INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

OPEN ACCESS

Received: 14-02-2022

Accepted: 20-05-2022

Published: 01-07-2022

Citation: Rajapaksha GKM, Clegg JK, Arachchige KSA, Coswaththa AVRS, Gunarathna GDNH, Fernando KMEP, Premasiri HMR, Sirimuthu NMS, Patabendige CNK, Sirimuthu NMS (2022) Detailed Chemical Analysis of Unusually Weathered Rocks. Indian Journal of Science and Technology 15(24): 1213-1223. https://doi.org/10.17485/IJST/v15i24.367

* **Corresponding author**.

cpatabendige@sjp.ac.lk

Funding: This project was supported by the Research Council, University of Sri Jayewardenepura (Grant number ASP/01/ RE/ FOT/2018/74).

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN

Print: 0974-6846

Electronic: 0974-5645

Detailed Chemical Analysis of Unusually Weathered Rocks

G K M Rajapaksha[1], J K Clegg[2], K S A Arachchige[3], A V R S Coswaththa[4], G D N H Gunarathna[5], K M E P Fernando[6], H M R Premasiri[7], N M S Sirimuthu[5], C N K Patabendige[1]*, N.M.S Sirimuthu[8]

1 Department of Science for Technology, University of Sri Jayewardenepura, Sri Lanka
2 School of Chemistry and Molecular Biosciences, The University of Queensland, St Lucia, Queensland, Australia, 4072, 4072
3 The centre for Microscopy and Microanalysis, The University of Queensland, St Lucia, Queensland, Australia, 4072, 4072
4 Department of Geology, University of Peradeniya, Sri Lanka
5 Department of Chemistry, University of Sri Jayewardenepura, Sri Lanka
6 Department of Botany, University of Sri Jayewardenepura, Sri Lanka
7 Department of Earth Resource Engineering, University Moratuwa, Sri Lanka
8 Center for Nanocomposite Research, University of Sri Jayewardenepura, Sri Lanka

Abstract

Objectives: This study aimed to conduct a detailed chemical analysis of the Samanalawewa dam to provide information on its weathering conditions. **Method:** The mineralogical composition of the dam was analyzed by powder X-ray diffraction (PXRD), atomic absorption spectroscopy (AAS), gravimetric, and X-ray fluorescence (XRF) analysis in order to identify chemical changes that have taken place. **Findings:** Widespread discoloured (brick red) and crushable areas in the dam and the quarry site indicate weathering of the compositional rocks. Each weathered rock sample showed a similar compositional pattern to each other as well as charnockite (CHA) rather than the other structural rocks of the dam; biotite gneiss (BIO), garnet biotite sillimanite gneiss (GAR), and limestone (LIM) indicating that only CHA has been weathered rapidly. Since LIM is not affected and the contact water (pH; reservoir 6.79 - 7.12 and holes in the quarry site 6.43-6.78) is almost neutral, this rapid weathering has not been governed by general chemical weathering processes like acid rains or stormwater. The relative contents of aluminium and magnesium have decreased during the weathering process while increasing the relative content of iron as well as sodium, which is a mobile element. The potassium content also has not decreased significantly. Moreover, chemical weathering indices like chemical index of alteration (CIA) and chemical index of weathering (CIW) values for completely weathered rocks were less than 50 revealing their unsuitability to assess the degree of weathering of the Samanalawewa dam. **Novelty:** Charnockite in the Samanalawewa dam has been weathered rapidly and chemical weathering indices; CIA and CIW are not valid to assess its degree of weathering.

Keywords: Metamorphic; Charnockite; Rock weathering; Rock composition; Chemical weathering indices

1 Introduction

Sri Lankan basement rock is composed of granulite grade Proterozoic age metamorphic rocks and is widely used in construction projects[1] of all sizes, including large-scale dams. In dam construction, these rocks are mainly used for filling. Samanalawewa reservoir is located in Belihul oya area about 160 km southeast of Colombo, Sri Lanka, which was built by damming the Walawe river between 1986 and 1992 as part of a 120 MW hydroelectric generation project. Additionally, this reservoir is used to supply irrigation water during the dry season to minor irrigation schemes that are located about 10 km downstream of the Samanalawewa dam is 110 m in height and is 530 m in length at crest level. Samanalawewa dam is a rock-filled gravity dam with a well-compacted clay core[2] constructed using high granulite grade, highly deformed metamorphic rocks, including CHA, BIO, GAR and LIM found at nearby a quarry site. Before use, the quarried rock's suitability was assessed using standard mechanical and physical tests. The dam has been significant unexpected weathering over the last thirty years[3]. However, under natural conditions, these rocks are expected to weather over a few thousand years[4].

Natural rock weathering results in the disintegration and breaking down of the surface minerals[5] due to a combination of physical, chemical, and biological processes[6]. The breakdown of rocks into small pieces due to tectonic activity, freeze-thaw cycles, root expansion, and wet-dry cycles are referred to as physical weathering[5]. Lithophilous lichens, fungi, and bacteria induce the biological weathering process[7] while chemical weathering results from acidification, dissolution, and/or oxidation[8]. Chemical weathering takes a longer period compared to biological weathering but does occur in almost all types of rock and the mechanical strength of rocks significantly decreases when the degree of chemical weathering increases[9]. The rate of rock weathering depends on several variables, for instance, parent rock type, size, climate, biological activity, topography and the chemical nature of interacting water[8,10], including ionic potential and temperature[11][12]. Chemical weathering can lead to changes in the mineralogical composition of rocks, forming Kaolinite, Vermiculite, Smectite, Montmorillonite, and Chlorite like minerals. The resulting minerals can provide some information about the weathering conditions. For instance, Kaolinite indicates the chemical weathering that has taken place under humid tropical conditions[13].

Since the accelerated weathering strongly affects the stability of the dam[3], it is required to identify the causes behind this to take remedies to minimise it. Hence, a detailed chemical analysis of each type of rock in the dam is more important. However, fewer research has been conducted on this, and they have analysed the composition of weathered rocks but not fresh rocks in the dam. The present study was carried out to identify the chemical and mineralogical changes that occurred in rocks in the Samanalawewa dam and adjacent quarry site during this rapid weathering and compare them with chemical changes in general rock weathering processes using chemical weathering indices.

