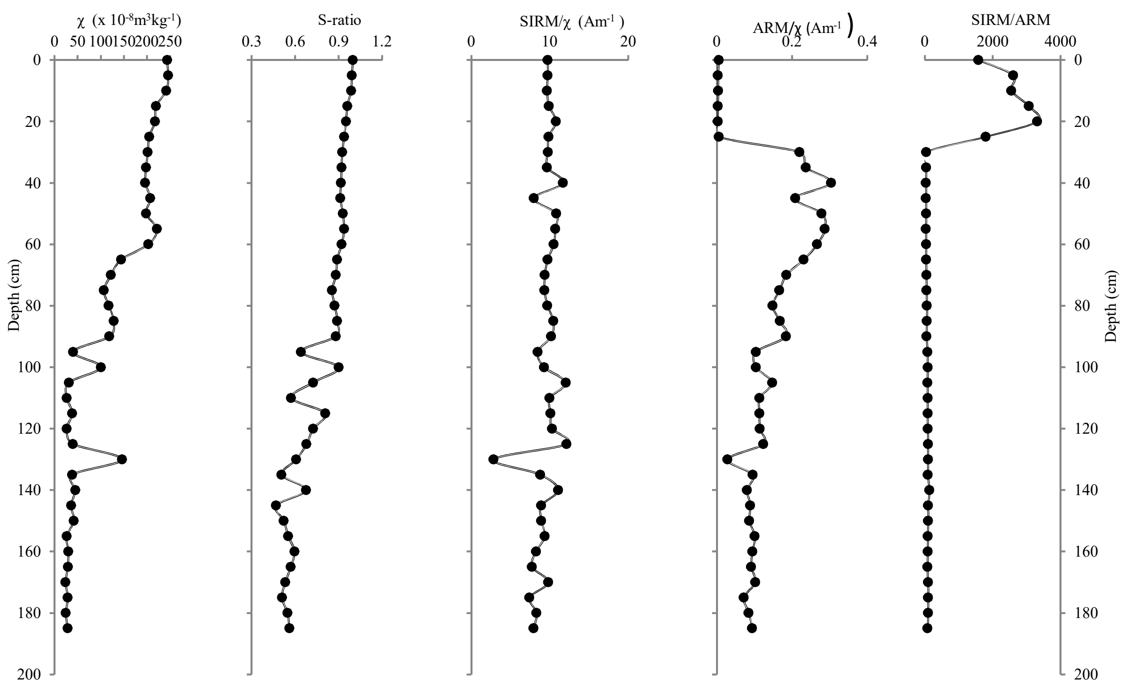

Figure 4: The variability of interparametric ratios down the core

The magnetic grain size has a very low influence and it the type of magnetic mineral that is imparting value to the sediment. The SIRM/ARM ratio is absolutely stable from the bottom to top indicating grain size has a minor role to play or there is hardly any change in the particle as well as magnetic grain size of the samples. The higher values at the very top of the core could be due to the presence of magnetite.

5.1 Observatory Data and Inclination Curve

The sedimentation rate at the mangroves and backwater areas is dependent on a range of factors right from climate to geology of the area. However, the sedimentation is never uniform. it happens in spurts and the tidal influence is most conspicuous. The mangrove area in and around Airoli is not an exception. But it is tempting to try and find the age of these sediments to make a qualitative and quantitative assessment of the climatic conditions prevailing in and around the study area. One of the ways to assign age to the sediments was to get the radiometric ages. However, we were not able to do so. So the next best thing was attempted. The inclination of the core sediments were determined in the laboratory and they were compared against the inclination values of the magnetic observatory recorded at IIG, Alibag, Maharashtra. This magnetic observatory is nearest to the sampling location and is likely to record almost the similar inclination signatures. Hence, the inclination obtained for the excavated core was first compared with the observatory values (Fig. 5). The data from Alibag was available from 1920 onwards and they were taken from the observatory records kept at Indian Institute of Geomagnetism, Navi Mumbai. A good match was seen between the observatory and core inclination values, though a hundred percent fit was not observed. It is expected because the excavated core could be recording these values at a time lag and the core cannot be as efficient as a magnetometer in recording the magnetic vicissitudes observed in nature. Also, the observatory records all the factors that are responsible for the magnetic field changes that occur in space and on sun and in earth. Since the magnetic field changes influenced by the solar dynamics are subdued they may not find their way in sedimentary records.

The excavated core variation in inclination was matched with the observatory inclination values. The best matching curve is thus fixed (Mudgal, 2012). As can be seen from Fig. 5 there is an overall match between the two curves. The annual inclination observatory values were taken against which the excavated core values are compared. Hence, it cannot be expected to have one on one correlation between them. In spite of this major difference the overall matching between the two is quite conspicuous.

