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Research Article

Geochemical characteristics and paleo weathering in sediments of Noyyal River Basin, Tamilnadu–India

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ABSTRACT

A geochemical study of surface sediment samples distributed in the Noyyal River basin in western Tamil Nadu was conducted for major oxides, parent rock source, and the extent of weathering. The Al_2O_3/TiO_2 ratio of the samples ranged from (4.5–18) during monsoon and (3.94–32.14) during summer and fell in the category of mafic and intermediate igneous rocks during both seasons. The samples exhibited PIA with an average value of 64.80 during monsoon and 66.36 during summer. CIA values of the samples averaged 61.48 during monsoon and 62.35 during summer. The CIA vs. PIA, CIA vs. K/Na, and CIA vs. Al/Na for the studied samples for both seasons show low to intermediate silicate weathering in almost all locations. ICV values of samples averaged 5.1 during monsoon and 5.8 during summer suggesting that rock-forming minerals like plagioclase and alkali-feldspar are more prevalent and fewer clay minerals are present. The A-CN-K plot shows the weathering tendency towards muscovite and illite, and the A-C-N plot shows the parent rocks' plagioclases are low to intermediately weathered and the sediments gradually reduce albite and are enriched in weathering of anorthite parent material. The A-CNK-FM shows all the sediment samples lying below the feldspar region, indicating garnet and biotite presence.

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INTRODUCTION

Rivers carry and deposit sediments from various sources, including geological formations that weather under various climatic and physiographic conditions [1]. The geochemistry of sediments relates to studying the chemical content, distribution, and processes that impact sediments. Numerous variables, such as the composition of the provenance, the temperature, the duration and energy of sediment movement, and the redox conditions in the depositional environment, have a significant impact on the geochemical composition of sediments [2]. Several factors, including the lithology of the watershed region, the temperature, the terrain, the flora, and the land use of the watershed region, all enhance the geochemistry of river sediments [3]. The sediment composition is also affected by the meteorological conditions that lead to weathering and erosion [4]. The physical and chemical weathering of the parent rocks influences river-borne sediments' texture, mineralogy, and geochemistry. Clay minerals like kaolinite and smectite are produced by varying degrees of chemical weathering, while sediments dominated by gibbsite and kaolinite are produced by strong chemical weathering. Sediments with illite and chlorite predominate result from physical weathering [1].

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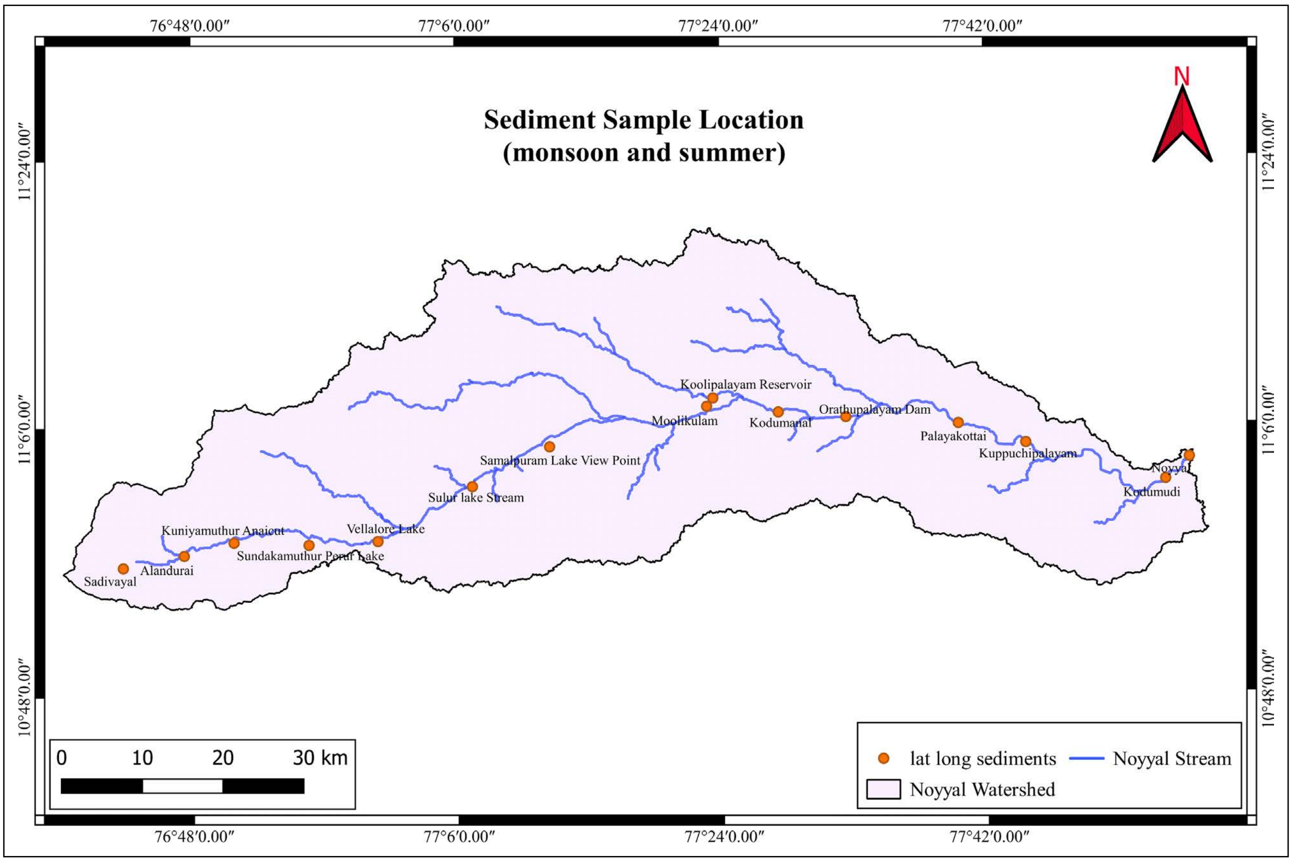