2 Methodology

2.1. Study area

The Samanalawewa reservoir is located in the Sothern central part of Sri Lanka, which stretches from the north at 80.680972°–80.925972° longitudes to the east at 6.554583°–6.783472° latitude[14] falling within the intermediate climatic zone of Sri Lanka. As a tropical region and all others, it shows a wide fluctuation of climatic parameters. Samanalawewa dam was constructed for the Samanalawewa hydropower project at the confluence of the Walawe river and Belihul Oya, about 160 km southeast of the capital Colombo. The altitude of the site is about 530 m, placed in a slightly V-shaped valley. The average annual rainfall of the site area is above 2500 mm, and the temperature varies from 19^{o}C to 30^{o}C.

Geologically, the dam site lies in the Sri Lankan Precambrian rock complex, which mainly consists of high-grade metamorphic rocks which belong to the Kaltota formation. These rocks have been subjected to different weathering processes since Gondwana to present under tropical environmental conditions. Samanalawewa dam is a rock-filled dam that mainly consists of four different rock types; charnockite (CHA), garnet biotite sillimanite gneiss (GAR), biotite gneiss (BIO), and crystalline limestone (LIM)[3].

2.2 Sampling

The samples were collected using the grab sampling method to cover a large geological region and represent all rock types available in the quarry site with both weathered and fresh samples. After a careful observation in the field, fresh rock samples from each type of rocks, which had used to build the dam and four different weathered rock samples depending on the color and crushability were collected representing all the weathered rock samples present at the quarry. All the collected samples were put into clean polythene bags soon after collection, and they were appropriately labelled. Later the collected samples were powdered to make homogeneous samples for chemical analysis.

2.3. Analytical methods

*2.3.1. **Determination of acidity/ alkalinity***

The acidity/ alkalinity of rock samples and water in both the Samanalawewa reservoir and holes in the adjacent quarry site was determined using their pH. For rock samples, pH was measured with HQ40D Portable Multi Meter by mixing powdered rocks with water (1:2 w/w). The mixture was stirred vigorously for 30 seconds and kept for one hour to settle before measuring the pH.

*2.3.2 **Determination of mineralogical composition***

The mineralogical composition of weathered and unweathered rock samples was determined using a Rigaku Ultima IV X-ray powder diffractometer (PXRD). The Cu K_{α} radiation (wavelength –1.540 Å) was used over a 2θ angle of 10° to 80° with a step size of 0.02°.

*2.3.3 **Determination of elemental and chemical composition***

Atomic absorption spectroscopy (AAS) and X-ray fluorescence spectroscopy (XRF) were used to determine the elemental and chemical composition of rock samples. Since Si content cannot be determined by AAS, it was determined using gravimetric analysis.

2.3.3.1 **Determination of elemental composition using the AAS technique**. Elemental compositions (Na, Mg, Al, K, Ca, and Fe) of both weathered and non-weathered rock types were analysed using the AAS with flame and graphite furnace mode (Thermo Scientific iCE 3000). Acetylene was used as the gas to generate the flame for the elements except Ca and Al. Nitrous oxide was used only for Ca and Al to generate the flame. Silicate rock samples were prepared by acid digestion[15]. In brief, the dried rock samples (0.6 g of each) were heated for 48 hours with 15 cm^3 of c. HF, 5 cm^3 of c. HNO_3 and 2 cm^3 of c. $HClO_4$, in a Teflon crucible for complete dissolution[15,16] [17] After obtaining clear solutions, all excess acids were evaporated and dried until a crust was visible. It was then heated again with 5 cm^3 of HNO_3 and a small amount of deionised water to a clear solution.

To prepare samples of limestone rock, deionized water and HCl were added to a known amount of powdered rock samples in a 1: 1 (v/v) ratio and heated for 1 hour while stringing. Then, it was cooled and filtered through a No.42 ashless filter paper, and then the filtrate was diluted up to the required volume[18].

2.3.3.2 **Determination of chemical composition using XRF technique**. Rigaku NexCG (USA)X-ray Fluorescence instrument was used for the analysis of the chemical composition of rock samples in an inert helium atmosphere and the diaphragm at 20 mm[19].

2.3.3.3 **Determination of SiO_2 content using gravimetric method**. SiO_2 content in rock samples was measured using a gravimetric method. Two different methods were followed for sample preparation of silicate rocks and limestone for gravimetric analysis.

For silicate rocks, rock samples (0.5 g of each) were mixed with anhydrous Na_2CO_3 (2.5 g) in a platinum crucible and fused using a muffle furnace at 1050 °C for one hour [17]. Then, the crucible was heated with a mixture of deionised water and c. HCl (about 50 cm^3 of each) until detaching the melt completely from the crucible, and the solution was filtered using No. 42 filter paper after further evaporation of the solvent. The residue was washed with deionised water, placed in a platinum crucible, and heated in a muffle furnace at 1050 °C for one hour. Then, it was cooled and weighed the precipitate with the crucible (W1). Then HF (about 10 cm^3)was added to the crucible and heated on a hot plate to release SiF_4, then ignited and weighed again (W 2). The SiO_2 content was determined using the difference between two weight readings (W1-W2). The above procedure was followed to determine SiO_2 content for all fresh and weathered rock samples except lime stones [20].

For limestone rocks, the residue in the filter paper that was separated by filtering the decomposed limestone was kept in a clean weighed platinum crucible and burnt in a muffle furnace at 1050 °C for two hours and weighed the crucible with the content (W3). Then, the platinum crucible was ignited after heating with a few drops of H_2SO_4 and HF acid (10 cm^3) to evaporate excess HF, then cooled and weighed again (W4). The SiO_2 content in limestone rocks was determined using the difference between two weight readings (W3-W4).

