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Radiological Assessment of Samanalawewa Quarry Site: An Initiative for Site Specific Rehabilitation Approaches

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Abstract

Abandoned quarry sites require suitable rehabilitation approaches based on comprehensive assessments. Site characterization based on slope stability, rock properties, weathering, geological and hydrological information are common for such purposes. This study attempts to integrate in-situ and ex-situ radioactivity measurements for site characterization, through gamma ray spectrometry analysis of representative soil and rock samples collected from the site. The mean values of activity concentrations of K-40, U-238, and Th-232 in rock samples were 694.38 Bq/kg, 38.70 Bq/kg, and 60.63 Bq/kg respectively. In soil samples, the mean values of activity concentrations were 637.04 Bq/kg for K-40, 23.73 Bq/kg for U-238, and 90.52 Bq/kg for Th-232. All these values except U-238 in soil exceed global average concentrations for soil radiation, indicating significant radiological signatures. These results were correlated with the field observations and records at the Samanalawewa abandoned quarry site which included rock properties including color, weathering, and rock types. Accordingly, higher radioactivity records on less weathered, light-colored rocks like feldspathic gneiss, while relatively lower levels were found in highly weathered, dark-colored rocks like biotite gneiss. The findings highlight the importance of assessing radioactivity alongside rock property characteristics to develop effective and safe rehabilitation strategies for abandoned quarries.

Keywords: Abandoned quarry, Gamma-ray spectrometry, Radioactivity, Rehabilitation

1 Introduction

Abandoned quarries, defined as “industrial pits discarded after their exploitation” [1] may cause serious environmental, social, and safety challenges. If left without proper rehabilitation these sites may experience unsafe and unstable steep slopes, deep waterlogged areas and general landscape degradation. Slope failures, soil erosion and groundwater contamination could be inevitable under such conditions endangering the neighbouring communities. Quarry sites which are abandoned without any clear post-operational management strategy, may lead to prolonged environmental concerns [2] on surrounding ecosystems, harming aquatic habitats and increasing soil and water toxicity.

The reasons for quarry abandonment may arise from various factors, including cease of operations due to depletion of extractable material, unfavorable geological conditions, regulatory restrictions, operational hazards, socio-economic shifts, or a lack of financial viability [3]. In many instances, quarrying operations terminate without a proper closure plan or post-mining rehabilitation activity, due to business aspects such as financial investments that will not provide direct returns. Furthermore, legislative issues, ambiguous procedures and limited funding may also hinder the rehabilitation initiatives.

Rehabilitation practices in Sri Lanka tend to be generic and mostly not tailored to cater the specific socio-environmental needs. Mostly, rehabilitation plans are formulated based on initial site conditions prior to the quarry operations with limited room for adopting the post mining site conditions. As a result, many rehabilitation attempts remain incomplete or ineffective, failing to restore ecological balance or meet community expectations.

In contrast, abandoned quarries can be transformed into ecologically beneficial and economically productive landscapes with comprehensive studies on structural, environmental and socio-economic conditions to adopt the local requirements. Depending on the specific needs and characteristics of the locality, there are reservoirs, recreational areas, or even residential developments [4], [5], [6] have been reported on abandoned quarry sites. Furthermore, there are several studies that have documented diverse approaches of rehabilitating abandoned quarry sites worldwide [7].

Considerations on rock stability and properties such as discontinuities, mineral composition, weathering grade and color are common in site assessment for rehabilitation. Lack of studies on radiological measurements of sites hinder information on potential radiation hazards. Hence, evaluating the presence of primordial radionuclides such as Potassium-40 (K-40), Uranium-238 (U-238), and Thorium-232 (Th-232) could assist in quantifying the site-specific natural radiation risks, as reported from several studies. Crushed rock samples from quarries in Nigeria using gamma-ray spectrometry revealed all radiological indices, including Radium equivalent value (Ra_{eq}) and hazard indices, were below global safety limits, and minimal health risks [8]. Having high radionuclide concentrations in granite samples from Malaysia, have recorded hazard indices below one, confirming low radiological risks [9]. In contrast, soil samples examined from Ethiopian quarry sites exceeded global averages for uranium and thorium levels, and calculated hazard indices remained under critical thresholds [10].

