

# Rare Earth Elements as Indicators of Paleoclimate, Chemical Weathering and Redox Variability in Chodha Lake Core Sediments, Korba Region, Central India

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## ABSTRACT

This study presents a rare earth element geochemical record using the 48cm long sediment core recovered from the Chodha Lake of the Korba district, Chhattisgarh. The rare earth elements were used to observe the fluctuating environmental conditions in and around the study area. The core was divided into four sections based on the variability in their concentration. The entire study is based on the down core characteristics such as  $\Sigma$ REEs,  $\Sigma$ LREEs,  $\Sigma$ HREEs, the  $\Sigma$ LREEs/ $\Sigma$ HREEs ratio, and Ce and Eu anomalies. At most of the depths  $\delta$ Ce values remained predominantly positive,  $\Sigma$ REEs,  $\Sigma$ LREEs,  $\Sigma$ HREEs and the  $\Sigma$ LREEs/ $\Sigma$ HREEs ratio were persistently low. Together, these proxies indicate dominantly oxygenated bottom-water conditions and warm, humid climate governed mainly by chemical weathering. Two notable episodic events at the depths of 26 cm in the zone-B and 17cm in the zone-C, marked by a sharp increase in  $\delta$ Ce, increased  $\Sigma$ REEs and the LREE/HREE ratio indicating a brief shift to more oxygenated conditions. These results demonstrate that REE geochemistry provides a sensitive, internally consistent multi-proxy tool for reconstructing redox and climatic fluctuations in lacustrine sedimentary archives.

**Keywords:** Chodha Lake, Rare Earth Elements, Environmental Conditions, Episodic Events, Sedimentary Archives

## INTRODUCTION

Rare Earth Elements (REEs) are being increasingly used as indicators for various geological processes such as provenance, paleo-redox conditions etc. (Taylor and McLennan, 1985; Bhat et al., 2019; Mir et al., 2022). Their chemical behaviour and relatively low mobility during weathering, transport and metamorphism, has made them one of the most extensively used geochemical tracers (Grunsky et al., 2009; Bhat et al., 2019; Mir et al., 2022). The REEs are also enhanced by their strong adsorptive capacity with sediments as well as chemical resistivity (Antonina et al., 2013; Sousa et al., 2022). They can reflect the characteristics of the source area because of their minimal fractionation in geochemical processes (Liu et al., 2021; Domingo et al., 2023; He et al., 2024; Liu and Zao, 2026). Based on the physical properties and ionic radius, the REEs are divided into LREEs (La, Ce, Pr, Nd, Sm and Eu) and HREEs (Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu) (Maulana et al., 2014).

Cerium (Ce) and Europium (Eu) anomalies may play a crucial role to understand the paleo-environment as well as autochthonous supply (Tostevin et al., 2016; Sousa et al., 2022). Thus, it is possible to investigate past climatic events for sedimentary dynamics (Xu et al., 2011). In order to examine the paleo-redox conditions, many authors have studied these anomalies since past few decades (Wright-Clark and Holser, 1981; Wang et al., 1986; Tostevin et al., 2016; Sousa et al., 2022). Sum  $\Sigma$ REEs,  $\Sigma$ LREEs and  $\Sigma$ HREEs measures the absolute concentrations, whereas their ratio shows how much the lighter elements have separated from the heavier elements during geological processes (Li et al., 2022).

Since REEs in lake sediments keep chemical stability during the weathering processes, they can serve as excellent indicators for tracing sediment provenance changes (Strakhovenko et al., 2023, Gao et al., 2024). In order to understand the provenance and weathering patterns, the Chodha Lake (22°18'35.73"N, 82°27'51.31"E) from the Core Monsoon Zone of Central India was chosen (Fig. 1). The lake is shallow and surrounded by certain industrial activities such as coal mining and thermal power plants. Geologically, the surrounding terrain consists of unclassified granitic gneiss belonging to the Chhota Nagpur Gneissic Complex, spanning the Archean to Proterozoic, with pediments and pediplains as the dominant geomorphic features (DRM 2005).

## MATERIALS AND METHODS

A 48cm long sediment core was retrieved from the centre of the Chodha lake. The core was sub-sampled on the basis of sequential changes in colour and texture of the sediments. Later, the dried sediment samples were sent for Tripple Quadrapole Inductively Coupled Plasma Mass Spectrometry (TQ ICP-MS) analysis at Wadia Institute of Himalayan Geology, Dehradun, India. The Certified Reference Material SCO-1 is used to ascertain the accuracy of the geochemical analyses. The obtained REE results were normalized using Chondrite values (Taylor and McLennan, 1995).

### Cerium Anomaly ( $\delta\text{Ce}$ )

A deviation in cerium concentration compared to its neighbours, lanthanum (La) and praseodymium (Pr) (Anenburg et al., 2022). It is calculated as:

$$\text{Ce/Ce}^* = 3\text{Ce}_N / (2\text{La}_N + \text{Nd}_N)$$

Positive Ce anomaly ( $\delta\text{Ce} > 1$ ) indicates enrichment of Ce, happens due to oxygenated environment (Sousa et al., 2022). Negative Ce anomaly ( $\delta\text{Ce} < 1$ ) indicates a depletion of Ce, happens due to anoxic environment (Sousa et al., 2022).

### Europium Anomaly ( $\delta\text{Eu}$ )

A deviation in europium concentration compared to its neighbours, samarium (Sm) and gadolinium (Gd) (Anenburg and Williams, 2022). It is calculated as:

$$\text{Eu/Eu}^* = \text{Eu}_N / (\text{Sm}_N + \text{Gd}_N)^{1/2}$$

Positive Eu anomaly ( $\delta\text{Eu} > 1$ ) indicates reducing conditions (Wang et al., 2024). Negative Eu ( $\delta\text{Eu} < 1$ ) indicates Oxidizing conditions (Wang et al., 2024).