3 Results and Discussion

3.1. Visual assessment of rock weathering at Samanalawewa dam and its adjacent quarry site

A widespread clear colour alteration from dark grey to brick red was observed in the Samanalawewa dam during the field inspection. That colour change was observed in both the upstream and downstream sides of the wall (Figure 1) as well as in some rock bands in the quarry site from which the construction materials were obtained. No discoloration was observed in the limestones. The discolored material was notably weaker and more crushable in both the dam and the quarry site. As a preliminary study, it was intended to find out the causes that might have caused this accelerated rock weathering within the geological timescale [3].

Four different types of weathered rock samples (W1, W2, W3, and W4) were collected for testing according to their appearance and crushability in order to cover the types of completely weathered rocks population found on the dam and the adjacent quarry site (Figure 2).

Fig 1. Current states of Samanalawewa dam site and quarry site. A) Upstream dam wall not exposed to water showing weathered and unweathered rocks. B) Downstream dam wall exposed to the water showing weathered and unweathered rocks. C) Current state of the abandoned quarry site

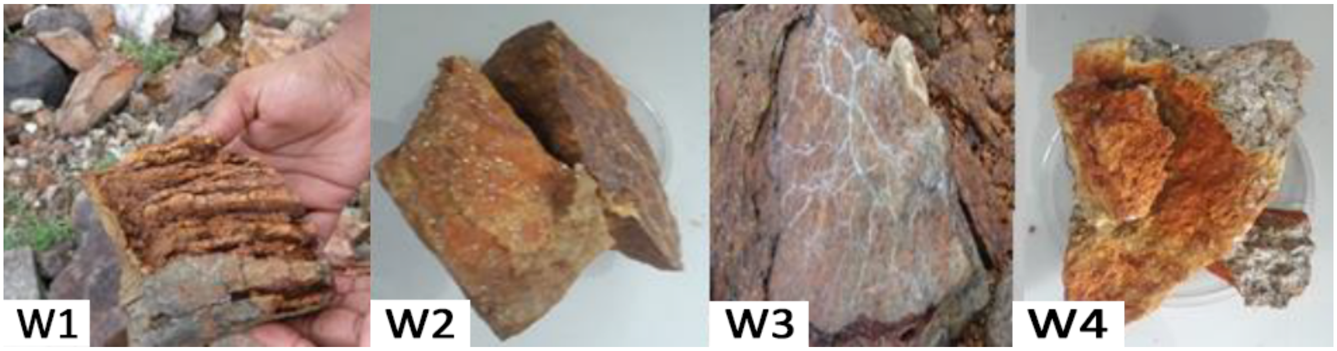

Fig 2. Physical nature of weathered rocks at the dam site and quarry site (W= Weathered Rock)

3.2 Acidity/ alkalinity of rock and water

pH measurement is a relatively rapid and also a simple method to determine the readily available acidity/ alkalinity of the soluble (or reactive) components of the rock samples. If the easily exchangeable cations for H^+ ions; base cations like Na^+, K^+, Mg^{2+} and Ca^{2+} are less in weathered rocks compared to unweathered rocks, the pH would be low[(21)]. Generally, melanterite-like acid generating minerals, high surface area pyrites like reactive sulfides and carbonates are assessed by pH measurement. The low pH is an indication of the sulfide oxidation in the sample, which indicates the degree of weathering of rocks. The samples with pH less than 5 would contain acidic sulphatesalts, which would release acidity when water is added[(21)].

The weathered rock samples were more acidic (pH; W1=4.32, W2=4.26, W3=4.54, W4=4.49) than unweathered rock samples. Unweathered CHA (pH 7.11)[(22)], BIO (pH 6.87), and GAR (pH 6.91) were neutral, and limestones (pH 8.53) were alkaline in pH. The pH of water in both the Samanalawewa reservoir (pH 6.79 - 7.12) and holes of its adjacent quarry site (pH 6.43-6.78) was much closer to each other than that found in the rock samples suggesting the higher acidity values observed in the weathered rock samples is not originating from water contact.

3.3 Mineralogical composition of unweathered and weathered rocks

PXRD of unweathered GAR rock type showed that it contains a mixture of quartz (ICDD card number is 01-070-2517), microcline (ICDD card number is 01-083-1895) biotite (ICDD card number is 00-003-0024), and orthoclase (ICDD card number is 01-071-0957). The relative abundance of those minerals in GAR was as follows, microcline > orthoclase> biotite > quartz (Figure 3 a).

PXRD of unweathered CHA rock type contained quartz (ICDD card number is 03-065-0466), albite calcian (ICDD card number is 00-041-1480), biotite 1M, Ti-rich (ICDD card number is 01-088-1899), and orthoclase (ICDD card number is 00-031-0966) (Figure 3 b). Quartz content was higher in CHA rock type, and its percentage was 57%. Albite calcian content in CHA rock type was low compared to the albite calcian content in the BIO rock type. BIO rock contains 72.5% of albite calcian mineral. However, CHA rock type contains only 26.4% of albite calcian content.

Calcite (ICDD card number is 01-085-1108), dolomite (ICDD card number is 01-089-5862), and quartz alpha, alpha SiO_2 (ICDD card number is 01-089-8940) minerals were present in unweathered LIM rock type. Their relative abundance in LIM was calcite > dolomite> quartz alpha, alpha SiO_2 (Figure 3 c).

Unweathered BIO rock type contained a mixture of quartz (ICDD card number is 00-046-1045), albite calcian (ICDD card number is 01-076-0926), and biotite (ICDD card number is 01-088-1905 d). Furthermore, PXRD quantitative analysis revealed that BIO rock contained more percentage of albite calcian than quartz and biotite.

PXRD of weathered rock samples reveals that the minerals of quartz (ICDD card number is 01-089-1961), orthoclase (ICDD card number is 01-071-0956), pigeonite and enstatite (ICDD card number is 01-083-0669) are contained in each weathered rock samples of W1, W2, W3 and W4 (Figure 4). However, the intensities of peaks were different in four weathered rock samples because the samples were obtained from heterogeneous rocks. Furthermore, it revealed that the weathered rock samples contained the minerals such as pigeonite and enstatite, which were not contained in fresh rock samples. According to the previous study conducted by Udagedara, Quarts, plagioclase, Orthoclase and microcline were contained in the entirely weathered rocks[(23)] .

