Rare Earth Elements Exploration in River Sediments (Belihul oya and Samanala wewa Areas, Sri Lanka)

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Abstract

The global REE deposits are mostly associated with carbonatites, alkaline igneous rocks, ion adsorption clay deposits and placers. In this context, previous geochemical studies of alluvial beds in Sri Lanka have disclosed significant concentrations of REEs. Moreover, the Walawe river basin is located at the boundary between Highland Complex and Vijayan Complex, which is a highly mineralized belt. Therefore, this study is focused on assessing the REE potential of stream sediments in Samanala-wewa reservoir and its upstream and downstream areas (i.e. Walawe river basin). The collected samples (n=26, covering 9 locations associated with Walawe river, Belihul Oya, Hiriketi Oya and Denagan Oya) were processed (< 63 µm grain size) and analyzed using XRD to identify their mineralogy. Monazite, bastnaesite, loparite and xenotime are the major RE minerals found in these samples. Additionally, the sampling locations were confined to six stream paths and a correlation was found between the stream order, and the number of REEs present at the location. Overall, this study provides a qualitative interpretation of the REEs present in the stream sediments of the study area. However, detailed quantitative analyses are required to further assess the true REE potential in this prospect.

Keywords: Alluvial placer deposits, Rare Earth Elements, Sri Lanka, Stream sediments, Walawe river basin

1. Introduction

Rare Earth Elements (REEs) are relatively inert and spread in small concentrations in the Earth's crust. There are 17 identified rare earth elements, including 15 Lanthanides with Y and Sc. Generally, REEs are found in trivalent oxidation state, but a few have other oxidation states as well. For example, cerium, praseodymium, and terbium can be found in tetravalent state, whereas samarium and europium can be found in divalent state [1]. Due to this, their charge density and the field strength tend to differ and, they appear as highly electropositive compounds. Due to such unique physical and chemical properties, REEs are considered to be useful for various technological applications [2]. REEs are not rare even if the name implies. For example, they are more abundant in Earth's crust than other valuable elements, such as gold and silver. REEs are spread all over the planet, in relatively small concentrations and rarely found in economic concentrations. Therefore, the term "rare" is used [3].

Currently, over 200 rare earth bearing minerals are identified, globally [4]. The dispersion of REEs is controlled by chemical and physical weathering. After weathering, REEs along with other elements are carried out by water and sunk in streams derived by surrounding watersheds. Basically, REEs are concentrated in igneous rocks, pegmatites, iron-oxide copper-gold deposits and marine phosphates [5], [6]. Weathering of such rock types form sediments that contain REEs. Due to the degree of weathering and erosion the concentration patterns of REEs may vary. In addition, different size fractions of the particles, associated with their concentrations present an overview of the placement of the possible sources of REEs. Moreover, the geology of the above-mentioned rock types governs the possibility of REEs concentration in surrounding streams and reservoirs.

REEs show immobile characteristics in any system due to incompatibility. Due to this immobility, they are found to be enriched in certain geological formations, especially in stream sediments [7]. Stream sediments are favourable media for elements to be accumulated and their compositions are representative of the catchment area [8]. Rainfall is one major factor that promotes the weathering action to accumulate elements in sediments. In Sri Lanka, monsoonal and tropical humid conditions are abundant throughout the year [9]. Such conditions facilitate high degree of physical weathering and sedimentation in drainage systems. Due to the island wide availability, stream sediment explorations are highly involved in geological interpretations of Sri Lanka [10].

2. Methodology

2.1 Study Area

Walawe river basin encloses an area of approximately 2400 km^2. It is one of the economically and geologically important river systems in the south of Sri Lanka [8]. According to the geology of the basin, there are pegmatites and intrusive rocks, with REEs potential. The boundary between Highland Complex and Vijayan Complex, divides the river basin into two segments. This mineralized belt naturally creates a potential for heavy minerals and REEs to deposit at the lower segment of the basin as well. Generally, REEs tend to be enriched in several rock forming minerals, such as monazite, apatite, sphene (titanite), zircon, garnets, and epidote. They are abundant in many pegmatites and carbonatites [11].

Almost 90% of Sri Lanka consists of metamorphic rocks. They are divided into three main units, Highland Complex (HC), Vijayan Complex (VC) and Wanni Complex (WC), with respect to their age, metamorphic grades and geology [12]. The Highland Complex is known for the above-mentioned REEs bearing rock types, predominantly pegmatites and intrusive rocks. Our study is focused on Samanala-wewa reservoir and its upstream and downstream flows. (Fig. 1).