### Absolute concentrations of REEs ( $\Sigma\text{REEs}$ , $\Sigma\text{LREEs}$ , $\Sigma\text{HREEs}$ )

The  $\Sigma\text{REEs}$  is the sum of all the fourteen REEs (Li et al., 2022). It is calculated as:

$$\Sigma\text{REEs} = (\text{La} + \text{Ce} + \text{Pr} + \text{Nd} + \text{Sm} + \text{Eu} + \text{Gd} + \text{Tb} + \text{Dy} + \text{Ho} + \text{Er} + \text{Tm} + \text{Yb} + \text{Lu})$$

In the context of abundance, low ( $\Sigma\text{REEs} < 50$  ppm) value indicates chemically pure rocks. Values between 50 to 300 ppm indicates standard background levels (Umrao and Sardar, 2022). Values between 300 to 1000 ppm indicate evolved or moderately enriched geological system (Umrao and Sardar, 2022). Values more than 1000 ppm, indicates economic or ore grade deposits (Kopačková-Strnadová et al., 2021).

In the context of paleoclimate, low values ( $\Sigma\text{REEs} < 100$  ppm), indicate arid to semi-arid conditions and mostly physical weathering (Condie et al., 1995). High values ( $\Sigma\text{REEs} > 400$  ppm), indicates warm and humid climatic conditions and mostly chemical weathering (Condie et al., 1995).

The  $\Sigma\text{LREEs}$  is the sum of all six Light REEs (Li et al., 2022). It is calculated as:

$$\Sigma \text{LREEs} = (\text{La} + \text{Ce} + \text{Pr} + \text{Nd} + \text{Sm} + \text{Eu})$$

In the context of abundance, low ( $\Sigma \text{LREEs} < 30 \text{ ppm}$ ) value indicates highly depleted samples (Phani and Sengupta, 2026). Values between 40 to 250 ppm indicates typical background signature for most of the LREEs (Phani and Sengupta, 2026). Values more than 1000 ppm signifies heavily fractionated alkaline rocks (Phani and Sengupta, 2026).

The  $\Sigma \text{HREEs}$  is the sum of all eight Heavy REEs (Li et al., 2022). It is calculated as:

$$\Sigma \text{HREEs} = (\text{Gd} + \text{Tb} + \text{Dy} + \text{Ho} + \text{Er} + \text{Tm} + \text{Yb} + \text{Lu})$$

In the context of abundance, low ( $\Sigma \text{LREEs} < 10 \text{ ppm}$ ) indicates the that the LREEs almost always dominate, leaving HREEs in tiny trace amounts (Umrao and Sardar, 2022). Values between 50 to 200 ppm Indicates a specialized geological process such as hydrothermal fluids concentrating heavy elements (Umrao and Sardar, 2022). Values more than 500 ppm considered highly enriched (Umrao and Sardar, 2022).

In the context of paleoclimate, high  $\Sigma \text{HREE}$  and  $\Sigma \text{HREE}$  values indicate cold and arid climate whereas low  $\Sigma \text{HREE}$  and  $\Sigma \text{LREE}$  value indicate warm and humid conditions (Xia et al., 2025).

#### $\Sigma \text{LREEs}/\Sigma \text{HREEs}$ ratio

The  $\Sigma \text{LREEs}/\Sigma \text{HREEs}$  ratio is used to measure the relative enrichment or depletion of different groups of rare earth elements within the sediments (Wang et al., 2024). Low values ( $<1$  to 2.5) indicates extreme LREE depletion or high HREE concentration (Wang et al., 2024). Moderate values (2.5 to 7) indicate average crustal baseline values (Wang et al., 2024). High values (7 to 15) indicate enrichment of LREEs (Wang et al., 2024).

In the context of paleoclimate, low ratio (3-6.5) indicates Cold/ arid to semi-arid conditions (Abou El-Anwar, 2025). The moderate (6.5 to 10.5) ratio indicates, temperate conditions (Abou El-Anwar, 2025), whereas the high ( $>10.5$ ) ratio, indicates warm and humid conditions (Abou El-Anwar, 2025).

## RESULTS

The REEs show variable concentrations throughout the sediment core and thus the section is divided into four zones (A to D) from bottom to top (Table 1; Fig. 2). The mean concentration of the REEs is decreasing in the following order:  $\text{Ce} > \text{La} > \text{Nd} > \text{Pr} > \text{Sm} > \text{Gd} > \text{Dy} > \text{Yb} > \text{Er} > \text{Eu} > \text{Ho} > \text{Tb} > \text{Tm} > \text{Lu}$  (Table 1). The mean concentration of the LREEs is decreasing in the following order:  $\text{Ce} > \text{La} > \text{Nd} > \text{Pr} > \text{Sm} > \text{Eu}$  (Table 1). The mean concentration of the HREEs is decreasing in the following order:  $\text{Gd} > \text{Dy} > \text{Yb} > \text{Er} > \text{Ho} > \text{Tb} > \text{Tm} > \text{Lu}$  (Table 1).

### Characteristics of REEs in the CLC Sediments

**Zone-A (46–37 cm):** Total concentration of all the REEs ranges from 182.93 to 372.39 (Table 2; Fig. 3). The sum of LREEs ranges from 170.24 to 353.88 whereas, the sum of HREEs ranges from 12.69 to 23.21 (Table 2; Fig. 3). The  $\Sigma \text{LREE}/\Sigma \text{HREE}$  ratio ranges from 12.36 to 23.21 (Table 2; Fig. 3). The  $\delta \text{Ce}$  value is ranging from 2.14 to 3.73 whereas,  $\delta \text{Eu}$  value is ranging from 0.62 to 0.67 (Table 2; Fig. 3).