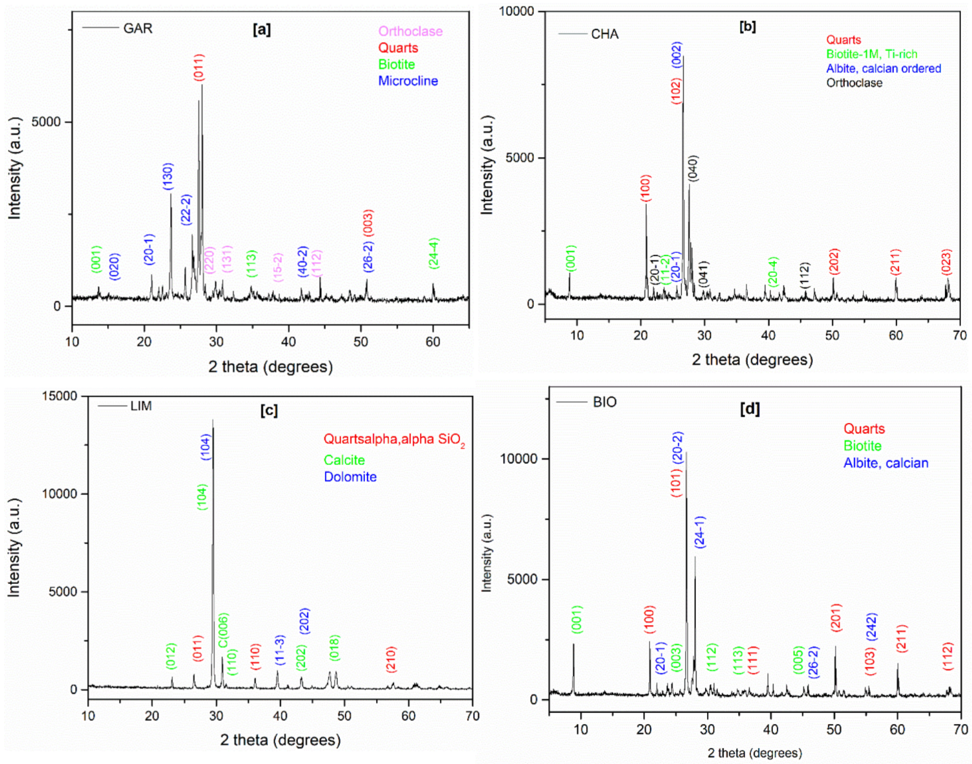

Fig 3. PXRD pattern of (a) Garnet biotite sillimanite gneiss, (b) Charnockite, (c) limestone, (d) Biotite gneiss

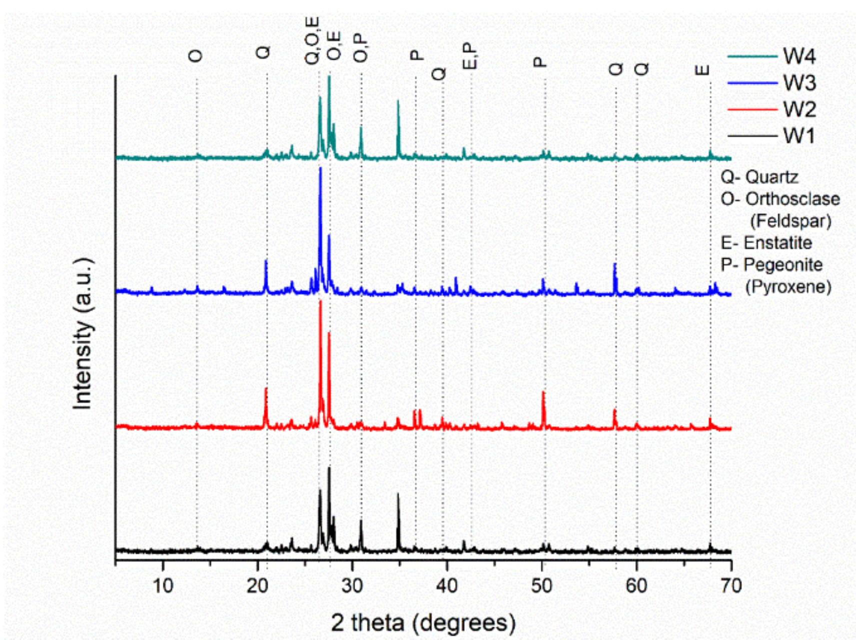

Fig 4. XRD patterns of weathered rock samples.

3.4 Elemental and chemical composition of unweathered and weathered rocks

The elemental composition of the samples was established (Table 1), and the unweathered samples are consistent with their mineralogical identity. For example, limestone contained a greater amount of Ca (61.79 %) compared to the Ca content in CHA (3.19 %), BIO (4.63 %), and GAR (1.47 %). The element compositions of non-weathered rocks were varied as follows. LIM; Ca > Al> Mg>Fe>K>Na, GAR; Al>Fe> K>Na>Ca>Mg, both BIO and CHA; Na> Fe> Al>Ca>Mg>K. However, the weathered rocks have more similarities to each other in elemental composition (Table 1) and contained lower silicon content compared to the unweathered rock types except for limestone because of in general weathering processes Si is leaching out[24]. However, the silicon content was very high in weathered rocks than that of limestones (Table 2).

Since XRF has low accuracy when used on heterogeneous samples, the analysis was performed on powdered unweathered rock samples. When considering the composition patterns of Na, Fe, Al, Ca, Mg, K and Si in the unweathered rocks, the results obtained by XRF analysis were similar to the results obtained from AAS analysis (Table 2).