Therefore, radioactivity measurements seem an essential parameter in site investigations for rehabilitation purposes, considering long-term health and environmental risks that could be associated with prolonged exposure to radioactive environments. However, guidelines or monitoring mechanisms to assess radioactivity in quarry sites do not exist to date in the Sri Lankan context. This research intends to propose a systematic approach for site characterization including field observations and laboratory testing of rock and soil samples for the measurement of radionuclide activity levels. It further seeks to understand how these radiation levels influence the rehabilitation approaches and repurposed site use.

Accordingly, a case study in Samanalawewa abandoned quarry was conducted for on-site and laboratory radiation measurements with reference to the available information on rock characteristics, conditions and degree of anomalous weathering. This study also aims to explore the influence of radioactivity on rock weathering and propose site specific rehabilitation strategies to promote sustainable use of land. Therefore, effective and evidence-based rehabilitation practices may be formulated to address the broader socio-economic and environmental considerations leading to a systematic framework to manage the abandoned quarry sites in Sri Lanka.

2 Methodology

2.1 The Study Area

The selected study site, Samanalawewa abandoned quarry is situated in the southern central part of Sri Lanka (Figure) approximately 160 km off Colombo. This area lies within the intermediate climatic zone of Sri Lanka, surrounding the coordinates 6.79597 °N latitude and 80.805063 °E longitude. It receives over 2500 mm of average annual rainfall, with the majority contributed by the southwestern monsoon and additional, though lesser, amounts from the northeastern monsoon and inter-monsoon cyclones. The region experiences temperatures between 19 °C and 30 °C, at an elevation ranging from 150 to 650 m above mean sea level.

Geologically, the abandoned quarry is located at the boundary of the Highland Complex, specifically the Kaltota Formation, which consists of high-grade metamorphic rocks such as gneisses, granulites, quartzites, and marbles. The gneisses are predominantly composed of quartz, feldspar, and biotite, with accessory minerals including sillimanite, amphiboles, and pyroxene. The quarry site is publicly accessible and has been developed through systematic bench blasting during the construction of the Samanalawewa hydropower project and its rock filled dam. Most remarkable observations on the site includes, soil generated from extreme weathering experienced by sections of the exposed rocks (Figure 1), randomly distributed white colored precipitation on the rocks (Figure), water seepage and waterlogged areas with trapped air bubbles mostly during wet seasons (Figure 3).

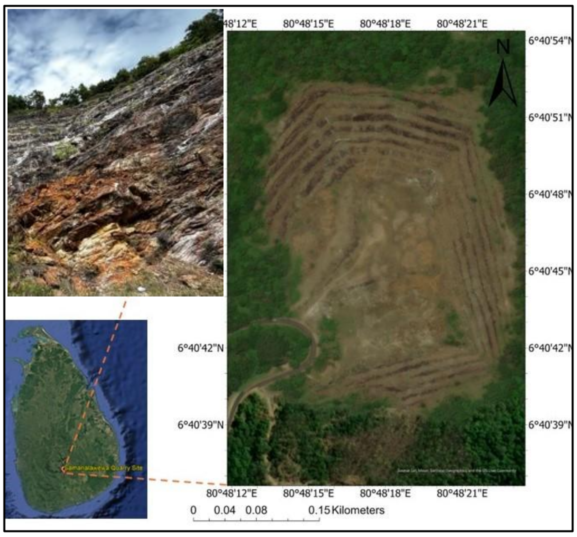

Figure 1: Study site with unusual weathering

Figure 2: White coloured precipitation on rocks

Figure 3: Trapped air bubbles in waterlogged areas

2.2 Sample Collection and Preparation

Four main regions as A, B, C, and D were identified within the site, based on varying rock types, weathering conditions and diverse characteristics observed. A total of 15 samples were collected from the four regions, including 05 rock samples (AR, BR, CR1, CR2 and DR) and 10 soil samples, for laboratory tests (Figure 5). Soil samples consist of two from each location (one from the ground near the rock surface and the other 20 m away from the first sample) and one each from the entrance to the quarry site and out of the quarry site.