**Zone-B (37–23 cm):** Total concentration of all the REEs ranges from 126.02 to 235.37 (Table 2; Fig. 3). The sum of LREEs ranges from 114.53 to 353.88 whereas, the sum of HREEs ranges from 9.22 to 23.21 (Table 2; Fig. 3). The  $\Sigma \text{LREE}/\Sigma \text{HREE}$  ratio ranges from 9.97 to 19.12 (Table 2; Fig. 3). The  $\delta \text{Ce}$  value is ranging from 1.42 to 3.9 whereas,  $\delta \text{Eu}$  value is ranging from 0.66 to 0.7 (Table 2; Fig. 3).

**Zone-C (23–9 cm):** Total concentration of all the REEs ranges from 62.29 to 431.17 (Table 2; Fig. 3). The sum of LREEs ranges from 55.26 to 410.17 whereas, the sum of HREEs ranges from 7.04 to 28

(Table 2; Fig. 3). The  $\Sigma\text{LREE}/\Sigma\text{HREE}$  ratio ranges from 4.44 to 19.53 (Table 2; Fig. 3). The  $\delta\text{Ce}$  value is ranging from 0.61 to 3.2 whereas,  $\delta\text{Eu}$  value is ranging from 0.61 to 0.73 (Table 2; Fig. 3).

**Zone-D (9-0 cm):** Total concentration of all the REEs ranges from 50.93 to 177.65 (Table 2; Fig. 3). The sum of LREEs ranges from 42.1 to 163.18 whereas, the sum of HREEs ranges from 8.83 to 15.98 (Table 2; Fig. 3). The  $\Sigma\text{LREE}/\Sigma\text{HREE}$  ratio ranges from 4.77 to 11.28 (Table 2; Fig. 3). The  $\delta\text{Ce}$  value is ranging from 0.77 to 1.8 whereas,  $\delta\text{Eu}$  value is ranging from 0.62 to 0.66 (Table 2; Fig. 3).

### Normalized Patterns of REEs

The UCC normalised REEs distribution patterns of CLC sediments show a broadly similar trend among all four zones (Fig. 4). This indicates a consistent REE source and geochemical behaviour throughout the core. The normalised concentrations are generally close or slightly above 1, except for 'Ce' in all the zones (Fig. 4). The enrichment of 'Ce' is particularly prominent in zone-A, where the normalised concentration reaches above 2.75, followed by zone-C, where it reaches up to 2 (Fig. 4). In the zone-B, normalised 'Ce' reaches up to 1.5, whereas it shows comparatively lowest value (Fig. 4). LREEs such as La, Pr and Nd show low values, whereas 'Sm' and 'Eu' show little enrichment (Fig. 4). HREEs such as Gd, Dy, Lm and Tu show high enrichment whereas Tb, Ho, Er and Yb show moderate enrichment (Fig. 4). The broadly parallel nature of the REE patterns suggests that the sediments have experienced similar provenance and depositional control (Fig. 4).

## DISCUSSIONS

The sedimentary sequence records considerable fluctuations in hydroclimatic conditions, sediment characteristics, and weathering intensity throughout the core (Fig. 3). The variations in grain size and degree of chemical weathering provide evidence for alternating phases of enhanced and reduced moisture availability, whereas the predominance of oxic to sub-oxic conditions throughout the succession suggests that changes in depositional redox conditions were comparatively limited (Fig. 3).

### Paleo-Climate and Paleo-Weathering

In the zone-A (48-36cm), the continuous declining trend of  $\Sigma\text{REEs}$  is observed, reflecting humid to semi-humid climate (Liu and Zhao, 2026). This condition confirms heavy rainfall throughout this zone as proved by decreased  $\Sigma\text{LREE}/\Sigma\text{HREE}$  ratio (Wu et al., 2026), and thus, the zone experiences high chemical weathering (Sandeep et al., 2022) (Fig. 3). The zone-B acts like a transition period, where semi-humid conditions were observed, as indicated by increasing  $\Sigma\text{REEs}$  (Liu and Zhao, 2026). This condition reflects moderate to low rainfall as shown by increasing  $\Sigma\text{LREE}/\Sigma\text{HREE}$  ratio (Wu et al., 2026) (Fig. 3). Thus, the zone-B shows moderate chemical weathering (Sandeep et al., 2022) (Fig. 3).

Zone-C show continuous increase in  $\Sigma\text{REEs}$ , reflecting arid and cold climatic conditions (Liu and Zhao, 2026). This results in low intensity of chemical weathering (Sandeep et al., 2022) as indicated by high  $\Sigma\text{LREE}/\Sigma\text{HREE}$  ratio (Wu et al., 2026) (Fig. 3). After the period of this dramatic climate, the conditions are again moving towards the warm and humid environment (Fig. 3). Similar humid conditions were continued throughout the zone-D, reflecting moderate chemical weathering (Fig. 3).