Table 1. The elemental composition of weathered and unweathered rocks

Rock type	AAS analysis (mass %) (X ± s)					
	Na	Fe	Al	Ca	Mg	K
CHA (n = 3)	7.13 ± 0.22	7.04 ± 0.09	3.79 ± 0.03	3.19 ± 0.10	2.48 ± 0.01	2.30 ± 0.06
BIO (n = 3)	5.50 ± 0.56	5.33 ± 0.18	5.17 ± 0.07	4.63 ± 0.08	2.56 ± 0.17	1.82 ± 0.17
GAR (n = 3)	2.73 ± 0.04	6.13 ± 0.06	6.92 ± 0.10	1.47 ± 0.08	1.03 ± 0.11	3.10 ± 0.12
LIM (n = 3)	0.02 ± 0.01	2.20 ± 0.08	0.68 ± 0.01	61.79 ± 0.11	0.50 ± 0.02	0.22 ± 0.01
W1 (n =3)	8.17 ± 0.03	7.92 ± 0.17	3.17 ± 0.06	3.53 ± 0.12	1.78 ± 0.07	2.16 ± 0.08
W2 (n = 3)	9.04 ± 0.09	8.49 ± 0.15	3.26 ± 0.04	3.08 ± 0.06	2.07 ± 0.01	2.05 ± 0.08
W3 (n = 3)	8.92 ± 0.09	7.85 ± 0.13	4.11 ± 0.07	3.26 ± 0.08	3.12 ± 0.04	1.78 ± 0.03
W4 (n = 3)	8.49 ± 0.19	8.27 ± 0.07	3.28 ± 0.08	3.51 ± 0.10	2.37 ± 0.04	1.84 ± 0.09

X – Mean, s – Standard deviation

Linear range: Na 100 – 300 ppm, Fe 10 – 80 ppm, Al 20 – 80 ppm, Ca 2 – 8 ppm, Mg 0.2 – 0.8 ppm and K 2 -8 ppm.

Table 2. Chemical composition of rock samples

Rock type	XRF analysis (mass %) (X ± s)							Gravimetric analysis (X ± s)
	Na_2O	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	SiO_2	SiO_2 % (w/w)
CHA (n=3)	10.14±0.16	9.92±0.15	7.15±0.08	4.32±0.09	3.97±0.14	2.73±0.11	51.30±0.15	75.95±0.94
BIO (n=3)	7.38±0.12	7.61±0.11	10.18±0.14	6.53±0.02	4.14±0.04	2.07±0.08	55.60±0.35	66.30±0.23
GAR (n=3)	3.77±0.11	8.59±0.15	13.11±0.15	2.08±0.08	1.82±0.18	3.72±0.06	61.35±0.23	58.83±0.10
LIM (n=3)	0.03±0.01	3.04±0.06	1.02±0.05	88.04±0.21	0.84±0.03	0.15±0.02	5.50±0.04	5.68±0.06
W1 (n=3)	-	-	-	-	-	-	-	60.06±0.19
W2 (n=3)	-	-	-	-	-	-	-	59.83±0.07
W3 (n=3)	-	-	-	-	-	-	-	63.43±0.10
W4 (n=3)	-	-	-	-	-	-	-	68.94±0.08

X – Mean, s – Standard deviation

3.5 Identification of weathered rock type

Mobile elements; Ca, Na, P, K, Sr, Ba, Rb, Mg, and Si, which are contained in the rock structures, are usually leached out during the chemically induced rock weathering, although the elements like Zr, Hf, Fe, Al, Th, Nb, and Sc are generally immobile[6]. However, the mobile elemental compositions in weathered rock samples have not decreased significantly compared to the mobile elemental compositions of unweathered rock types. Regardless of the slight variations caused by the residual components present in the samples, similar elemental compositions (Figure 5) were obtained for all the weathered rocks, concluding that only one rock type might have weathered within the short period out of the four rock types present in the dam.

Si content of fresh limestone (LIM) is significantly lower than other rock samples of both weathered and unweathered rocks, indicating that weathered rocks have not originated from limestones. Al content of GAR and BIO is considerably higher than weathered rock samples. Na content of GAR and BIO is considerably lower than weathered rock samples. However, the weathered rock samples show similar elemental composition patterns as charnockite rocks (CHA) rather than other fresh rock types.

Collectively the results of each analysis suggest that Charnockite (CHA) is the weathered rock. However, this conclusion is different to the results obtained by Udagedara, who suggests that garnet biotite sillimanite gneiss (GAR) is the weathered rock type in the Samanalawewa dam [23]. The reason for that may be the previous studies have analysed the composition of weathered rocks only. However, the current study analysed the chemical composition of weathered rocks and also each fresh rock type in the Samanalawewa dam and then compared them.