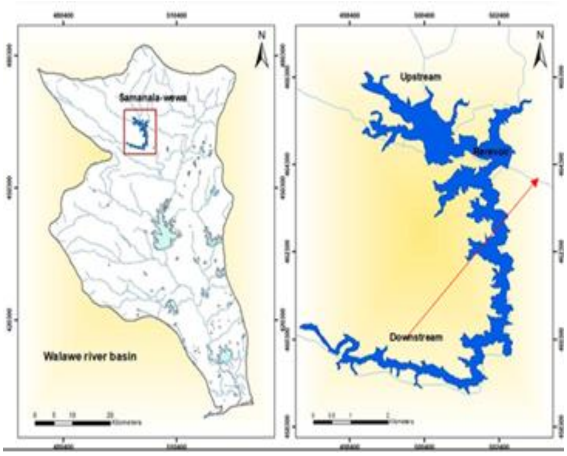

Figure 1 – Study area (Samanala wewa and Belihul oya areas.)

Samanala-wewa reservoir is in the Highland Complex. Furthermore, the upper catchment contains weathered pegmatites along with other rock types. Thus, Samanala-wewa reservoir can be considered as a sink for REEs, derived from the weathered products of rocks. The twisted shape of the downstream of the Samanala-wewa reservoir provides a natural suitability of sediments to be accumulated more than in other locations.

2.2 Sample collection

Following the literature, regarding previous REE explorations carried out in the Walawe river basin, Samanala-wewa reservoir, upstream and downstream regions were selected as the study area. During the field visits, 26 sediment samples and one sand sample was collected from six locations in the upstream region and in one location at the downstream. Samples were collected after panning initial sediment collection. Sampling locations are listed in the Table 1.

2.3 *Sample Analysis*

The mineralogical analysis was carried out using X-Ray Diffraction (XRD) technique. Out of 26, 15 selected samples were subjected to Wilfley table process (with a table angle of 8.43^0 and a water inflow rate of 28.55 ml/s) to separate concentrates. Then the concentrates were oven dried at 100^0C - 120^0C, for 8 – 10 hours. After that further comminution was done using tema mill. The powdered output was sieved and the portion passing through 63 µm was subjected to XRD analysis at the 2-theta range of 5^0-80^0. However, another portion of dried samples was subjected to sieve analysis to plot the particle size distribution. Match.v3 software was used to analyse the X-ray diffractogram for each sample.

Table. 1: Sampling locations

Location Name	Sample Name	Latitude	Longitude
Hiriketi Oya	13 SE 1	6.72123	80.78238
Belihul Oya	13 SE2	6.716280	80.769150
Denagan Oya	13 SE3	6.694610	80.749810
Walawe River (Upstream)	13 SE 4	6.657620	80.712780
Belihul Oya	B1 - A	6.716490	80.768850
	B1 - B	6.716488	80.768845
	B2	6.716455	80.769206
	B3	6.716480	80.769510
	B4	6.715950	80.770240
	B5	6.715786	80.770472
	B6 - A	6.716440	80.769671
	B6 - B	6.716440	80.769670
	B7	6.716568	80.769321
	B8 - A	6.716109	80.769134
	B8 - B	6.716109	80.769134
	B9	6.716500	80.768820
Puwakgahawela (A stream connecting with Hirikatu Oya	P1	6.722360	80.797930
	P2 - A	6.722333	80.797997
	P2 - B	6.722333	80.797997
	P3	6.722235	80.797853
Walawe River	W1	6.664070	80.880280
	W2	6.664009	80.880390
	W3	6.663900	80.880257
	W4	6.663900	80.880330
A stream connecting with Walawe River	SE 1	6.663930	80.646920
	SE 3	6.664750	80.647520

3. Results

From results obtained for the 15 representative samples, Rutile, Zircon, Magnetite, Garnet, Ilmenite were present as heavy minerals, whereas Calcite, Apatite, Feldspar and Quartz were present as associated light minerals. When identifying REE bearing minerals, "Excellent quality of diffraction pattern" and the higher figure-of-merit (FoM) values for each composition was considered. By studying the XRD phase reports of each individual sample, Table 2 was prepared. This information was further used to assess various relationships between the parameters. Presence of REEs and other associate minerals can be listed as follows:

Table. 2: Presence of REE at different locations

Sample Name	Location Name	Location		REE present	Number of Elements
		Latitude	Longitude		
13 SE2	Belihul Oya	6.716280	80.769150	Ce, La, Gd, Nd, Pr, Sm, Y, Dy, Er, Yb, Eu, Tm	12
13 SE3	Denagan Oya	6.694610	80.749810	Ce, La, Gd, Nd, Pr, Sm, Y, Ge, Dy, Er	10
13 SE 4	Walawe River	6.657620	80.712780	Ce, La, Nd, Dy, Er, Gd, Sm, Y, Yb, Lu, Eu	11
B1 - B	Belihul Oya	6.716488	80.768845	Ce, La, Nd, Pr, Sm, Y, Yb	7
B2	Belihul Oya	6.716455	80.769206	Ce, La, Y, Ge, Yb, Nd, Pr	7
B5	Belihul Oya	6.715786	80.770472	Ce, La, Nd, Y, Yb.	5
B6 - A	Belihul Oya	6.716440	80.769671	Ce, La, Gd, Nd, Pr, Sm, Y, Yb, Ge	9
B7	Belihul Oya	6.716568	80.769321	Ce, La, Yb, Y	4
B8 - B	Belihul Oya	6.716109	80.769134	Ce, La, Nd, Y, Eu.	5
P2 - B	Puwakgahawela (A stream connecting with Hirikatu Oya	6.722333	80.797997	Ce, La, Eu, Ge, Gd, Yb, Pr, Y, Dy, Er, Nd, Tb	12
P3	Puwakgahawela (A stream connecting with Hirikatu Oya	6.722235	80.797853	Ce, La, Dy, Er, Gd, Nd, Yb, Y, Pr, Ge	10
W2	Walawe River	6.664009	80.880390	Ce, La, Nd, Y, Yb, Ge, Tb	7
W3	Walawe River	6.663900	80.880257	Ce, La, Eu, Y, Ge, Nd, Tb	7
SE 1	A stream connecting with Walawe River	6.663930	80.646920	Ce, La, Nd, Sm, Y, Gd, Pr, Dy, Yb, Tb	10
SE 3	A stream connecting with Walawe River	6.664750	80.647520	Ce, La, Nd, Sm, Y, Gd, Pr, Dy, Yb, Tb	10

When studying the stream order at the study area along with the amount of REEs present, streams varying from order 1 to 6 could be identified.
For this the "stream order" tool available in ArcMap 10.5 was used (Fig. 2). However, the relationship between the stream order and the number of REEs present is tabulated in Table 3. The graphical representation is given by Figure 3.

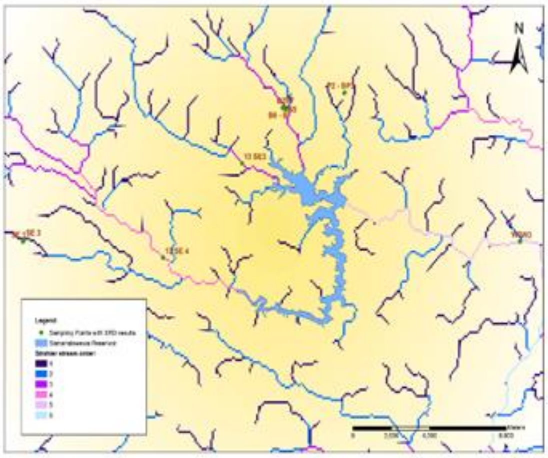

Figure. 2: Sampling locations and stream order of the territory

Table. 3: Relationship with streams, stream order and number of Rare Earth Elements present.

Stream Name	Upstream/ Downstream	Samples	Stream Order	Number of REE present
Denagan Oya	Upstream	13 SE 3	3	10
Walawe River	Upstream	13 SE 4	4	11
Belihul Oya	Upstream	13 SE 2, B1 - B, B2, B5, B6 - A, B7, B8 - B	3	7
Puwakgahawela (A stream closer to Hiriketi Oya)	Upstream	P 2 - B, P3	1	4,5
Near Massenna Zircon Granite rock outcrop (A stream connecting to Walawe River)	Upstream	SE 1, SE 3	1	10
Walawe River	Downstream	W2, W3	1	7