### Paleo-Redox

The basal part of the sequence is characterized predominantly by oxic and conditions, as indicated by elevated  $\delta\text{Ce}$  values, particularly at 46 cm ( $\delta\text{Ce} = 3.73$ ), 40–37 cm ( $\delta\text{Ce} = 2.21\text{--}2.46$ ), and 34–31 cm ( $\delta\text{Ce} \approx 2.01\text{--}2.03$ ). These values suggest oxygen availability in the depositional environment (Wang et al., 2024) at the beginning of zone-A. The persistence of oxic signatures in the lower part indicates that the lake bottom likely experienced relatively well oxygenated conditions during the earlier stage of sediment accumulation (Wang et al., 2024). In the upper section, the redox regime becomes more variable. Strongly oxidizing/sub-oxic conditions are recorded at 42 and 36 cm, whereas the interval around 27 cm shows a transition toward oxic/oxidizing conditions. Thus, Zone B represents a transitional

and fluctuating redox phase rather than a uniformly reducing environment. The zone-C is predominantly characterized by oxic to suboxic conditions, However, a distinct reducing/anoxic episode occurs around 17.5–15 cm, where  $\delta\text{Ce}$  reaches 2.46–3.20. This indicates highly oxygenated conditions generally prevailed, the lake experienced episodic development of oxygen-rich bottom waters. The uppermost sediments show a clear shift toward more oxygenated and oxidizing conditions. The shallowest samples at 1–4 cm have  $\delta\text{Ce}$  values close to 1 (0.77–1.08) and are classified as oxic, while 6–11 cm are predominantly oxic–suboxic.

## CONCLUSIONS

The vertical variability in chemical weathering intensity and inferred moisture conditions indicates that the studied lake–catchment system experienced repeated environmental variations during the period represented by the sediment sequence. The succession from Zone D through Zone A indicates repeated hydroclimatic fluctuations. Therefore, the combined evidence supports an interpretation of alternating humid and relatively dry phases, accompanied by corresponding changes in catchment weathering, under broadly oxic to sub-oxic conditions. The paleo-redox pattern indicates decreased oxygen availability toward the recent depositional period and suggests that the lake became poorly oxygenated as compared with the deeper sediments.

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**Table 1:** Concentrations of Rare Earth Elements in the Chodha Lake Core Sediments

| Depth (cm) | La (ppm) | Ce (ppm) | Pr (ppm) | Nd (ppm) | Sm (ppm) | Eu (ppm) | Gd (ppm) | Tb (ppm) | Dy (ppm) | Ho (ppm) | Er (ppm) | Tm (ppm) | Yb (ppm) | Lu (ppm) |
|------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 1          | 8.454    | 19.68    | 2.442    | 9.12     | 1.986    | 0.414    | 1.938    | 0.354    | 2.34     | 0.468    | 1.5      | 0.27     | 1.686    | 0.276    |
| 3          | 34.506   | 56.898   | 8.154    | 29.46    | 5.55     | 1.074    | 4.758    | 0.738    | 4.29     | 0.738    | 2.304    | 0.366    | 2.232    | 0.348    |
| 4          | 31.686   | 73.038   | 7.614    | 26.898   | 5.142    | 1.038    | 4.554    | 0.714    | 4.23     | 0.804    | 2.394    | 0.39     | 2.502    | 0.39     |
| 6          | 26.922   | 102.324  | 6.432    | 22.11    | 4.488    | 0.906    | 4.014    | 0.636    | 3.858    | 0.714    | 2.16     | 0.36     | 2.352    | 0.378    |
| 7          | 19.848   | 79.728   | 5.262    | 18.714   | 3.666    | 0.78     | 3.396    | 0.552    | 3.198    | 0.6      | 1.794    | 0.312    | 1.944    | 0.312    |
| 9          | 21.576   | 88.164   | 5.562    | 19.614   | 3.786    | 0.792    | 3.582    | 0.558    | 3.276    | 0.594    | 1.776    | 0.3      | 1.914    | 0.306    |
| 11         | 25.614   | 90.678   | 6.666    | 23.382   | 4.614    | 0.948    | 4.146    | 0.678    | 4.02     | 0.756    | 2.316    | 0.396    | 2.556    | 0.408    |
| 15         | 30.924   | 163.566  | 7.524    | 27.084   | 5.208    | 1.062    | 5.064    | 0.756    | 4.314    | 0.804    | 2.394    | 0.39     | 2.52     | 0.396    |
| 16.6       | 45.6     | 309.168  | 10.62    | 36.18    | 7.134    | 1.464    | 6.846    | 0.972    | 5.478    | 0.966    | 2.856    | 0.474    | 2.958    | 0.456    |
| 17.5       | 61.566   | 176.802  | 13.824   | 47.166   | 8.874    | 1.758    | 7.974    | 1.224    | 7.266    | 1.368    | 4.212    | 0.72     | 4.542    | 0.702    |
| 19.5       | 14.97    | 21.966   | 4.776    | 17.592   | 3.606    | 0.768    | 3.246    | 0.6      | 3.78     | 0.762    | 2.358    | 0.42     | 2.742    | 0.444    |
| 21         | 8.502    | 33.078   | 2.466    | 8.91     | 1.866    | 0.438    | 1.734    | 0.3      | 1.854    | 0.366    | 1.146    | 0.198    | 1.248    | 0.192    |
| 23         | 22.398   | 64.968   | 4.788    | 17.754   | 3.834    | 0.786    | 2.844    | 0.498    | 3.192    | 0.63     | 1.842    | 0.306    | 1.902    | 0.276    |
| 25.5       | 38.802   | 130.842  | 8.82     | 31.23    | 6.036    | 1.242    | 5.346    | 0.846    | 4.896    | 0.906    | 2.7      | 0.462    | 2.802    | 0.444    |
| 26.5       | 18.846   | 161.97   | 4.842    | 16.902   | 3.336    | 0.738    | 3.486    | 0.51     | 3.036    | 0.576    | 1.776    | 0.306    | 1.896    | 0.294    |
| 29         | 25.962   | 88.812   | 6.51     | 22.824   | 4.344    | 0.912    | 3.918    | 0.618    | 3.822    | 0.696    | 2.142    | 0.36     | 2.304    | 0.372    |
| 31         | 17.442   | 77.934   | 4.59     | 16.152   | 3.216    | 0.678    | 2.982    | 0.468    | 2.91     | 0.528    | 1.644    | 0.288    | 1.806    | 0.294    |
| 34         | 19.068   | 79.23    | 4.056    | 14.85    | 3.24     | 0.654    | 2.406    | 0.414    | 2.556    | 0.504    | 1.452    | 0.246    | 1.44     | 0.204    |
| 37         | 21.606   | 118.134  | 5.664    | 20.094   | 3.936    | 0.804    | 3.732    | 0.57     | 3.354    | 0.612    | 1.86     | 0.306    | 1.962    | 0.294    |
| 40         | 29.91    | 135.516  | 6.39     | 23.73    | 5.016    | 1.02     | 3.996    | 0.648    | 4.038    | 0.78     | 2.286    | 0.378    | 2.328    | 0.348    |
| 42         | 46.386   | 224.022  | 11.064   | 39.936   | 7.728    | 1.584    | 7.182    | 1.068    | 6.06     | 1.098    | 3.348    | 0.558    | 3.36     | 0.534    |
| 44         | 30.054   | 138.954  | 7.35     | 26.394   | 5.298    | 1.116    | 4.86     | 0.786    | 4.47     | 0.822    | 2.484    | 0.414    | 2.706    | 0.414    |