The in-situ radiation measurements and representative sample collection was performed on these clusters (Figure 5). A reference grid of 1 m×1 m was constructed on the ground at each region for soil sampling (Figure 4). The grid was sub-divided into nine equal areas and samples were collected from 1,3,5,7, and 9 sections.

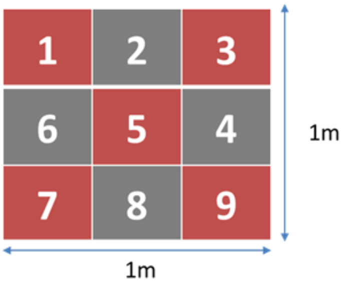

Figure 4: Grid used for soil sample collection

All the soil samples were collected into labelled resealable plastic bags from a depth of no more than 1 cm below the ground surface. Location coordinates of each sample were recorded using Placer.ai software and indicated by Table 1.

Table 1: Coordinates of sample locations

Sample locations	Latitude (°N)	Longitude (°E)
Rock		
AR	6.6802267	80.8046883
BR	6.6801866	80.8047787
CR1	6.6799833	80.8048733
CR2	6.6800600	80.8053683
DR	6.6799183	80.8053383
Soil		
AS1	6.6801866	80.8047787
AS2	6.6799833	80.8048733
BS1	6.6799183	80.8053383
BS2	6.6797369	80.8050445
CS1	6.6795950	80.8054117
CS2	6.6795400	80.8051700
DS1	6.6793767	80.8054667
DS2	6.6793100	80.8052550
ES	6.6794183	80.8047933
FS	6.6742317	80.8056212

Figure 5: Aerial view of the sampling regions and sample locations (14 in total) of the quarry site

In-situ radiation measurements at each sampling location were recorded using a dosimeter Radiagem^{TM} 2000 (Canberra) (Figure 6) during the field visit on 31st of October 2024. The in-situ radiation survey covered selected representative regions of the Samanalawewa quarry site, though it was not on a predefined grid.

Figure 6: Dosimeter

Laboratory analysis of rock and soil samples for radioactivity were conducted at the Counting Lab, Nuclear Science Department, University of Colombo from December 2024 to May 2025 using Gamma-ray Scintillation Spectrometer (Figure 7). The sample preparation included air drying of soil samples for two weeks prior to sieving through 1mm. Sieved samples were oven dried for 24 hours and sealed in a container for 21 days to come to an equilibrium state.

The rock samples were crushed and sieved using 1.18 mm sieve at the Rock Mechanics Laboratory, University of Moratuwa. Sieved samples were dried in oven for 24 hours and sealed in containers for 21 days identically to the soil samples before transferring for the laboratory analysis for radioactivity.

Figure 7: Gamma-ray spectrometer

2.3 Gamma-ray Scintillation Spectrometry Analysis

The activity concentrations of natural radionuclides K-40, U-238, and Th-232 were measured using a Gamma-ray spectrometer equipped with a NaI (TI) detector. USX software was used to compute the spectra of radionuclides. First energy calibration and shape calibration were completed before testing for background radiation levels. Samples obtained from the International Atomic Energy Authority (IAEA) and available at the laboratory were used as the standards for K-40, U-238, and Th-232 radionuclides.

Matrix method was used to calculate the activity concentrations of K-40, U-238 and Th-232 of each sample, when the gamma spectra for test samples were conducted. The 3×3 matrix of observed count rate [R] was calculated using Equation 1.

$$[R] = [A] \times [C] + [B] \quad (1)$$

Where;

[R] - 3×3 matrix of observed count rate in counts per second.

