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Potential of Thorium-Bearing Minerals from an Abandoned Radioactive Mineral Mine in Neluwa, Sri Lanka

Yapa YMIDA, Jathursan P, Indula NAS, *Vijitha AVP, Ratnayake NP, Premasiri HMR, Abeysinghe AMKB and Rohitha LPS

Department of Earth Resources Engineering, University of Moratuwa, Sri Lanka.

*Corresponding author – vijitha@uom.lk

Abstract

Sri Lanka hosts historically significant thorianite deposit in the Neluwa region, which may still contain valuable thorium-bearing minerals. Renewed global interest in thorium for advanced clean energy technologies, higher technological applications, and national economic development underscores the importance of this study. This research investigates the presence and distribution of thorium through mineralogical and geochemical analyses of the abandoned mine. Sampling involves surface sediment samples, pegmatitic rock, subsurface sediments, and plants. A multidisciplinary approach for field inspections including radiometric surveys, heavy mineral separation using bromoform, microscopic analysis to identify thorianite crystals and elemental analysis using Inductively Coupled Mass Spectrometry (ICP-MS) to quantify targeting thorium. The results provide insight into zones with potential for thorium, significant surface sediments, subsurface sediments, rock, and plants. The findings suggest that the Neluwa abandoned mine represents a significant natural trap for thorium-bearing heavy minerals, particularly in subsurface sediments. While mineralogical and geochemical evidence supports resource potential, the observed bioaccumulation underscores environmental and health risks. This study highlights the value of integrated geochemical and mineralogical approaches in evaluating radioactive mineral anomalies.

Keywords: Geochemical Analysis, Radiation Survey, Sri Lanka, Thorianite, Thorium, Uranium

1 Introduction

Thorium is a naturally occurring radioactive element which is three to four times more abundant than uranium [1]. It is approximately 6 to 10 parts per million (ppm) in the Earth's upper crust. Its dominant isotope is thorium-232(Th-232), and it has a half-life of 14.05 billion years [2]. This isotope produces a series of radionuclides including radium-228 and radon-220(thoron), which can impact ecosystems and human health through long-term exposure.

Globally, thorium resources are estimated at over 6.2 million tonnes, according to the International Atomic Energy Agency (IAEA) and the Organization for Economic Co-operation and Development (OCED) Nuclear Energy Agency (NEA) report. Thorium deposits are categorised into four principal classes of deposits, which are placer deposits, carbonatite-hosted deposits, vein deposits, and alkaline rock-hosted deposits [3].

Geologically, thorium occurs in igneous environments like granites and pegmatites, where it concentrates in final-stage crystallisation and carbonatites. Alkaline rock-hosted deposits provided a smaller contribution to global thorium content. Secondary placer deposits are formed due to weathering and fluvial transport [4]. Thorium naturally occurs in a group of minerals that include monazite, thorite, thorianite, and some rarer forms such as allanite and zircon [5].

Thorianite (ThO_2), containing 70–90% thorium dioxide, is a major thorium-rich mineral mostly present along with uranium dioxide (UO_2). It is a rare and dense oxide mineral, which denotes its genesis in high-temperature igneous and metamorphic settings. Its colour is black to dark gray with a cubic crystal habit and a vitreous to submetallic lustre. It is the densest thorium mineral, as its Specific Gravity (SG) is approximately 9.7-10 [6].

It crystallizes in granitic pegmatites and alkaline intrusions as a primary formation. Secondary thorianite placer deposits weather from igneous sources and deposits (due to the density and hardness of thorianite) in river bottoms and beaches through water flow. Sri Lanka has a long history of thorium discovery, with thorianite first identified in Rathnapura gem gravels in the early 20th century [7].

Subsequent occurrences were reported in Maddegama, Bambarabotuwa in Balangoda, We-Ganga, and Kondurugala [7], [8], [9]. Moreover, thorianite was mined in the Maddegama area by a group of Canadian people during the period of 1905-1906, and it was exported at £1,700 per ton and used for the manufacture of incandescent gas mantles [10]. However, small-scale thorianite mining activities were terminated due to the decrease in global demand for thorianite at that time.

The growing global demand for thorium underscores the strategic importance of potential identification from the maddegama abandoned mine in Neluwa, where thorianite indicates significant untapped reserves. This study aims to assess the distribution of thorium in an abandoned mining site at Maddegama, evaluating its potential for resource recovery.