Figure 1. Study area and Sediment sample location (monsoon and summer).

Precipitation and co-precipitation, adsorption on Fe, Mn oxides, Al-hydroxides (gibbsite), kaolinite, organic matter surfaces, and human activities are other factors that impact trace elements [5]. Strong chemical weathering attaches cations like Cs, Ba, and Rb to the weathering profile and by adsorption onto clays, selectively removes cations like Ca, Na, and Sr from the weathering profile [6]. Clays and heavy minerals have higher concentrations of trace elements than silts and sands [7]. Elements usually appear in sediments as phosphates, hydroxides, carbonates, silicates, sulfides, sulfates, coupled ions, organometallic compounds, and oxides [8]. Applying chemical weathering indices reflects the strength of chemical weathering processes and quantifies the extent of soil and river sediment depletion in mobile vs immobile components as a result of weathering [9]. Chemical weathering indices, also known as indicators of modification, are often used to describe weathering profiles. Chemical weathering indices condense a sample's overall main element oxide chemistry into a single value.

Noyyal River in the southwest region of Tamil Nadu originates from the Velliangiri mountain ranges and is a major tributary of the Cauvery River. It flows through several villages in the districts of Karur, Tirupur, Erode, and Coimbatore before joining the Cauvery River near Noyyal in the Karur district (Fig. 1) [10]. The 180 km long river basin has a total area of 3,500 sq. km. The watershed has an agricultural area of 1,800 sq. km, and its populations in urban and rural areas are 1000 and 120 people per sq. km [10]. Rainfall in the basin varies greatly throughout the year; during the southwest monsoon, it receives over 3000 mm of intense rain, while during the northeast monsoon, it receives 600 mm. Pre-monsoon precipitation averages between 100 and 300 mm in April and May [10]. The geological formations of the Noyyal River basin include a wide range, from the ancient Archean crystalline rocks to the more recent alluvium deposits. Colluvial formations are seen on the western edge of the Coimbatore district [11]. The Noyyal basin has various soil types, ranging from shallow red non-calcareous soils to deep grey calcareous soils [12]. Basic and ultra-mafic rocks, garnet-sillimanite graphite gneiss, granite, charnockite, fissile hornblende biotite gneiss, and hornblende biotite gneiss cover the Noyyal River basin [13]. In the basin, there is a lack of knowledge on the features of the sediments, the weathering, and the origin of the surface sediments. Hence this study will aid in understanding the sediment geochemistry of the basin. Therefore the objective of the study is to provide an interpretation of the principal oxides geochemistry, the degree of weathering, and the provenance of the surface sediments in the basin of the Noyyal River.

MATERIALS AND METHODOLOGY

Sampling and Analysis

When selecting the sample areas, consideration was given to the industrial activity and land use along the river. These sample locations were chosen according to the area type (urban/ rural). A total of 20 sediment samples, 10 during monsoon (November 2021) (Fig. 1) and 10 during summer (May