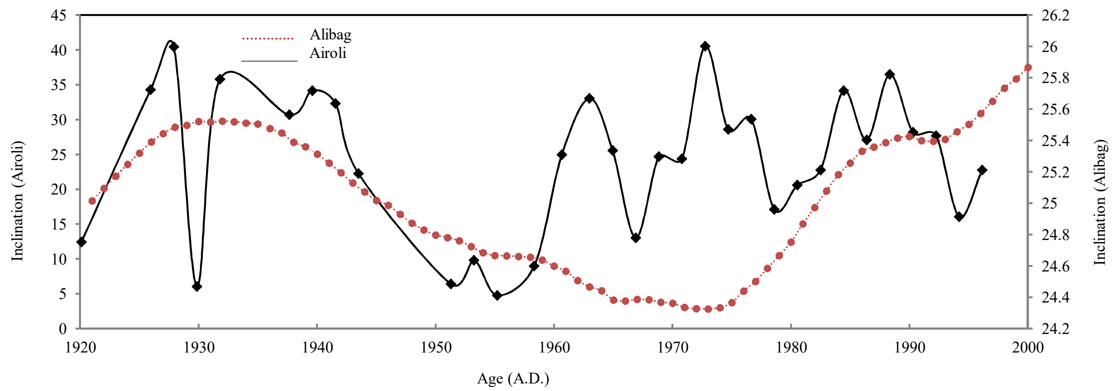

Fig.5. Age-Depth model of Airoli mangroves, Curve matching of inclination values of Airoli mangroves with that of Alibag observatory values

To arrive at the sedimentation rate along Airoli mangrove, we assumed an unchanging and constant rate of sedimentation. We developed an age-depth model wherein the match of the core and observatory inclination was used to arrive at the sedimentation rate, which came to about 1.28 cm/year (Fig. 6).

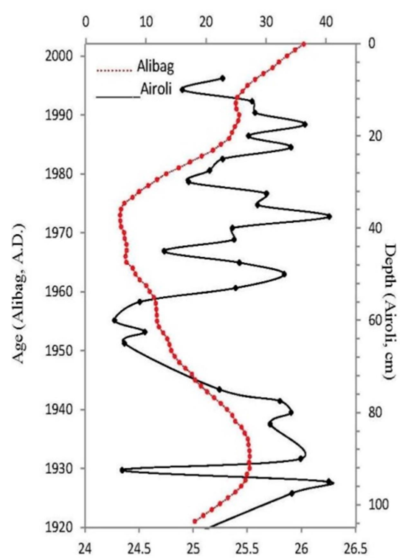

Fig. 6.Determination of sedimentation rate from Age-Depth model

To summarize, the magnetic parameters derived from the sedimentary core brought up from the Airoli mangrove reveals the change in climatic and environmental vicissitudes. The monsoonal vagaries in the tropical region of Maharashtra are quite strong and they have been recorded at many places (Gawali *et al*, 2019). The marked changes in the magnetic susceptibility signatures at the base and top of the excavated core reveals two different climatic regimes in the region. The subdued signals at the bottom is likely to signify two things. If the presence of haematite is taken to be at the bottom of the core then the detrital pathways could be different that have brought the detritus from a far off place. It must be noted that the current study area is within the deccan basaltic terrain that comparatively have copious amount of magnetite within them. Hence, it can be precluded that the occurrence of haematite is highly unlikely in this terrain (Gawali *et al*, 2010, Rajshekhar *et al*, 2004). It has also been observed that after about 5000 or 4000 14C yr B.P., the monsoons gradually reduced leading to drying up of many of the marginal marine mangrove ecosystems (Kumaran *et al*., 2005). A case study of Hadi profile provides an insight to the relevance of magnetic susceptibility to record the ecological shift in Late Holocene (Kumaran *et al*., 2004).

The only other alternative explanation for the subdued values is the diagenetic changes that have taken place. The residence time of these sediments is quite long and the aqueous environment may be leading to oxidation-reduction changes within the sedimentary domain to bring about changes in the magnetic phase of the mineral. If the latter explanation for the subdued values is taken to be true then the implications on the vagaries of monsoon could be quite significant. The area has not undergone any significant change in the monsoonal precipitation and the strength of the monsoon has not changed drastically over the years. However, minor variations in the sedimentary signatures in other magnetic parameters and their ratios indicate some small scale and low amplitude changes in the monsoonal precipitation. However, the presence of certain industries in the vicinity of the study area may be contributing anthropogenic material enhancing the magnetic susceptibility values at the top of the core. The sedimentation rate, though assumed to be constant, is not so and the particle grain size is quite constant. The fine particle grain size is reflective of the magnetic grain size, which seems to be in the nature of single domain. The magnetic parameters are a good primer for undertaking climate and environment related issues.

6. CONCLUSION

Mangroves are the treasure troves of a spectrum of information. The fine sediments arrest within them signatures that reflect the environmental and climatic changes within the realm of the accumulated deposits. These can be efficiently tracked by understanding magnetic mineralogy extant in the deposits. The present study revealed uniform mineralogy and magnetic grain size throughout the core. The provenance and the detrital pathways of the sediments are seen to be unchanged. The oxidation-reduction domain seems to have changed at the bottom of the core. The mineral magnetic phases have undergone modification due to diagenetic processes at the bottom of the core. The upper part signifies enhancement in the accumulation of magnetic mineral carrying sediments. However, it may also mean increase in anthropogenic activity around the study area. The inclination values from the magnetic observatory and the samples can be correlated to develop age-depth model.

Conflict of Interest

The authors declare no conflict of interest.

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