2 Methodology

2.1 Study Area and Geological Setting

This study employed a multidisciplinary methodology that incorporated radiometric surveys, chemical digestion, elemental analysis, and mineralogical identification. Each stage was designed to extract accurate data that could establish the thorium potential and distribution across the abandoned mine site.

The research focuses on an abandoned radioactive mineral mine in Pahala Maddegama village located within Neluwa Divisional Secretariat of Galle District, Sri Lanka as the study area.

Figure 1: Google Earth image: Aerial view of the abandoned mine site

Geologically, this area is a part of the Highland Complex, a Precambrian high-grade metamorphic terrane within Sri Lanka's crystalline basement. Dominant lithologies include garnet sillimanite, schists and gneisses, quartz-feldspar, granulites, charnockitic gneisses and crosscutting pegmatite intrusions, which may be significant for thorium mineralization.

The target location is primarily underlain by coarse-grained pegmatites, which are indicative of potential thorianite mineralisation.

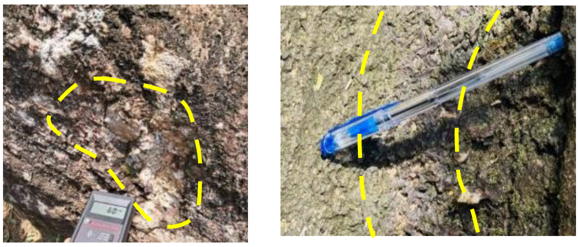

Figure 2: Coarse-grained pegmatites in surface rocks

The abandoned mine was situated at the base of a hill with low relief terrain, suggesting it may act as a natural trap for facilitating the deposition of heavy minerals such as thorianite. Minerals may be mobilised from elevated source rocks, and the stream flowing through the area may act as the primary agent of sediment transport while enhancing the potential for downstream accumulation.

Furthermore, the lower section of this low-lying area is a soil sedimented terrain with a vegetation cover through which the stream continues to flow. It further supports alluvial or colluvial accumulation where favourable for thorianite enrichment.

2.2 Radiometric Survey

An initial reconnaissance survey was conducted using a portable Geiger Counter (Radalert 100X, Model R100X), to measure the surface radioactivity. It can provide real-time radioactivity measurements in counts per minute (CPM) and micro-Sieverts per hour(µSv/h). The instrument was verified against known background radiation level prior to the field visit to ensure its operational accuracy under field conditions.

Figure 3: Radiometric measurement of gneiss outcrops

Figure 4: Radiometric measurement of pegmatitic rocks

The survey was conducted to take random measurements directly from exposed outcrops and hard specimens of both pegmatitic and gneiss rocks, which were identified within the area. Approximately 60 CPM to 200 CPM values were detected on some rocks and surrounding ground surfaces. Each measurement was recorded after a brief stabilization period to ensure consistent reading.

2.3 Mineralogical Characterization

Mineralogical analysis was carried out on the heavy mineral fraction of the bulk samples. The 125–177 µm fraction was sieved and subjected to bromoform (SG = 2.85) heavy mineral separation. Magnetic minerals such as ilmenite were removed manually using a hand magnet, and non-magnetic residues were mounted on slides for microscopic identification of thorianite by following its optical properties.

2.4 Sampling

Surface rock and sediment samples were randomly collected with the use of a hammer and hand auger. Samples were collected from locations with high radioactivity, as indicated by the Geiger counter. Two additional sediment samples were collected from Nawadiya Ela (a nearby stream historically related to regional gem gravels). Additionally, a gem-gravel sample was obtained from the historically mined site. It was exhibited with a radioactivity level of approximately 200 CPM.

Figure 5: Representative field samples: **left**; surface sediment, **right upper**; gem gravel, and **right below**; stream sediment.

Two subsurface samples were obtained from two locations at depths of approximately 1 m using a borehole drilling machine. The primary objective was to capture buried mineral accumulations within the sedimented terrain.

Additionally, three plant samples; *Lasia spinosa* and grass, including roots, stems, and leaves, were collected from the vegetation cover in the sedimented terrain to evaluate the bioaccumulation of radioactive elements.