**Table 2:** Physical characteristics of Rare Earth Elements in the Chodha Lake Core Sediments

| Depth (cm) | $\Sigma$ REEs | $\Sigma$ LREEs | $\Sigma$ HREEs | $\Sigma$ LREEs/ $\Sigma$ HREEs | $\delta$ Ce | $\delta$ Eu |
|------------|---------------|----------------|----------------|--------------------------------|-------------|-------------|
| 1          | 50.928        | 42.096         | 8.832          | 4.766                          | 1.007       | 0.637       |
| 3          | 151.416       | 135.642        | 15.774         | 8.599                          | 0.774       | 0.624       |
| 4          | 161.394       | 145.416        | 15.978         | 9.101                          | 1.076       | 0.642       |
| 6          | 177.654       | 163.182        | 14.472         | 11.276                         | 1.777       | 0.64        |
| 7          | 140.106       | 127.998        | 12.108         | 10.571                         | 1.801       | 0.665       |
| 9          | 151.8         | 139.494        | 12.306         | 11.335                         | 1.854       | 0.648       |
| 11         | 167.178       | 151.902        | 15.276         | 9.944                          | 1.6         | 0.65        |
| 15         | 252.006       | 235.368        | 16.638         | 14.146                         | 2.456       | 0.624       |
| 16.6       | 431.172       | 410.166        | 21.006         | 19.526                         | 3.202       | 0.632       |
| 17.5       | 337.998       | 309.99         | 28.008         | 11.068                         | 1.375       | 0.627       |
| 19.5       | 78.03         | 63.678         | 14.352         | 4.437                          | 0.607       | 0.673       |
| 21         | 62.298        | 55.26          | 7.038          | 7.852                          | 1.679       | 0.733       |
| 23         | 126.018       | 114.528        | 11.49          | 9.968                          | 1.415       | 0.698       |
| 25.5       | 235.374       | 216.972        | 18.402         | 11.791                         | 1.607       | 0.655       |
| 26.5       | 218.514       | 206.634        | 11.88          | 17.393                         | 3.904       | 0.657       |
| 29         | 163.596       | 149.364        | 14.232         | 10.495                         | 1.569       | 0.663       |
| 31         | 130.932       | 120.012        | 10.92          | 10.99                          | 2.01        | 0.659       |
| 34         | 130.32        | 121.098        | 9.222          | 13.131                         | 2.03        | 0.687       |
| 37         | 182.928       | 170.238        | 12.69          | 13.415                         | 2.464       | 0.632       |
| 40         | 216.384       | 201.582        | 14.802         | 13.619                         | 2.21        | 0.674       |
| 42         | 353.928       | 330.72         | 23.208         | 14.25                          | 2.26        | 0.64        |
| 44         | 226.122       | 209.166        | 16.956         | 12.336                         | 2.142       | 0.661       |
| 46         | 372.39        | 353.88         | 18.51          | 19.118                         | 3.732       | 0.645       |

**Table 3:** Normalized concentrations of Rare Earth Elements in the Chodha Lake Core Sediments with Chondrite values

| Depth (cm) | La      | Ce      | Pr     | Nd    | Sm     | Eu     | Gd     | Tb     | Dy     | Ho     | Er     | Tm     | Yb     | Lu     |
|------------|---------|---------|--------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 1          | 27.271  | 24.356  | 20.016 | 15.2  | 10.185 | 5.633  | 7.483  | 7.468  | 7.267  | 6.518  | 7.143  | 8.333  | 8.067  | 8.571  |
| 3          | 111.31  | 70.418  | 66.836 | 49.1  | 28.462 | 14.612 | 18.371 | 15.57  | 13.323 | 10.279 | 10.971 | 11.296 | 10.679 | 10.807 |
| 4          | 102.213 | 90.394  | 62.41  | 44.83 | 26.369 | 14.122 | 17.583 | 15.063 | 13.137 | 11.198 | 11.4   | 12.037 | 11.971 | 12.112 |
| 6          | 86.845  | 126.639 | 52.721 | 36.85 | 23.015 | 12.327 | 15.498 | 13.418 | 11.981 | 9.944  | 10.286 | 11.111 | 11.254 | 11.739 |
| 7          | 64.026  | 98.673  | 43.131 | 31.19 | 18.8   | 10.612 | 13.112 | 11.646 | 9.932  | 8.357  | 8.543  | 9.63   | 9.301  | 9.689  |