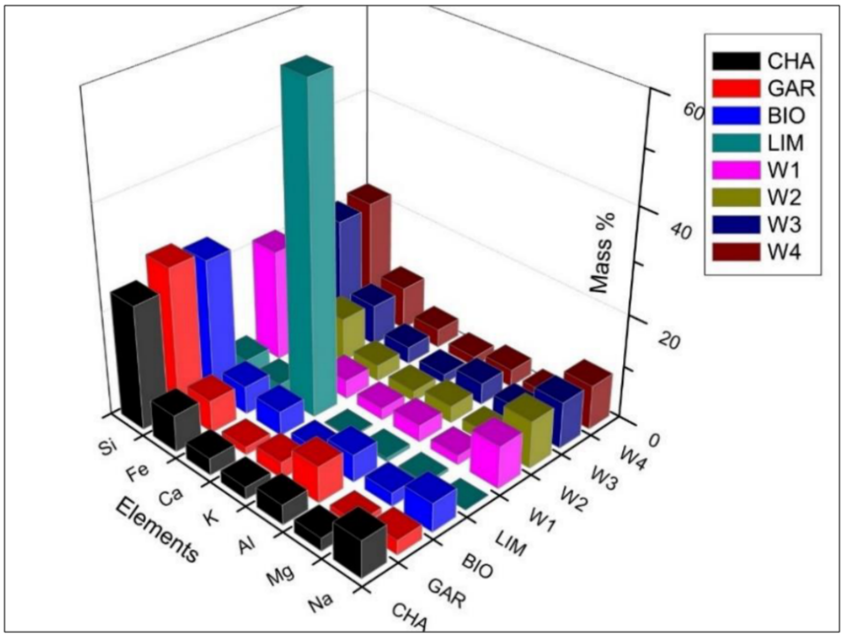

Fig 5. Elemental composition of weathered and unweathered rock samples

3.6 Determination of the degree of rock weathering at the quarry site

Although the silicate weathering rate of metamorphic rocks in Sri Lanka is comparatively low; 14 mm ky^{-1} [25], the unusual weathering of charnockite in the Samanalawewa dam has been observed since 2005 is growing rapidly. There are various methods and weathering indices to determine the degree of rock weathering. Among them Weathering potential index, Product index, Ruxton index, Parker index, Mium index, Chemical index of alteration (CIA), chemical index of weathering, mobiles index, and CALMAG index are a few chemical weathering indices [23], Intensity of rock weathering also can be measured with the content of dissolved solute in water where water-rock interface exists. Because solute cataion contribution depends on the degree of weathering of contact rocks [26]. The climatic condition and atmospheric CO_2 content also affect rock weathering, mainly the chemical weathering of silicate and carbonate rocks [27]. If HCO_3 and total cation in interacted water is 1:1, it suggests that the solute mainly comes from chemical weathering [11].

However, as CIA and CIW indices are suitable for metamorphic rock types [23] these weathering indices were used to determine the degree of rock weathering at the Samanalawewa dam and its adjacent quarry site. CIA and CIW values of CHA, BIO, and GAR rock samples were calculated using the elemental composition data obtained from AAS analysis [28].

$$CIA = \frac{Al_2O_3 \times 100}{Al_2O_3 + CaO + Na_2O + K_2O} \quad \text{Eq. (1)}$$

$$CIW = \frac{Al_2O_3 \times 100}{Al_2O_3 + CaO + Na_2O} \quad \text{Eq. (2)}$$

If the CIA and CIW values of rock are equal or less than 50, that rock type is considered unweathered. If the values are more than 50, that rock is considered weathered [29].

Table 3. Calculated CIA and CIW values for fresh metamorphic silicate rocks & weathered rocks

Sample name	Na_2O	MgO	Al_2O_3	K_2O	CaO	Fe_2O_3	SiO_2	CIA	CIW
CHA	19.23	4.12	14.30	5.53	4.46	20.14	51.20	**32.87**	**37.65**
GAR	7.36	1.71	26.15	7.46	2.05	17.54	59.50	**60.80**	**73.55**
BIO	14.81	4.25	19.53	4.38	6.48	15.23	55.70	**43.21**	**47.85**
W1	22.03	2.95	11.98	5.20	4.94	22.65	45.90	**27.13**	**30.76**
W2	24.37	3.43	12.32	4.94	4.31	24.28	48.00	**26.82**	**30.05**
W3	24.05	5.17	15.53	4.29	4.56	22.45	45.90	**32.07**	**35.19**
W4	22.89	3.93	12.40	4.43	4.91	23.65	47.20	**27.77**	**30.84**

The calculated CIA and CIW values of fresh rock samples were less than 50 for CHA and BIO rocks, confirming that CHA and BIO rocks are unweathered. However, the calculated CIA and CIW values of GAR rocks were greater than 50 (Table 3) because the natural weathering rate of garnet biotite sillimanite gneiss (GAR) is higher than other rock types[(30)]. The fresh rocks at the Samanalawewa dam and the quarry site have completely weathered within less than thirty years[(3)], which indicates the rate of rock weathering has occurred at the Samanalawewa dam, and quarry site is greater than the natural rock weathering rate of GAR (Figure 6).

CIA and CIW values have been introduced to apply for the most abundant chemically weathered rocks where the mobile elements such as Na and K are leaching out during the weathering process and immobile elements such as Al is accumulated. Although the CIA and CIW values below 50 indicate unweathered rocks theoretically, the calculated CIA and CIW values for completely weathered rock samples collected from the Samanalawewa dam site were below 50 (Table 3). In this scenario, chemical weathering indices are not valid to determine the degree of weathering of the Samanalawewa dam.

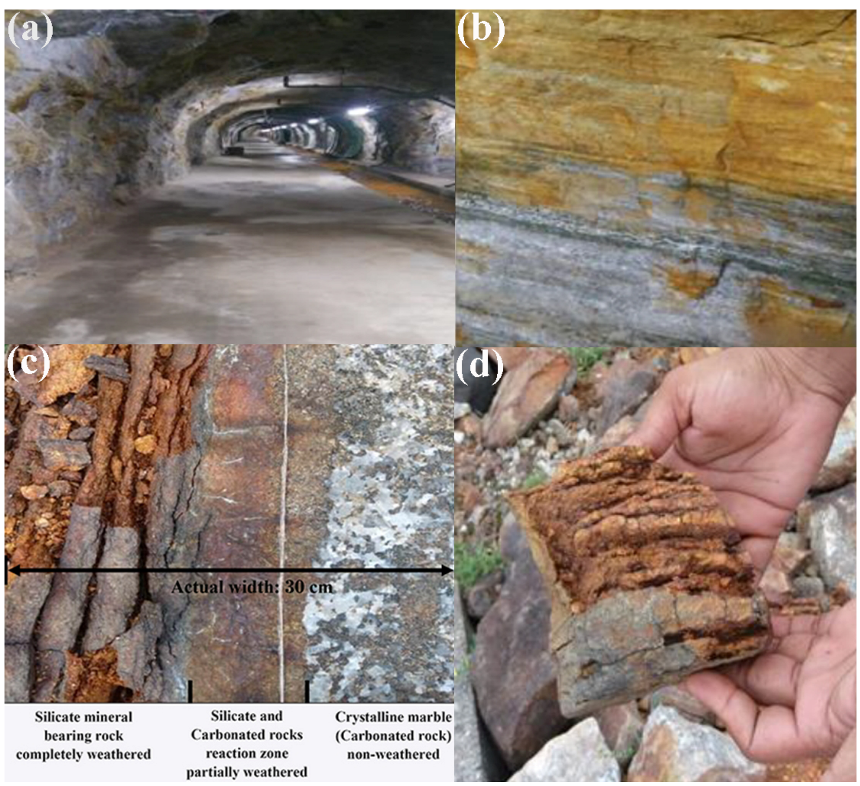

Fig 6. Comparing the rock weathering at the tunnel and the dam site. (a) Samanalawewa dam's tunnel, (b) Natural rock weathering of GAR rock type, (c) & (d) Rapid rock weathering at the dam site

4 Conclusion

This study indicates that the weathering of the Samanalawewa dam is not governed by natural chemical weathering processes. Although the dam was built recently, a widespread crushable, discoloured area from dark grey to brick red in the upstream and downstream of the dam as well as the quarry site where the rocks were quarried to build the dam, is notably visible showing a rapid weathering of metamorphic rocks.