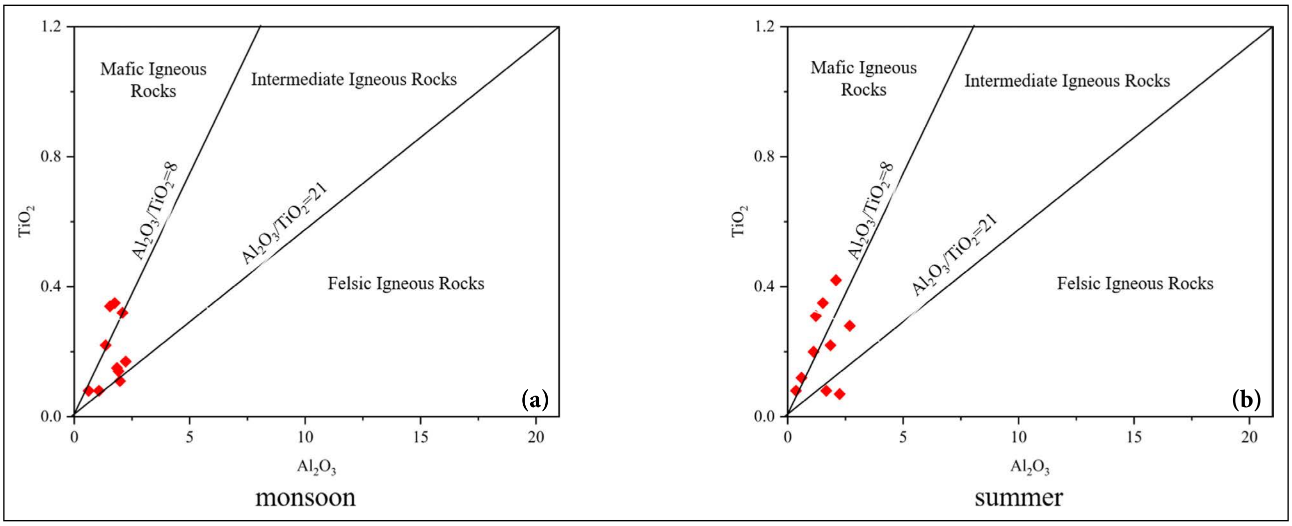

Figure 2. Al_2O_3 (wt%) and TiO_2 (wt%) ratio of the study area **(a)** monsoon and **(b)** summer.

Table 1. Major elements of monsoon samples (ppm)

Name	Ti	Al	Fe	Mg	Mn	Ca	Na	K
Sadivayal	2090.23	9238.89	32452.01	9229.28	206.78	4801.93	159.82	3478.10
Alandurai	1288.92	7203.48	33596.01	5101.04	278.73	2424.60	8.54	1899.73
Sulur Stream	998.13	11823.19	46170.78	13197.64	498.46	5625.00	239.82	2937.21
Samalpuram Lake	2040.71	8183.77	39949.88	27585.79	258.01	4283.85	171.44	3223.42
Moolikulam	679.53	10495.65	38703.93	7818.81	357.30	4111.15	105.73	2102.67
Kodumanal	1918.44	11072.31	48298.01	13955.53	332.33	5625.00	959.11	4170.25
Kuppuchipalayam	810.11	10137.44	29443.03	11790.01	355.02	4673.33	1193.04	2251.38
Orathupalayam Dam	457.23	5688.40	21047.97	9120.58	556.95	5921.00	265.59	1171.18
Kodumudi	905.44	9765.59	34298.31	10108.69	462.70	5406.44	203.82	1686.72
Noyyal	486.53	3278.83	19924.56	4883.14	127.12	4321.00	157.96	668.46

2022) (Fig. 1), were collected using a shovel from the Noyyal River basin. At each sampling location, ~1kg of sediment samples were obtained from a depth of 5cm by removing the top layer with the shovel and stored in zip-lock bags at 4°C in the laboratory until further analysis. For analysis, 0.5g of sediment sample was digested in a mixture of concentrated HNO3 and HCl (5:2, v:v) using a Microwave-assisted extraction/digestion for soil/sediment (CEM MARS 6) reaction system. The major elements were analyzed using Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES) (Make: Thermo Fisher Scientific, USA) (Model: iCAP 7400 Duo). Analysis was repeated thrice with an average error percentage of less than 1% was considered.

Determination of Weathering Intensity

The assessment of weathering intensity in sediments often relies on widely employed weathering indices, including the Plagioclase Index of Alteration (PIA), Chemical Index of Alteration (CIA), and Index of Compositional Variation (ICV). These indices play a pivotal role in characterizing the extent of weathering and are particularly essential in determining the nature of lithological changes in sediments [14].