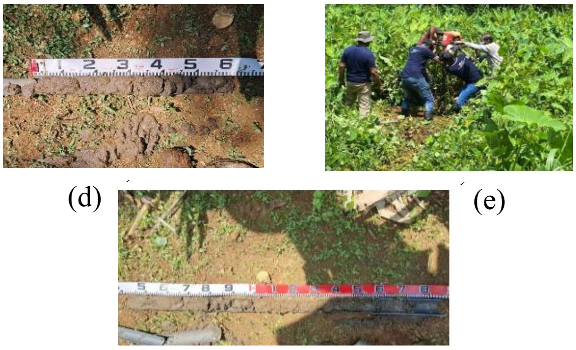
(d) (e)
(f)

Figure 6: Subsurface sampling process: (d) first core sample, (e) drilling operation, and (f) second core sample.

2.5 Sample Preparation

Figure 7: Plant sampling –*Lasia spinosa* and grass

Detailed laboratory analysis was conducted for the samples taken at the field. Sediment, gem, rock, and plant samples were analysed at the laboratories. For the sediment samples, the cone and quartering method was followed to obtain a representative sample from the collected samples.

Afterwards, all sediment samples were dried at 105°C for about 24 hours to remove the moisture. Separately, sediment samples were sieved into 2mm, 1mm, and 63 µm fractions using a dry sieving method, and the fraction <63 µm was selected for acid digestion. The fraction retained on the 1 mm sieve was crushed using a disc mill, and the passing fraction through 63µm was selected for acid digestion to increase the accuracy of the results.

Rock samples were crushed using a Jaw crusher, ground in a disc mill, and passed through a 63µm sieve used for acid digestion. A similar procedure was followed for gem sample preparation.

Furthermore, plant samples were dried at 105°C for 48 hours, and afterwards, those were subjected to ignite in a muffle furnace at 550°C for 3 hours, which were then used as ash samples for digestion.

Each sample underwent the Aqua Regia digestion. Approximately 0.5 g of each sample (rock, sediment and plant samples) with 5mL of acid volume. The mixture was refluxed for 3 hours at 110°C on a temperature-controlled hot plate and diluted up to 100 times using distilled water.

Then all samples were collectively subjected to Inductively Coupled Plasma Mass Spectrometry (ICP-MS) to determine concentration of total of twenty trace elements (Li, Be, Sc, V, Cr, Mn, Ga, As, Rb, Sr, Y, Zr, Nb, Cs, Ba, Tl, Pb, Bi, Th, U).

Figure 8: Sample preparation and digestion for ICP-MS

3 Results and Discussion

3.1 Radioactivity Measurement

Several locations within the mined site were evaluated using the Geiger counter to identify radiometric anomalies associated with pegmatitic and gneiss rock formations. The gneiss rocks consistently exhibited low CPM values in the range of 20 to 40 CPM. These values fall within the expected natural background radiation levels and suggest a negligible concentration of radioactive minerals in these rock types.

In contrast, pegmatitic rocks displayed significantly elevated radioactivity, with CPM values ranging from 80 to 220 CPM. The highest reading 220 CPM was recorded adjacent to a weathered pegmatite outcrop located in proximity to an abandoned mine site. This aligns with previous studies in Sri Lanka and India, where pegmatitic intrusions are known to host thorium-rich minerals [8], [9]. The spatial correlation between high CPM values and pegmatite exposures suggests that these rock types are the primary hosts of radioactive elements in the area.

Although the survey confirms elevated levels of natural radioactivity in pegmatitic zones, it does not conclusively identify the specific radionuclides responsible. Although the proximity to a former thorianite mine strongly suggests thorium as a likely source, the contribution of other radionuclides such as uranium cannot be ruled out.

3.2 Microscopic Analysis

Microscopic examination confirmed the presence of black, isotropic thorianite crystals. It exhibits a distinct cubic crystal structure as Figure 9.

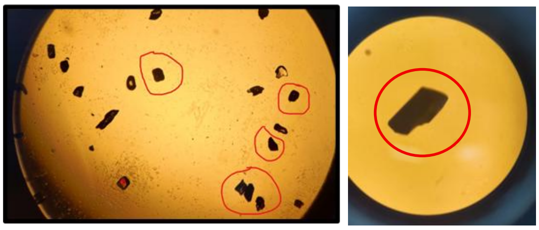

Figure 9: Thorianite crystals identified using microscope

Thorianite crystals displayed a metallic to resinous lustre under plane polarized light and remained optically isotropic. Although thorianite presents significant level, it reflects genetic link to the pegmatitic source rocks and validates historical thorianite occurrence in the region.