[A] - 3×3 matrix of the calibration coefficient (calculated using the IAEA standard samples); [C] - 3×3 matrix of the nuclide concentration in Bq/kg.

[B] - 3×1 matrix of background count rate in counts per second.

3 Results

3.1 Radioactivity

The in-situ radiation values at the Samanalawewa abandoned quarry site are shown in Table 2. Laboratory results of activity concentrations calculated using matrix method (Equation 01) for radionuclides K-40, U-238, and Th-232 are shown in Table .

Table 2: In-situ radiation values at sample locations and survey points

Sample Location Code	In-situ Radiation (μSvh^{-1})
AR	0.05
AS1	0.00
AS2	0.02
BR	0.05
BS1	0.05
BS2	0.10
CR1	0.43
CR2	0.14
CS1	0.01
CS2	0.01
DR	0.14
DS1	0.01
DS2	0.09
ES	0.10
Survey Point Code	**In-situ Radiation (μSvh^{-1})**
SV1	0.05
SV2	0.00
SV3	0.02
SV4	0.05
SV5	0.05
SV6	0.10
SV7	0.10
SV8	0.12
SV9	0.12
SV10	0.00

Table 3: Radioactivity concentration of rock and soil samples

Sample ID	^{40}K	^{238}U	^{232}Th
Rock Samples			
AR	976.47	57.02	174.09
BR	433.06	55.74	10.37
CR1	967.72	19.79	18.54
CR2	351.39	43.48	48.52
DR	743.09	17.45	51.64
Soil Samples			
AS1	825.38	8.86	79.00
AS2	898.87	9.03	87.75
BS1	803.03	10.95	87.58
BS2	487.60	16.16	95.76
CS1	571.33	25.39	48.80
CS2	689.94	12.67	112.92
DS1	315.24	25.10	87.04
DS2	527.25	47.90	55.76
ES	614.72	57.59	160.14

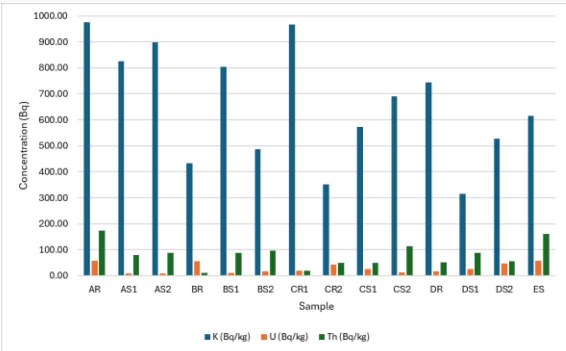

Figure 8: Radioactivity concentrations of K-40, U-238, and Th-232 for rock and soil samples

Table 4: Radioactivity concentration statistics for rock samples

Statistics	Rock sample (Bq/kg)		
	^{40}K	^{238}U	^{232}Th
Min.	351.39	17.45	10.37
Max.	976.47	57.02	174.09
Mean	694.35	38.70	60.63
SD	292.66	19.09	65.95

Table 5: Radioactivity concentration statistics for soil samples

Statistics	Soil sample (Bq/kg)		
	^{40}K	^{238}U	^{232}Th
Min.	315.24	8.86	48.8
Max.	898.87	57.59	160.14
Mean	637.04	23.73	90.52
SD	186.12	17.73	32.57

3.2 Rock Characteristics

Environmental setup and rock characteristics of the sampling regions were observed, identified and recorded as follows.

Region A: The reddish-brown rocks show chemical weathering and oxidation, with a mix of hard and crumbly textures, and a layered structure. The rock type has been identified as Biotite Gneiss.

Region B: The light-colored, foliated rock (likely gneiss or quartzite) shows alternating mineral bands, a coarse-grained texture from high-grade metamorphism, and minimal weathering, with fractures indicating physical stress can be identified as Quartzite.