The extent of weathering in the source rock is often measured using PIA values [15]. The PIA can be computed using Eq.1 [14, 15].

$$PIA = \frac{Al_2O_3 - K_2O}{Al_2O_3 + CaO^* + Na_2O - K_2O} x100 \quad (1)$$

Plagioclase and K-feldspars' gradual alteration to clay minerals may be quantified using the CIA [16]. The CIA can be computed using Eq.2 [14, 16].

$$CIA = \frac{Al_2O_3}{Al_2O_3 + CaO^* + K_2O + Na_2O} x100 \quad (2)$$

ICV suggested by Cox et al. [17], can be used to calculate the chemical composition of the sample's non-quartz components using Eq.3 [18].

$$ICV = \frac{Fe_2O_3 + K_2O + Na_2O + CaO^* + MgO + MnO + TiO_2}{Al_2O_3} \quad (3)$$

RESULTS AND DISCUSSION

Major Oxides Geochemistry

This study analyzed major elements (Ti, Al, Fe, Mg, Mn, Ca, Na, and K) and represented them as ppm in Tables 1, 2. The significant oxides in the sediment sample compositions

Table 2. Major elements of summer samples (ppm)

Name	Ti	Al	Fe	Mg	Mn	Ca	Na	K
Sadivayal	1197.17	5906.08	23663.62	4247.41	236.59	2836.67	137.78	1585.32
Alandurai	389.86	11889.21	38471.38	5553.56	374.67	3844.00	199.55	1799.57
Kuniyamuthur Anaicut	1313.33	9775.39	34532.62	5992.21	312.79	2741.37	309.35	2112.96
Perur Lake	470.95	1924.38	20929.23	3225.83	163.69	4481.13	290.88	717.42
Vellalore Lake	1870.82	6434.34	32626.02	10988.59	253.77	5632.00	266.81	2857.75
Sulur Stream	2101.67	8070.52	40666.00	16384.57	165.19	5982.00	432.03	2482.11
Samalpuram Lake	2530.42	11062.16	33329.15	6932.39	427.12	1443.96	51.07	4319.05
Moolikulam	499.68	8845.35	37068.61	6301.31	106.99	2208.90	146.48	1937.76
Koolipalayam Reservoir	1668.48	14214.82	44366.55	16159.83	311.43	5485.00	367.89	3661.48
Palayakottai	704.19	3180.26	29336.92	6445.71	255.33	2358.00	411.91	924.01

Table 3. Major oxide (wt%) and weathering indices of monsoon samples

Location	TiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	Na_2O	K_2O	CIA	PIA	ICV
Sadivayal	0.35	1.75	4.64	1.53	0.03	0.67	0.02	0.42	61.08	65.67	4.39
Alandurai	0.22	1.36	4.80	0.85	0.04	0.34	0.00	0.23	70.51	76.89	4.75
Sulur Stream	0.17	2.23	6.60	2.19	0.06	0.79	0.03	0.35	65.57	69.65	4.56
Samalpuram Lake	0.34	1.55	5.71	4.57	0.03	0.60	0.02	0.39	60.47	65.04	7.55
Moolikulam	0.11	1.98	5.53	1.30	0.05	0.58	0.01	0.25	70.18	74.58	3.95
Kodumanal	0.32	2.09	6.91	2.31	0.04	0.79	0.13	0.50	59.59	63.44	5.26
Kuppuchipalayam	0.14	1.92	4.21	1.96	0.05	0.65	0.16	0.27	63.82	66.87	3.88
Orathupalayam Dam	0.08	1.07	3.01	1.51	0.07	0.83	0.04	0.14	51.67	51.93	5.28
Kodumudi	0.15	1.85	4.90	1.68	0.06	0.76	0.03	0.20	65.15	67.69	4.22
Noyyal	0.08	0.62	2.85	0.81	0.02	0.60	0.02	0.08	46.72	46.27	7.20

Table 4. Major oxide (wt%) and weathering indices of summer samples

Location	TiO_2	Al_2O_3	Fe_2O_3	MgO	MnO	CaO	Na_2O	K_2O	CIA	PIA	ICV
Sadivayal	0.20	1.12	3.38	0.70	0.03	0.40	0.02	0.19	64.79	69.00	4.41
Alandurai	0.07	2.25	5.50	0.92	0.05	0.54	0.03	0.22	74.19	78.23	3.26
Kuniyamuthur Anaicut	0.22	1.85	4.94	0.99	0.04	0.38	0.04	0.25	73.10	78.92	3.72
Perur Lake	0.08	0.36	2.99	0.53	0.02	0.63	0.04	0.09	32.57	29.38	12.04
Vellalore Lake	0.31	1.22	4.66	1.82	0.03	0.79	0.04	0.34	51.00	51.40	6.58
Sulur Stream	0.35	1.52	5.81	2.72	0.02	0.84	0.06	0.30	56.08	57.79	6.62
Samalpuram Lake	0.42	2.09	4.77	1.15	0.06	0.20	0.01	0.52	74.14	88.26	3.41
Moolikulam	0.08	1.67	5.30	1.04	0.01	0.31	0.02	0.23	74.83	81.39	4.19
Koolipalayam Reservoir	0.28	2.69	6.34	2.68	0.04	0.77	0.05	0.44	68.10	73.32	3.95
Palayakottai	0.12	0.60	4.19	1.07	0.03	0.33	0.06	0.11	54.74	55.95	9.84