Elemental composition of the weathered rocks (W_1; Na 8.17%, Fe 7.92%, Al 3.17%, Ca 3.53%, Mg 1.78%, K 2.16%, W_2; Na 9.04%, Fe 8.49%, Al 3.26%, Ca 3.08%, Mg 2.07%, K 2.05%, W_3; Na 8.92%, Fe 7.85%, Al 4.11%, Ca 3.26%, Mg 3.12%, K 1.78%, W_4; Na 8.49%, Fe 8.27%, Al 3.28%, Ca 3.51%, Mg 2.37%, K 1.84%) were most similar to each other as well as to CHA (Na 7.13%, Fe 7.04%, Al 3.79%, Ca 3.19%, Mg 2.48%, K 2.30%) rather than GAR (Na 2.73%, Fe 6.13%, Al 6.92%, Ca 1.47%, Mg 1.03%, K 3.10%), BIO (Na 5.50%, Fe 5.33%, Al 5.17%, Ca 4.63%, Mg 2.56%, K 1.82%), and LIM (Na 0.02%, Fe 2.20%, Al 0.68%, Ca 61.79%, Mg 0.50%, K 0.22%). According to the results obtained, among the major rock types of GAR, CHA, BIO and LIM which are consisted in the dam, only charnockite (CHA) has been weathered rapidly although it takes a long to weather in a natural circumstance.

The weathered rock samples were acidic (pH; W1 4.32, W2 4.26, W3 4.54, W4 4.49), although fresh rocks were almost neutral or basic (pH; BIO 6.87, GAR 6.91, CHA 7.11 and LIM 8.53). Also, the pH of water in the reservoir (pH 6.79 - 7.12) and holes of the quarry site (pH 6.43-6.78) were almost neutral, suggesting that the higher acidity of weathered rock samples is not originating from water contact. Moreover, the rocks of the dam except CHA, specially limestone were not affected by this weathering issue suggesting that this rapid rock weathering is not governed by general chemical weathering processes like acid rains or stormwater.

Furthermore, the relative contents of aluminum, and magnesium have decreased and iron, as well as some mobile elements like sodium, have increased in this weathering process. The relative potassium content also has not decreased significantly. Also, the calculated CIA and CIW values were less than 50 for weathered rocks although they were completely weathered (CIA; W_1 27.13, W_2 26.82, W_3 32.07, W_4 27.77 and CIW; W_1 30.76, W_2 30.05, W_3 35.19, W_4 30.84). Hence, chemical weathering indices such as CIA and CIW are not valid to explain this rapid rock weathering.

References

1) Cassar J, Standing JR. Geomaterials: aggregates, building stone and earthworks: papers from 50 years of QJEGH. *Quarterly Journal of Engineering Geology and Hydrogeology*. 2017;50(2):95–105. Available from: http://dx.doi.org/10.1144/qjegh2016-101.
2) Laksiri K, Gunathilake J, Iwao Y. A Case Study of the Samanalawewa Reservoir on the Walawe River in an Area of Karst in Sri Lanka. *Sinkholes and the Engineering and Environmental Impacts of Karst*. 2005;p. 253–62. Available from: ttps://doi.org/10.1061/40796(177)27.
3) Udagedara DT, Oguchi CT, Gunatilake AAJK. Combination of chemical indices and physical properties in the assessment of weathering grades of sillimanite-garnet gneiss in tropical environment. *Bulletin of Engineering Geology and the Environment*. 2017;76(1):145–157. Available from: https://doi.org/10.1007/s12303-016-0060-7.
4) Přikryl R. Durability assessment of natural stone. *Quarterly Journal of Engineering Geology and Hydrogeology*. 2013;46(4):377–390. Available from: https://doi.org/10.1144/qjegh2012-052.
5) Carroll D. Rock weathering. Springer Science & Business Media. and others, editor;Springer US. 1970. Available from: https://doi.org/10.1007/978-1-4684-1794-4.
6) Price JR, Velbel MA. Chemical weathering indices applied to weathering profiles developed on heterogeneous felsic metamorphic parent rocks. *Chemical Geology*. 2003;202(3-4):397–416. Available from: https://doi.org/10.1016/j.chemgeo.2002.11.001.
7) Taylor LL, Leake JR, Quirk J, Hardy K, Banwart SA, Beerling DJ. Biological weathering and the long-term carbon cycle: integrating mycorrhizal evolution and function into the current paradigm. *Geobiology*. 2009;7(2):171–191. Available from: https://doi.org/10.1111/j.1472-4669.2009.00194.x.
8) Bufe A, Cook KL, Galy A, Wittmann H, Hovius N. The effect of lithology on the relationship between denudation rate and chemical weathering pathways. 2021;p. 1–27. Available from: https://doi.org/10.5194/esurf-2021-87.
9) Han C, Tian J, Hu C, Liu H, Wang W, Huan Z, et al. Lithofacies characteristics and their controlling effects on reservoirs in buried hills of metamorphic rocks: A case study of late Paleozoic units in the Aryskum depression, South Turgay Basin, Kazakhstan. *Journal of Petroleum Science and Engineering*. 2020;191:107137–107137. Available from: https://doi.org/10.1016/j.petrol.2020.107137.
10) Borrelli L, Perri F, Critelli S, Gullà G. Minero-petrographical features of weathering profiles in Calabria, southern Italy. *Catena*. 2012;92:196–207. Available from: http://dx.doi.org/10.1016/j.catena.2012.01.003.
11) Upendra B, Ciba M, Aiswarya A, Dev VV, Sreenivasulu G, Krishnan KA. Mechanisms controlling the dissolved load, chemical weathering and CO2 consumption rates of Cauvery River, South India: role of secondary soil minerals. *Environmental Earth Sciences*. 2022;81(3). Available from: https://doi.org/10.1007/s12665-022-10222-1.
12) Zhang S, Bai X, Zhao C, Tan Q, Luo G, Wang J, et al. Global CO2 Consumption by Silicate Rock Chemical Weathering: Its Past and Future. *Earth's Future*. 2021;9(5):1–20. Available from: https://doi.org/10.1029/2020EF001938.
13) Borrelli L, Greco R, Gullà G. Weathering grade of rock masses as a predisposing factor to slope instabilities: Reconnaissance and control procedures. *Geomorphology*. 2007;87(3):158–175. Available from: https://doi.org/10.1016/j.geomorph.2006.03.031.
14) Kumarasiri ADTN, Udayakumara EPN, Jayawardana JMCK. Impacts of soil erosion and forest quality on water quality in Samanalawewa watershed, Sri Lanka. *Modeling Earth Systems and Environment*. 2022;8(1):529–544. Available from: https://doi.org/10.1007/s40808-021-01082-y.
15) Zhang W, Hu Z. Recent advances in sample preparation methods for elemental and isotopic analysis of geological samples. *Spectrochimica Acta Part B: Atomic Spectroscopy*. 2019;160:105690–105690. Available from: https://doi.org/10.1016/j.sab.2019.105690.