|      |             |             |             |           |            |            |            |            |            |            |            |            |            |            |
|------|-------------|-------------|-------------|-----------|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| 9    | 69.6        | 109.11<br>4 | 45.59       | 32.6<br>9 | 19.41<br>5 | 10.77<br>6 | 13.83      | 11.77<br>2 | 10.17<br>4 | 8.273      | 8.457      | 9.259      | 9.158      | 9.503      |
| 11   | 82.626      | 112.22<br>5 | 54.639      | 38.9<br>7 | 23.66<br>2 | 12.89<br>8 | 16.00<br>8 | 14.30<br>4 | 12.48<br>4 | 10.52<br>9 | 11.02<br>9 | 12.22<br>2 | 12.23      | 12.67<br>1 |
| 15   | 99.755      | 202.43<br>3 | 61.672      | 45.1<br>4 | 26.70<br>8 | 14.44<br>9 | 19.55<br>2 | 15.94<br>9 | 13.39<br>8 | 11.19<br>8 | 11.4       | 12.03<br>7 | 12.05<br>7 | 12.29<br>8 |
| 16.6 | 147.09<br>7 | 382.63<br>4 | 87.049      | 60.3      | 36.58<br>5 | 19.91<br>8 | 26.43<br>2 | 20.50<br>6 | 17.01<br>2 | 13.45<br>4 | 13.6       | 14.63      | 14.15<br>3 | 14.16<br>1 |
| 17.5 | 198.6       | 218.81<br>4 | 113.31<br>1 | 78.6<br>1 | 45.50<br>8 | 23.91<br>8 | 30.78<br>8 | 25.82<br>3 | 22.56<br>5 | 19.05<br>3 | 20.05<br>7 | 22.22<br>2 | 21.73<br>2 | 21.80<br>1 |
| 19.5 | 48.29       | 27.186      | 39.148      | 29.3<br>2 | 18.49<br>2 | 10.44<br>9 | 12.53<br>3 | 12.65<br>8 | 11.73<br>9 | 10.61<br>3 | 11.22<br>9 | 12.96<br>3 | 13.12      | 13.78<br>9 |
| 21   | 27.426      | 40.938      | 20.213      | 14.8<br>5 | 9.569      | 5.959      | 6.695      | 6.329      | 5.758      | 5.097      | 5.457      | 6.111      | 5.971      | 5.963      |
| 23   | 72.252      | 80.406      | 39.246      | 29.5<br>9 | 19.66<br>2 | 10.69<br>4 | 10.98<br>1 | 10.50<br>6 | 9.913      | 8.774      | 8.771      | 9.444      | 9.1        | 8.571      |
| 25.5 | 125.16<br>8 | 161.93<br>3 | 72.295      | 52.0<br>5 | 30.95<br>4 | 16.89<br>8 | 20.64<br>1 | 17.84<br>8 | 15.20<br>5 | 12.61<br>8 | 12.85<br>7 | 14.25<br>9 | 13.40<br>7 | 13.78<br>9 |
| 26.5 | 60.794      | 200.45<br>8 | 39.689      | 28.1<br>7 | 17.10<br>8 | 10.04<br>1 | 13.45<br>9 | 10.75<br>9 | 9.429      | 8.022      | 8.457      | 9.444      | 9.072      | 9.13       |
| 29   | 83.748      | 109.91<br>6 | 53.361      | 38.0<br>4 | 22.27<br>7 | 12.40<br>8 | 15.12<br>7 | 13.03<br>8 | 11.87      | 9.694      | 10.2       | 11.11<br>1 | 11.02<br>4 | 11.55<br>3 |
| 31   | 56.265      | 96.453      | 37.623      | 26.9<br>2 | 16.49<br>2 | 9.224      | 11.51<br>4 | 9.873      | 9.037      | 7.354      | 7.829      | 8.889      | 8.641      | 9.13       |
| 34   | 61.51       | 98.057      | 33.246      | 24.7<br>5 | 16.61<br>5 | 8.898      | 9.29       | 8.734      | 7.938      | 7.019      | 6.914      | 7.593      | 6.89       | 6.335      |
| 37   | 69.697      | 146.20<br>5 | 46.426      | 33.4<br>9 | 20.18<br>5 | 10.93<br>9 | 14.40<br>9 | 12.02<br>5 | 10.41<br>6 | 8.524      | 8.857      | 9.444      | 9.388      | 9.13       |
| 40   | 96.484      | 167.71<br>8 | 52.377      | 39.5<br>5 | 25.72<br>3 | 13.87<br>8 | 15.42<br>9 | 13.67<br>1 | 12.54      | 10.86<br>4 | 10.88<br>6 | 11.66<br>7 | 11.13<br>9 | 10.80<br>7 |
| 42   | 149.63<br>2 | 277.25<br>5 | 90.689      | 66.5<br>6 | 39.63<br>1 | 21.55<br>1 | 27.73      | 22.53<br>2 | 18.82      | 15.29<br>2 | 15.94<br>3 | 17.22<br>2 | 16.07<br>7 | 16.58<br>4 |
| 44   | 96.948      | 171.97<br>3 | 60.246      | 43.9<br>9 | 27.16<br>9 | 15.18<br>4 | 18.76<br>4 | 16.58<br>2 | 13.88<br>2 | 11.44<br>8 | 11.82<br>9 | 12.77<br>8 | 12.94<br>7 | 12.85<br>7 |