are listed in Tables 3, 4. The calculated concentration is given as wt%. The major oxides (%) during monsoon consists of TiO_2 (0.08–0.35), Al_2O_3 (0.62–2.23), Fe_2O_3 (2.85–6.91), MgO (0.81–4.57), MnO (0.02–0.07), CaO (0.34–0.83), Na_2O (0.001–0.16), K_2O (0.08–0.50), and during summer TiO_2 (0.07–0.42), Al_2O_3 (0.36–2.69), Fe_2O_3 (2.99–6.34), MgO (0.53–2.72), MnO (0.01–0.06), CaO (0.20–0.84), Na_2O (0.01–0.06), and K_2O (0.09–0.52). Due to chemical weathering that occurred during the transit of clastic material, Ca^{2+}, Na^{+}, and K^{+} ions were lost, as shown by the low amounts of CaO, Na_2O, and K_2O in the samples.

The K_2O/Al_2O_3 ratio is a useful indicator for determining the amount of clay and feldspar in the siliciclastic sample [19]. The K_2O/Al_2O_3 ratio ranges from 0.16 to 0.31 for clay minerals and from 0.3 to 0.9 for feldspar [17]. In the present study, the siliciclastic sediments have a higher value of K_2O/Al_2O_3 which rang-

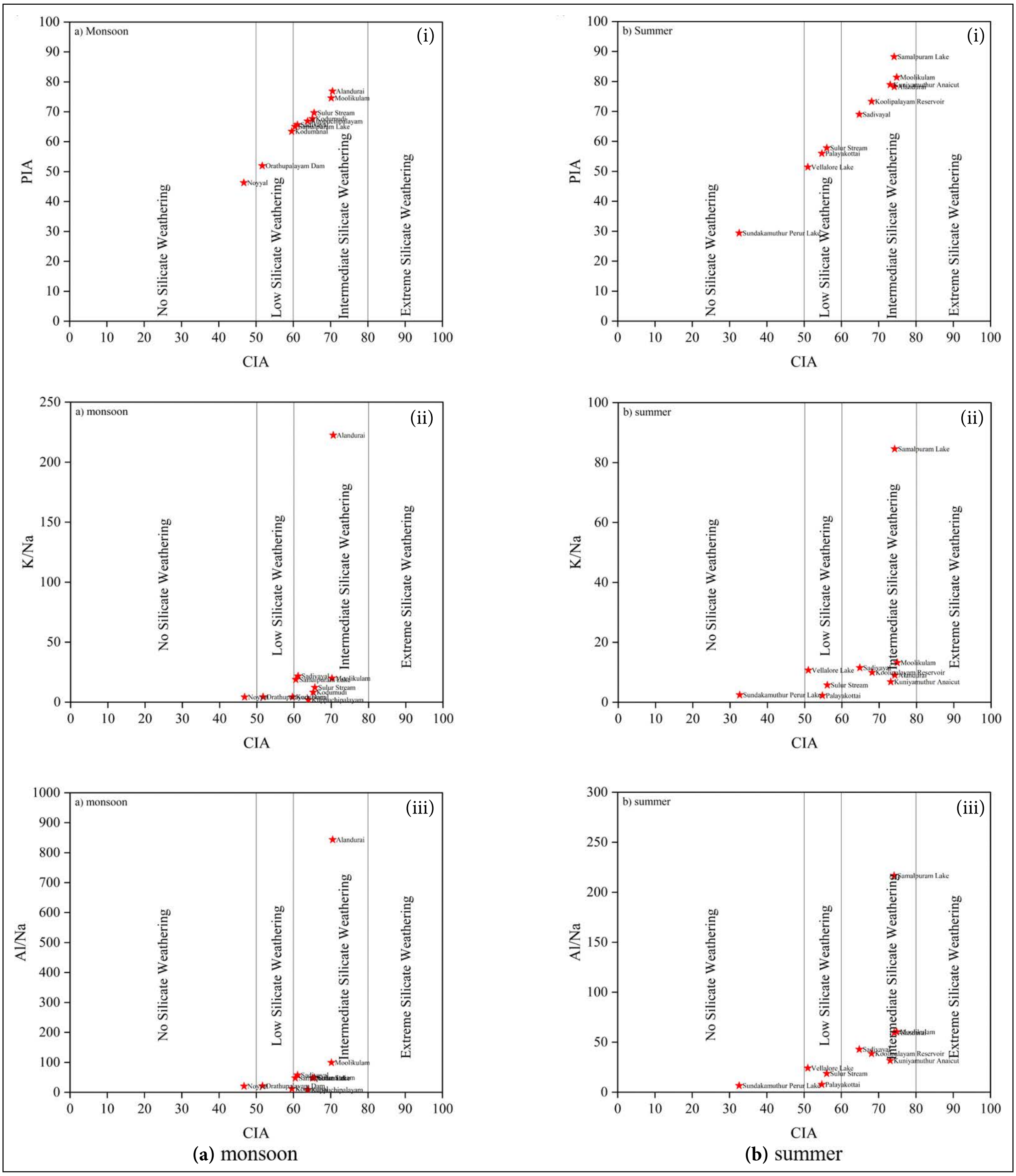

Figure 3. (i) The plot of the CIA against PIA **(a)** monsoon and **(b)** summer; (ii) The binary plot of CIA against K/Na **(a)** monsoon and **(b)** summer; (iii) The binary plot of CIA against Al/Na **(a)** monsoon and **(b)** summer.