Region C: The main rock type is metamorphic, likely gneiss or quartzite, suggested by greenish color, well-defined foliation, and coarse grain. Light and dark mineral bands indicate varied mineral composition. Multiple fractures and joints reflect significant weathering, while a rust-colored streak hints at iron oxidation. The rock type is classified as metamorphosed Charnockitic rocks.

Region D: The dark and reddish-brown color of the rock indicates highly weathered metamorphic rocks. Rock has appeared as porous due to the weathering induced voids. Differential lateritic weathering can be identified by the mixture of highly weathered and moderately weathered rock fragments. Traces of iron-rich minerals can be identified in the rock and can also be determined as this area belongs to Garnet-Biotite Gneiss.

4 Discussion

Recorded in-situ radiation measurements in the Samanalawewa abandoned quarry site reported the highest radiation dose of 0.43 μSvh^{-1} at CR1 sampling location. Lowest radiation doses were reported from sampling locations AS1, survey points 1, and 10. Variations of radiation measurements across the site are plotted by Figure . According to this plotted map it can be determined that higher in-situ radiation values have been recorded near the areas where less weathered rocks were present.

Contrasting in-situ radiation doses were recorded in nearby two locations in the region C. Therefore, separate rock samples were collected from each point as CR1 (0.43 μSvh^{-1}) and CR2 (0.14 μSvh^{-1}) to perform laboratory analysis separately. Comparatively lower weathering features demonstrated at CR1 location.

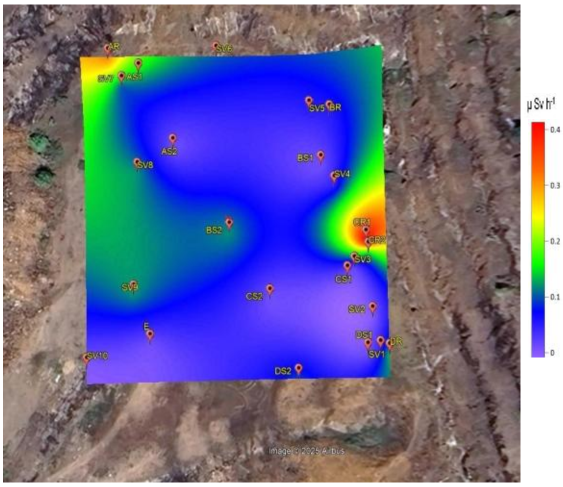

Figure 10: Variation of in-situ radiation

According to the laboratory results, activity concentration for radionuclides K-40, U-238, and Th-232, the highest was recorded from K-40 and the lowest was recorded by U-238. For rock samples, activity concentrations of K-40, U-238, Th-232, demonstrated a range of 351.39 to 976.47 Bq/kg, 17.45 to 57.02 Bq/kg, and 10.37 to 174.09 Bq/kg, with corresponding mean values of 694.38 Bq/kg, 38.70 Bq/kg, and 60.63 Bq/kg respectively (Table). These values indicate that K-40 is the most dominant radionuclide in the rock samples, which can be attributed to the abundance of potassium-bearing minerals such as feldspar and biotite within the metamorphic bedrock. In contrast, the comparatively lower concentrations of U-238 and Th-232 suggest either limited natural abundance or restricted geochemical mobility within the rock matrix under existing environmental conditions.

In soil samples, the activity concentrations ranged from 315.24 to 898.87 Bq/kg for K-40, 8.86 to 57.59 Bq/kg for U-238, and 48.80 to 160.14 Bq/kg for Th-232, with corresponding mean values of 637.04 Bq/kg, 23.73 Bq/kg, and 90.52 Bq/kg respectively (Table). High K-40 in soil could be due to potassium-rich minerals in the parent rock, like feldspar and biotite, and is further supported by organic matter that holds onto potassium ions in the soil. According to Figure , the highest activity concentration for K-40, U-238, and Th-232 recorded from, AR, ES, and AR respectively. The rock sample, AR shows less weathering than other rock samples with the highest K-40, U-238, and Th-232 activity concentration among rock samples. Minimum activity concentration for K-40, U-238, and Th-232 recorded from CR2, AS, and BR respectively.