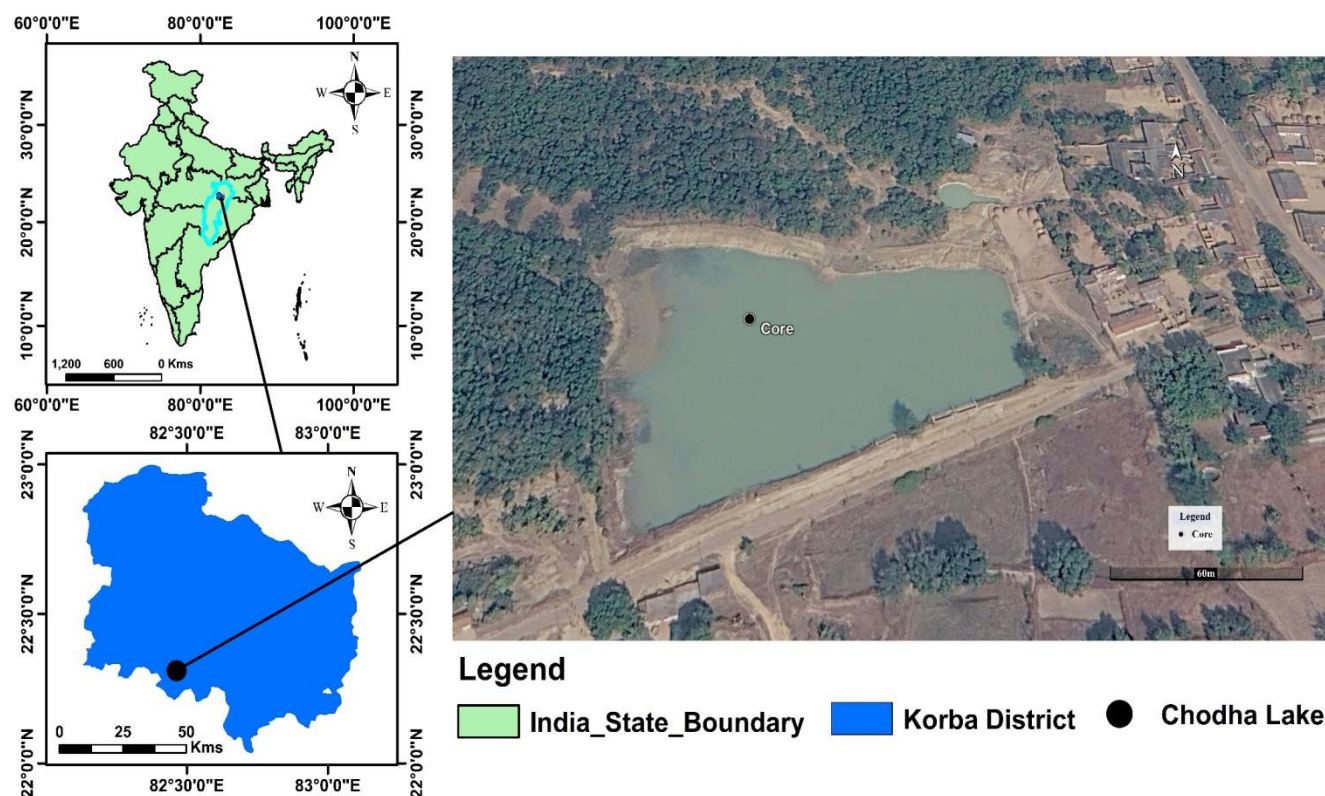


Fig. 1: Location Map of the Study area

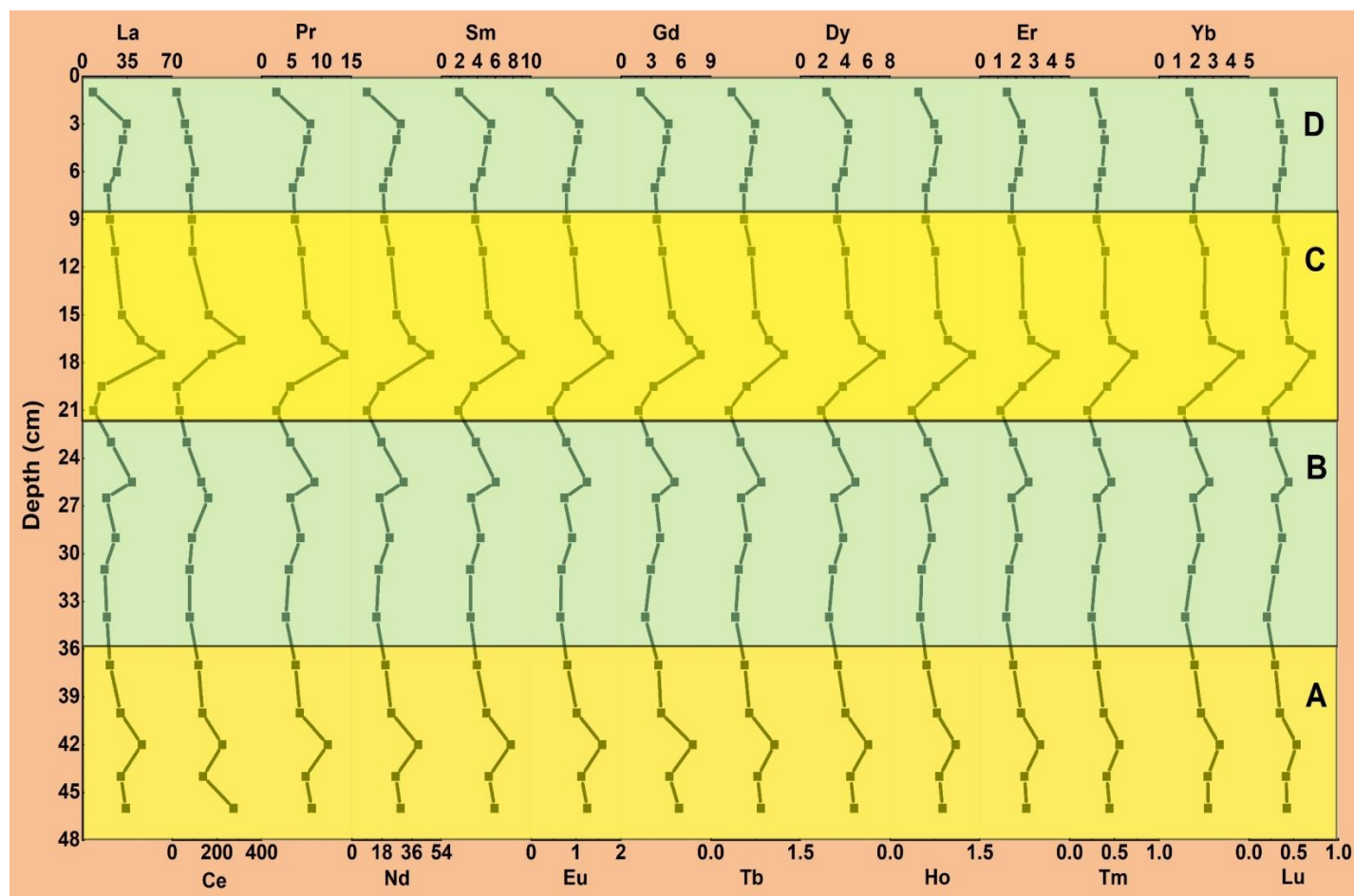


Fig. 2: Vertical Distribution of REEs in Chodha Lake Core Sediments