es between 0.11–0.24 during monsoon and 0.10–0.28 during summer suggesting that most of the sediments contain more clay minerals that range from 0.16 to 0.31 due to consequences of intense weathering in a warm and humid climate [19].

Parent Rock Type

A stable composition allows for the preservation of both Al and Ti throughout the weathering process of the parent rock. As a result, the ratios of Al_2O_3/TiO_2 are typically constant with the parent rocks [20]. Al_2O_3/TiO_2 >21 denotes felsic rocks, Al_2O_3/TiO_2 in the range of 8–21 shows intermediate igneous rocks, and Al_2O_3/TiO_2 <8 suggests mafic rocks, according to the threshold established by the ratios of Al_2O_3/TiO_2 [21]. The Al_2O_3/TiO_2 ratio of the sample locations ranged from (4.5–18) during monsoon with an average of 10.06 and (3.94–32.14) during summer with

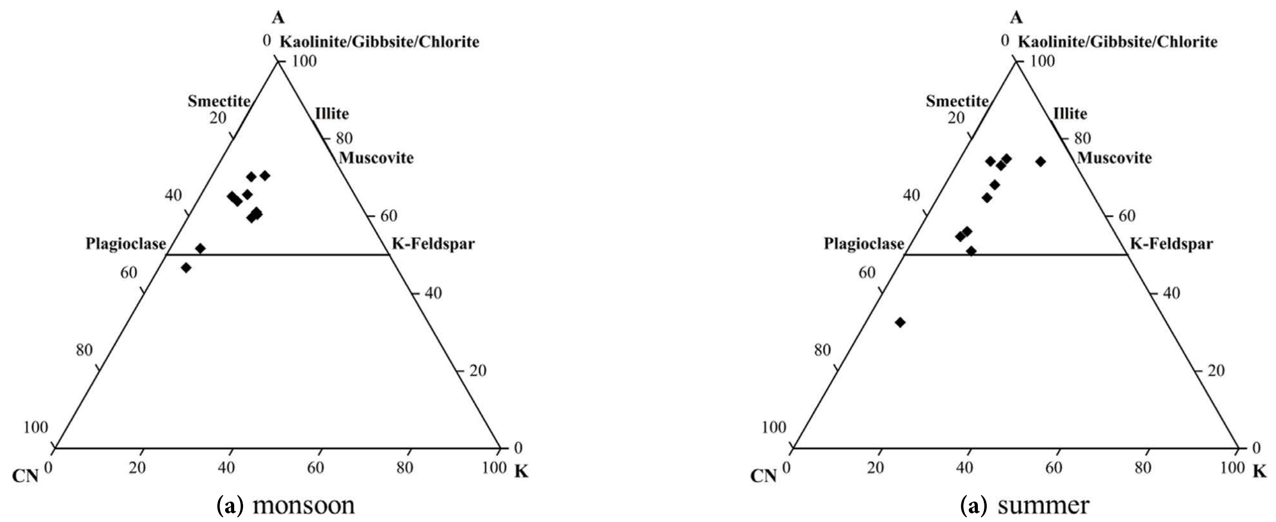

Figure 4. A-CN-K ternary diagram of the study area **(a)** monsoon and **(b)** summer.

an average of 9.94. Most of the samples were mafic and intermediate igneous rocks during both seasons (Fig. 2). Intermediate igneous rocks are formed when magma with moderate silica cools and solidifies. This magma is formed by a variety of processes occurring inside the Earth, including partial melting, fractional crystallization, and the mixing of different magmas [22]. Mafic rocks are the result of the process of magma cooling and solidifying, which occurs when the magma contains a significant amount of magnesium and iron. Mafic magma could form through two primary mechanisms; Partial melting and fractional crystallization [23].