16) Hu Z, Qi L. Sample Digestion Methods. In: and others, editor. Treatise Geochemistry;vol. 15. 2013;p. 87–109. Available from: https://doi.org/10.1016/B978-0-08-095975-7.01406-6.
17) Balaram V, Subramanyam KSV. Sample preparation for geochemical analysis: Strategies and significance. *Advances in Sample Preparation*. 2022;1:100010–100010. Available from: https://doi.org/10.1016/j.sampre.2022.100010.
18) Gharti RB, Hitan DK, Prasad MK, Oli HB. Chemical Analysis of Limestone of Bojhe, Halesi-Tuwachung Municipality, for Industrial Applications. *Amrit Research Journal*. 2020;1(1):59–64. Available from: https://doi.org/10.3126/arj.v1i1.32455.
19) Boyle JF. Rapid elemental analysis of sediment samples by isotope source XRF. *J Paleolimnol*. 2000;23(2):213–234. Available from: https://doi.org/10.1023/A:1008053503694.
20) Matilainen R, Tummavuori J. Determination of SiO 2 in lime mud by gravimetry. *Fresenius' Journal of Analytical Chemistry*. 1999;364(8):700–704. Available from: https://doi.org/10.1007/s002160051417.
21) Weber PA, Hughes JB, Conner LB, Lindsay P, Smart RSC. hort-term acid rock drainage characteristics determined by paste pH and kinetic NAG testing: Cypress prospect, New Zealand. *Journal American Society of Mining and Reclamation*. 2006;2006(2):2289–2310. Available from: https://doi.org/10.21000/jasmr06022289.
22) Vinnarasi F, Srinivasamoorthy K, Saravanan K, Gopinath S, Prakash R, Ponnumani G, et al. Rare earth elements geochemistry of groundwater from Shanmuganadhi, Tamilnadu, India: Chemical weathering implications using geochemical mass-balance calculations. *Geochemistry*. 2020;80(4):125668–125668. Available from: https://doi.org/10.1016/j.chemer.2020.125668.
23) Udagedara DT, Oguchi CT, Gunatilake JK. Evaluation of geomechanical and geochemical properties in weathered metamorphic rocks in tropical environment: a case study from Samanalawewa hydropower project, Sri Lanka. *Geosciences Journal*. 2017;21(3):441–452. Available from: https://doi.org/10.1007/s12303-016-0060-7.
24) Mantha NM, Schindler M, Murayama M, Hochella MF. Silica- and sulfate-bearing rock coatings in smelter areas: Products of chemical weathering and atmospheric pollution I. Formation and mineralogical composition. *Geochimica et Cosmochimica Acta*. 2012;85:254–274. Available from: http://dx.doi.org/10.1016/j.gca.2012.01.033.
25) Blanckenburg FV. Cosmogenic nuclide evidence for low weathering and denudation in the wet, tropical highlands of Sri Lanka. *Journal of Geophysical Research*. 2004;109(F3). Available from: https://doi.org/10.1029/2003JF000049.
26) Beerling DJ, Kantzas EP, Lomas MR, Wade P, Eufrasio RM, Renforth P, et al. Potential for large-scale CO2 removal via enhanced rock weathering with croplands. *Nature*. 2020;583(7815):242–248. Available from: https://doi.org/10.1038/s41586-020-2448-9.
27) Ramyapriya R, Elango L. Atmospheric CO2 consumption by rock weathering over a five year period in a large non-perennial tropical river basin of southern India. *Environmental Science and Pollution Research*. 2021;28(21):26461–26478. Available from: https://doi.org/10.1007/s11356-020-12257-y.
28) Bahlburg H, Dobrzinski N. Chapter 6 A review of the Chemical Index of Alteration (CIA) and its application to the study of Neoproterozoic glacial deposits and climate transitions. *Geological Society, London, Memoirs*. 2011;36(1):81–92. Available from: https://doi.org/10.1144/M36.6.
29) Arnaud F, Révillon S, Debret M, Revel M, Chapron E, Jacob J, et al. Lake Bourget regional erosion patterns reconstruction reveals Holocene NW European Alps soil evolution and paleohydrology. *Quaternary Science Reviews*. 2012;51:81–92. Available from: https://doi.org/10.1016/j.quascirev.2012.07.025.
30) Falkum T, Grundvig S. Geochemical evidence in support of sedimentary precursors to Proterozoic sillimanite-bearing rocks. *NGU Bull*. 2006;446. Available from: https://hdl.handle.net/11250/2674170.