Moreover, the heavy mineral concentration exhibits a significantly higher abundance of monazite, as shown in Figure 10. The dominance of monazite in heavy mineral fraction validates the existence of a thorium enrichment, as it is a well-established pathfinder mineral for thorium. These mineralogical observations validate the potential enrichment of thorium within this region.

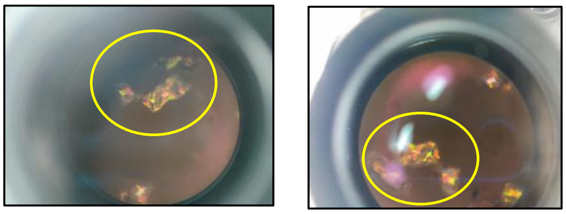

Figure 10: Monazite identified at a higher percentage within several samples

3.3 ICP-MS Analysis

ICP-MS analysis of 28 selected samples showed thorium concentrations ranging from 30 ppm to 293.16 ppm. Sediment samples (e.g., B2_5 and B2_6) demonstrated higher values than the Upper Continental Crust value (UCC), which is 10.70 ppm. Also, those are exceeding 200 ppm, suggesting potential secondary concentration.

Table 1: Total elemental content of each sample

Sample ID	Sample Type	Thorium (ppm)
L1_R1	Pegmatitic Rock	12.320
L1_R2	Pegmatitic Rock	4.440
L1_R3	Pegmatitic Rock	126.290
L1_R4	Pegmatitic Rock	108.000
L1_F_S1	Surface Sediment	150.660
L1_C_S1	Surface Sediment	55.090
L1_F_S2	Surface Sediment	146.180
L2_C_S1	Surface Sediment	205.540
L2_C_S2	Surface Sediment	183.870
L3_F_S1	Surface Sediment	96.530
B1-1	Subsurface Sediment	150.990
B1-2	Subsurface Sediment	259.560
B1-3	Subsurface Sediment	143.270
B1-4	Subsurface Sediment	221.280
B1-5	Subsurface Sediment	214.990
B1-6	Subsurface Sediment	213.680
B2-1	Subsurface Sediment	173.660
B2-2	Subsurface Sediment	151.720
B2-3	Subsurface Sediment	293.160
B2-4	Subsurface Sediment	214.230
B2-5	Subsurface Sediment	128.690
B2-6	Subsurface Sediment	16.700
P1	Plant-Ash	52.750
P2	Plant-Ash	128.240
P3	Plant-Ash	10.080
Gem	Gem Gravel	5909.640

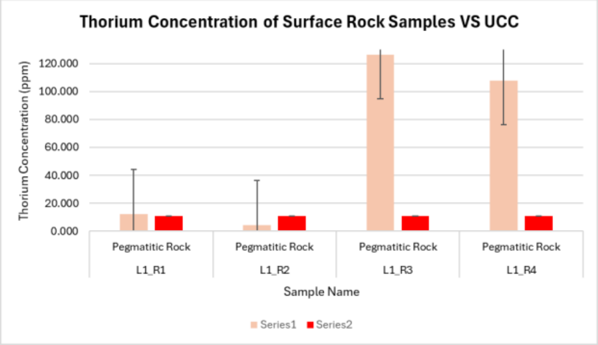

Figure 11: Thorium concentration of rock samples compared with UCC values

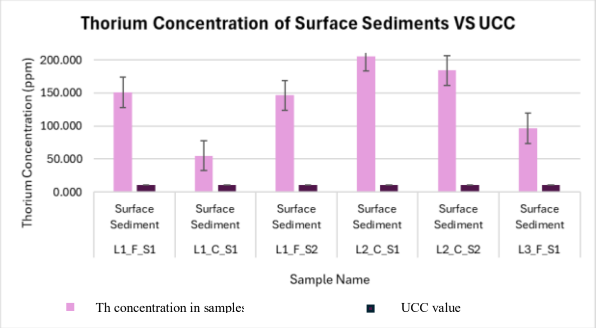

Figure 12: Thorium concentration of surface sediment compared with UCC values

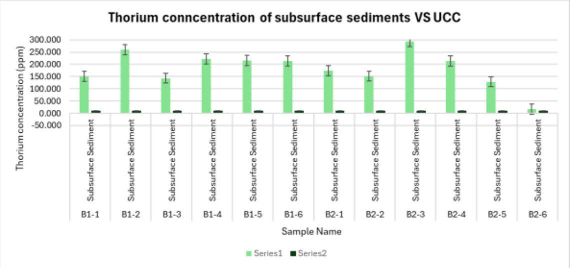

Figure 13: Thorium concentration of subsurface sediments compared with UCC values