Paleo Weathering

The highest PIA value (100) denotes entirely altered materials like kaolinite and gibbsite and unweathered plagioclase is indicated when 50% of the maximum PIA value is reached [14]. The samples exhibit the range of PIA values from 46.27–76.89 with an average value of 64.80 during monsoon and 29.38–88.26 with an average value of 66.36 during summer, illustrating the weathering characteristics of the parent rocks. Sediment CIA values are a vital measure of the degree of weathering in the provenance. CIA of fresh feldspar and unweathered igneous rocks typically fall within the range of 40 to 50, and residual rocks that have been significantly affected by weathering have values that are more proximate to 100 [16]. CIA values of the samples ranged from 46.72–70.51 with an average value of 61.48 during monsoon and 32.57–74.83 with an average value of 62.35 during summer is seen as a representation of low to intermediate degree of weathering (Fig. 3i). PIA and CIA assess the contrast between weathering occurring in the origin and distant transportation. Despite experiencing some degree of weathering at the origin, the sediments may not have traveled a significant distance before being deposited [24]. The CIA vs. K/Na (Fig. 3ii) and CIA vs. Al/Na (Fig. 3iii) for the studied samples for both seasons show low to intermediate silicate weathering in almost all locations.

ICV values below 1 signify a higher proportion of clay minerals. Conversely, values exceeding 1 show the existence of minerals found in rocks, such as plagioclase, alkali-feldspar, and pyroxenes [17]. ICV values of samples ranged from 4.39–7.55 with an average value of 5.10 during monsoon and 3.26–12.04 with an average value of 5.80 during summer (Table 2a, b). The average ICV score suggests that rock-forming minerals like plagioclase and alkali-feldspar are more prevalent and fewer clay minerals are present. This is due to the geology of the region which is dominated by ultramafic rocks and also gneiss and granite [13].

The A-CN-K plot (Al_2O_3-(CaO* + Na_2O)-K_2O) is a dependable measure for evaluating weathering patterns [25]. The weathering tendency tends to be around the A-vertex and toward muscovite and illite (Fig. 4) due to the metasomatism of potassium [15]. The increased concentrations of Al_2O_3 and Fe_2O_3 in all the samples indicate the existence of aluminum silicate minerals such as muscovite [26]. Nearly every sample in the core of the A–CN–K ternary diagram is above the feldspar join line, indicating plagioclase with CIA values ranging from (46–70) during monsoon and (32–74) during summer. The CIA values were >50 (UCC ~50) in almost all samples indicating low to moderate chemical weathering.

The A-C-N diagram was used to depict the molar proportions of (Al_2O_3-K_2O), CaO*, and Na_2O to observe the plagioclase weathering pattern in the sediments. All samples in the (A–C–N) triangle plot have a distribution field close to the A apex, which may be due to the impact of significant weathering. The majority of the sediments in the study show a single line for the plagioclase weathering trend, indicating that the parent rocks' plagioclases are low to intermediately weathered. The sediments display a linear trend with high CaO values and are enriched in Al_2O_3 suggesting that the sediments gradually reduce albite and are enriched in the weathering of anorthite parent material (Fig. 5). The PIA values of the sediment samples ranged from (46–77) during monsoon and (29–88) during summer.

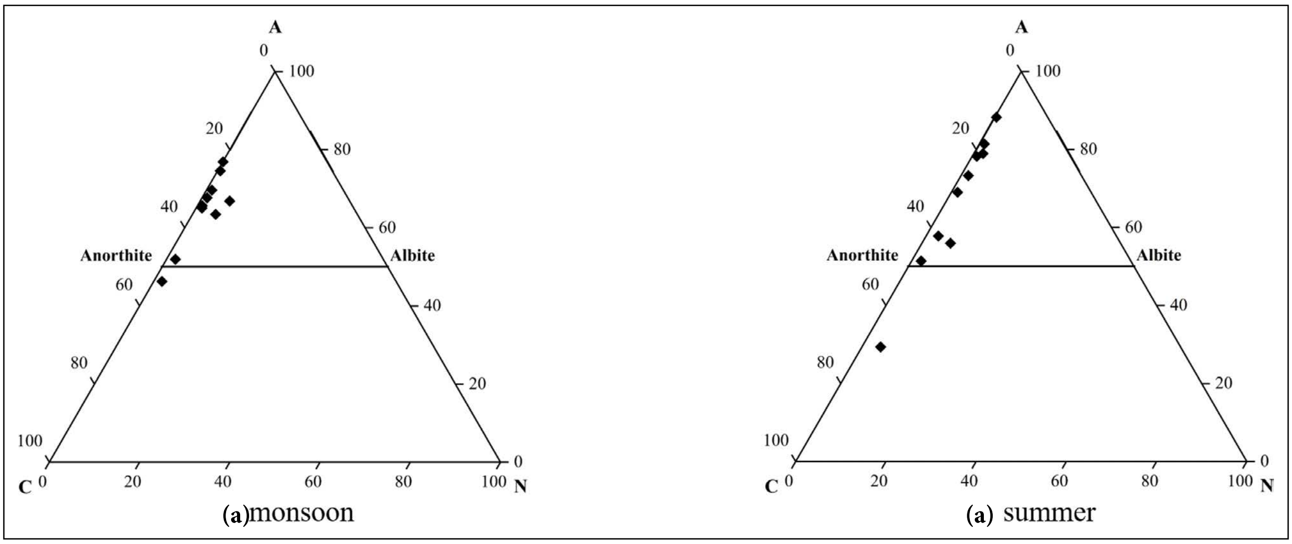

Figure 5. A-C-N ternary diagram of the study area **(a)** monsoon and **(b)** summer.