Calculated mean values for all the three radionuclides except U-238 in soil samples exceed the global average (Table 6) according to the UNSCEAR, 2000b [11], [12].

Table 6: Results of this study compared to global reference values (Bq/kg) [11], [12].

Location		40-K (Bq/kg)	238-U (Bq/kg)	232-Th (Bq/kg)
Rock	Mean ± STD	694.34 ± 292.66	38.69 ± 19.09	60.63 ± 65.95
	Range	351- 977	17-57	10-174
Soil	Mean ± STD	637.04 ± 186.12	23.74 ± 17.73	90.53 ± 32.57
	Range	315-899	8-58	48-160
Global Mean		400	35	30

Source: (UNSCEAR, 2000b;).

In general, higher radioactivity values were reported from lesser weathered rock samples. Lower radioactivity values were reported from the samples that have undergone higher weathering activity.

However, activity concentrations of natural radionuclides can be influenced by several external factors such as sample size and site-specific characteristics which include groundwater condition, topography, fracturing and porosity. The corresponding results may vary due to any contamination, temperature differences and other disturbances like moisture content and surrounding environment inside the laboratory. Minor contamination was possible when preparing the samples by drying, crushing and milling. And the temperature also directly affects the result because the room temperature condition in the laboratory may vary with time. When there is a delay in the sample container sealing procedure moisture can be reabsorbed by soil and rock particles. These external factors may cause deviation of the results from real values and decrease the accuracy of the values.

The rock properties including colour, weathering condition and rock type were observed with a considerable variation across the quarry site. More light-coloured rock surface was observed at region B and C while Dark reddish coloured rock surface was observed at region D and A. Main rock type presented in quarry site was observed as metamorphic rocks. At region B minimal weathering was presented while high weathering features were observed at region D.

As the study site has undergone extreme weathering conditions which the underlying scientific phenomena are yet unclear, its radioactivity measurements could complement towards finding scientific reasons that accelerate the weathering process. As we observe intense weathering at random locations where disintegration of rock is possible even with a minimal force or soils have been developed as weathered products, any correlation to the radiation measurements could facilitate deducing potential chemical reactions that could have encountered over the short span of rock exposure to the atmospheric conditions.

Overall, this study underlines how important it is to include radiation measurements as a part of environmental assessment in abandoned quarry sites. When radiation data are considered alongside physical and chemical properties, they provide a clearer picture of how the site behaves and how safe it is for future use. Developing a consistent approach for such evaluations across similar sites would not only improve the scientific understanding of quarry environments but also help decision-makers plan rehabilitation in a safer and more sustainable way.

5 Conclusions

This study presents a preliminary attempt to measure the radiation values of an abandoned quarry site. It reveals significant anomalies at certain locations, with some localities exceeding global reference average values. However, further investigations will be required to confirm the potential sources of anomalous radiation and their behavioural dynamics under the present conditions.

Observing elevated radiation levels at both extremely weathered and less weathered locations confirms that visual inspection and weathering grade alone would not be sufficient to determine radiological safety of a site. Hence, the findings underscore the importance of a thorough understanding and site characterization specially for sites with natural rock exposures, beyond physical, geological, chemical and structural parameters.

This pilot study at the Samanalawewa abandoned quarry site emphasizes the necessity of measuring natural radioactivity as the results reveal significant variations in radionuclide concentrations across the area of interest. It provides a basic framework for radiological assessments, from which the guidelines could be derived for future studies. Since radioactivity is a natural phenomenon that could impact land suitability for future use, it must be routinely measured, to ensure public safety and environmental protection.

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