Fig. 3: Characteristics of Rare Earth Elements the Chodha Lake Core Sediments

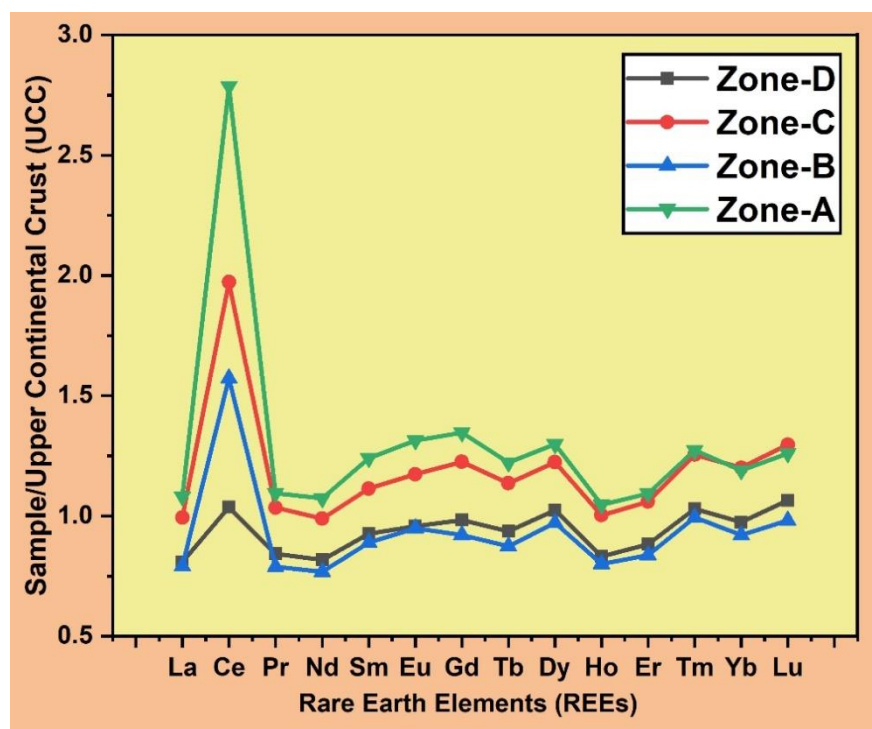
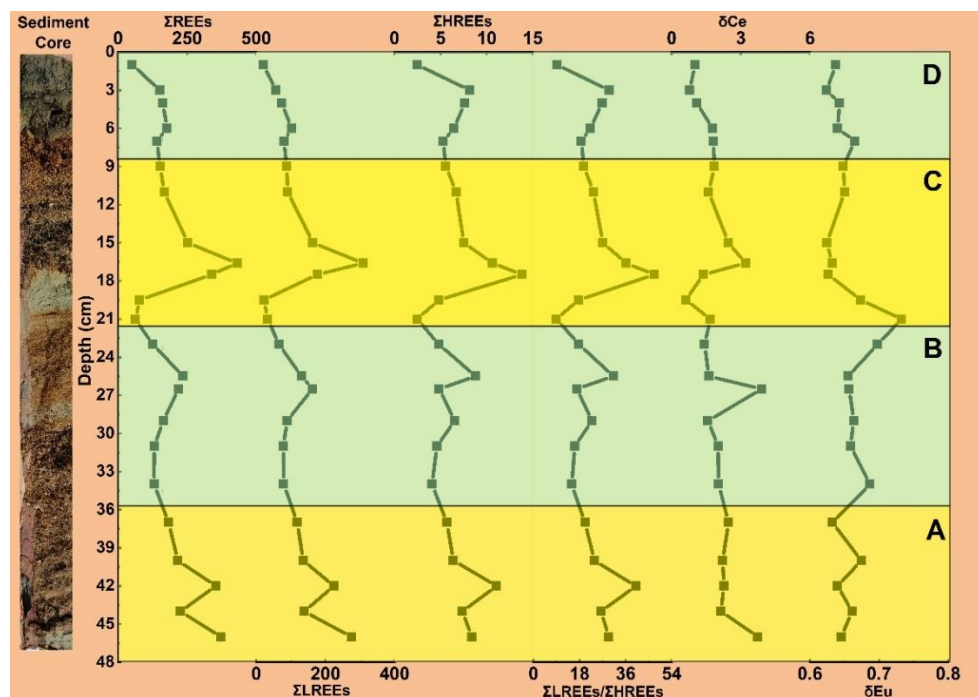


Fig. 4: Rare Earth Elements distribution patterns normalized to UCC