The thorium (^{232}Th) concentration graphs Figure 11,12 and 13 are comprehensive illustrations of thorium distribution over rock and sediments in Maddegama area compared with the Upper Continental Crust (UCC) reference value of 10.70 ppm [11], [12]. It highlights the relative thorium abundance in different sample types and locations and hence delineates geochemically anomalous areas from background levels.

Pegmatitic rocks showed variable concentrations (4–126 ppm), reflecting localized enrichment zones within the host lithology (Figure 11). Surface sediments contain thorium levels between 55 and 205 ppm (Figure 12).

Subsurface sediments exhibited even higher concentrations, ranging from 128 to 293 ppm. These results suggest that the low-relief sedimentary terrain functions as a natural trap, concentrating heavy minerals through alluvial and colluvial processes. These sediments are having comparable grade compared to reported global thorium-bearing placer deposits, which typically range from 100–500 ppm.

The most striking anomaly was detected in gem gravel samples, with thorium concentrations exceeding 5900.640 ppm. Such extreme enrichment underscores the potential of secondary deposits as high-grade thorium sources, an aspect rarely quantified in Sri Lankan literature.

In plant samples thorium was detected concentrations of 10–128 ppm as in Table 1, which is several orders of magnitude above typical background values (~0.1 ppm foliage, ≤1 ppm roots) reported in international studies [13]. The presence of thorium in vegetation indicates enhanced bioavailability and ecological mobility. It contradicts the general assumption that thorium is largely immobile in soil–plant systems.

Compared with UNSCEAR (2000) baselines, which estimate dietary thorium intake at <1 Bq/day (equivalent to <0.1 ppm in plants) [14]. The values reported here correspond to 41–520 Bq/kg [15], a significant elevation.

The correlation between radiometric readings and thorium concentrations reinforces the utility of combining field detection with geochemical validation. Sediments and soils downstream from weathered pegmatitic sources proved particularly enriched, emphasising the presence of thorium anomalies.

As a summary, the display values exceeding 10 to 20 times the UCC standard, as in Figure 11,12 and 13, allow to indicate moderate thorium enrichment. These indications suggest that both surface weathering and subsurface accumulation contribute to thorium dispersion and concentration in this region.

4 Conclusion

This study evaluated the potential for thorium-bearing minerals from the abandoned thorianite mineral mine in the Neluwa region of Sri Lanka. It focused on geochemical and mineralogical characterization along with mineralogical analysis and environmental impact. Field investigations within the selected region followed by heavy mineral separation, microscopic analysis, and ICP-MS analysis. All these analyses validate geological enrichment of thorium, particularly from rocks and sediments from weathered pegmatitic rock.

Microscopic analysis validated the presence of a significant amount of thorianite with aits optical properties, and it highlights the presence of a historical abandoned mine at that area. Additionally, the presence of monazite in several heavy mineral samples validates the presence of thorium within that area.

Thorium concentrations exceeded 200ppm in several samples which is 20 times above the UCC value. It concludes that the abandoned mine site has geological enrichment of thorium anomalies. The subsurface samples showed comparatively higher values than rock and surface sediments. It suggests that the area is a natural trap for heavy mineral accumulation.

Plant sample analysis revealed significant thorium anomalously high thorium concentrations, far exceeding global background levels. This indicates that thorium is at least partially bioavailable in the Maddegama environment while contradicting traditional assumptions of its immobility. Such findings raise concerns about ecological transfer and long-term environmental contamination. Gradually, thorium level in surface soils can be reduced with the use of phytoremediation programs using accumulating plant species such as *Sunflower*, *Indian mustard,* where shows high thorium levels.

Overall, the geochemical and mineralogical information confirms that the Maddegama area has thorium anomalies within areas of pegmatitic exposure. Expanded exploration, such as systematic geochemical soil surveys and shallow borehole sampling, can be used for further investigation to evaluate the enrichment of thorium. In proper environmental control with a further focused exploration, this occurrence promises to help Sri Lanka's strategic mineral resource base. Particularly for future thorium-based technological pursuits.

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