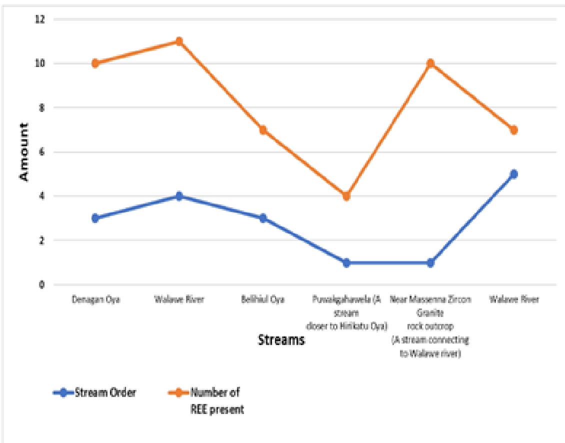

Figure. 3: Graphical representation for the relationship between the stream order and the number of REEs present in each stream

Thereby, the sieve analysis was carried out for the representative dried samples, using 1400, 1180, 850, 500, 425, 300, 250, 212, 180, 90, 75, 63 microns and results were obtained to assess the grain size distribution along 4 representative streams at the upstream (Fig. 4).

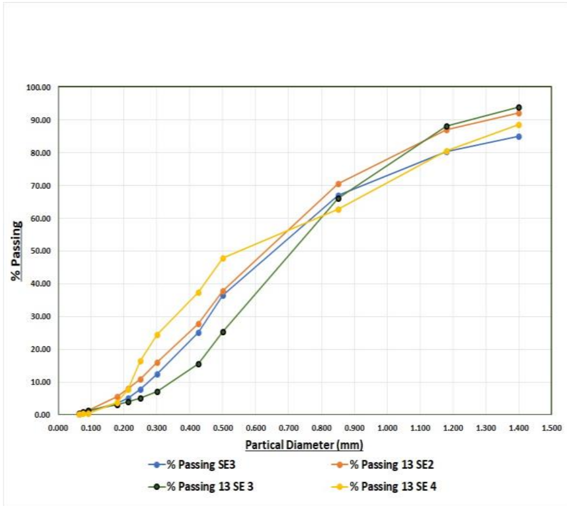

Figure. 4: Particle size distribution curve.

4. Discussion

Aforesaid six streams were selected to justify the sampling locations and 4 stream paths showed a positive correlation, whereas two anomalies were identified, each from upstream and downstream. The reason for the positive correlation was due to high stream orders, the stream span is high. Since a relatively larger catchment area is available for the sediments to be accumulated, higher number of REEs can be expected to be present. However, at the stream closer to the Massenna Zircon Granite, higher number of REEs was recorded despite the lowest river order. It might be due to the proximity to the source. Massenna zircon granite is identified as a massive pegmatite, prone to contain REEs. At the Walawe river branch, a lesser number of REEs were recorded even if the stream order was high. The reason might be due to the distance (approximately 10 km) from the reservoir.

From the particle size distribution data, it could be noted that 4 upstream sediment samples that represented the stream paths, were poorly or moderately sorted. It implies that there has not been enough time for the particles to settle. The average distance to the afore-said sampling locations from the reservoir was approximately 5 km. Therefore, it could be identified that the source might be in a relative proximity. However, the proximity alone will not impact the poor grading. In case of beach sand, the well grading happens despite the proximity of the source. If the transporting media is weak, the grading happens in a poor manner. Therefore, the impact from the proximity of the source and the strength of the transporting medium must have contributed for the poor grading of sediments at upstream.

5. Conclusions

Abundance of Rare Earth Elements in mineral compounds in the study area, were successfully identified in a qualitative manner. Sampling locations could be confined to 6 major stream paths. Out of them, Walawe river branch (upstream) has the majority of Rare Earth Elements. In upstream, number of REE was found to increase with the stream order. Results for the samples at the Massenna Zircon Granite and the downstream Walawe river branch was anomalous due to the afore-said reasons. However, more sampling from the reservoir area along with advanced analysis such as ICP-MS can generate a clear understanding about the REE concentration in the study area.

Acknowledgements

The authors are thankful to the following personnel and institutions who helped us in various ways and means to make this research project, a success. The academic and non-academic staff of the Department of Earth Resources Engineering, University of Moratuwa, the Department of Materials Science, University of Moratuwa and the Faculty of Applied Sciences, University of Sri Jayewardenapura.

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