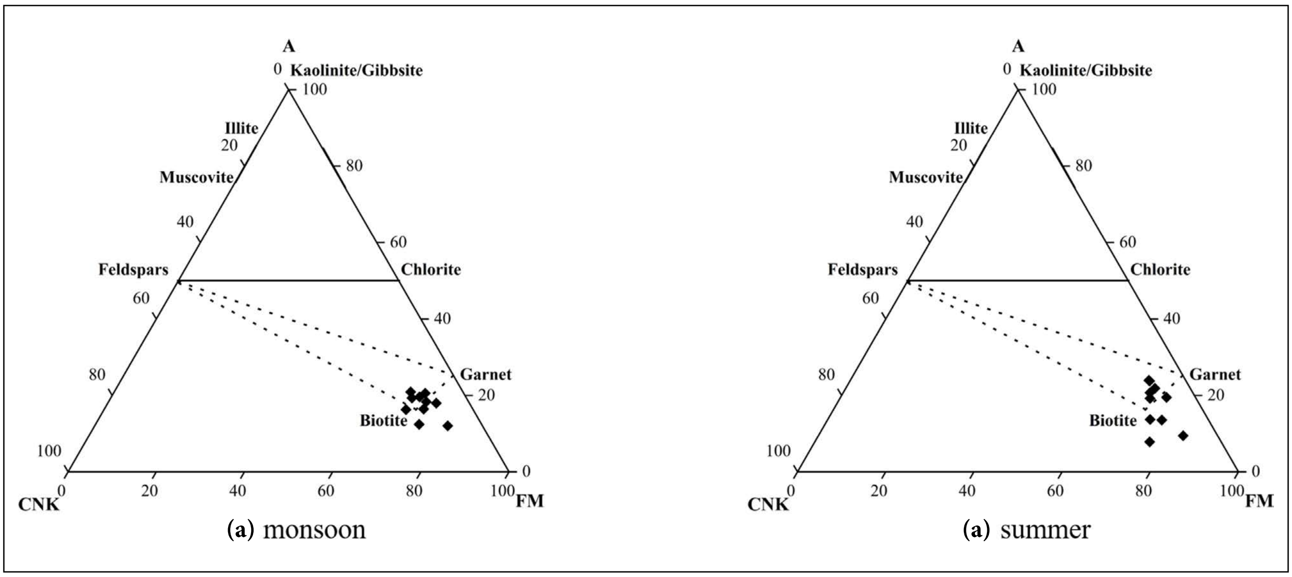

Figure 6. A-CNK-FM ternary diagram of the study area **(a)** monsoon and **(b)** summer.

In the A-CNK-FM (Al_2O_3 - ($CaO + Na_2O + K_2O$) - ($Fe_2O_3 + MgO$)) diagram all the sediment samples lie below the feldspar region indicating the presence of garnet and biotite in the study area (Fig. 6). Gneiss dominates the Noyyal basin's subsurface, reaching its maximum in the center. The southern and southeast regions of Noyyal are home to charnockite and on the eastern edge basic rock are found. Patches of pink granite may be observed in the western, southwestern, and southeast sections. The basin is also encompassed by several types of rocks, including basic and ultra-mafic rocks, garnet-sillimanite graphite gneiss, granite, charnockite, fissile hornblende biotite gneiss, and hornblende biotite gneiss [13]. The A-CNK-FM diagram provides evidence of the existence of these minerals in the studied sediment samples indicating that the underlying rock formations are mostly composed of igneous and metamorphic rocks.

CONCLUSION

The surface sediment of the Noyyal River basin was geochemically analyzed to understand the major oxide geochemistry, weathering intensity, and provenance. Based on the findings and the subsequent discussion of the current study, the following conclusions may be drawn:

- Major element data suggests that the major sources of sediments were mafic and intermediate igneous rocks.
- The CIA and PIA values, CIA and K/Na values, and the sediments' CIA and Al/Na values suggest low to intermediate silicate weathering in the sample locations.
- The average ICV score suggests that rock-forming minerals like plagioclase and alkali-feldspar are more prevalent and fewer clay minerals are present.
- The A-CN-K plot shows that the weathering tendency tends to be around the A-vertex and toward muscovite

and illite. All the samples are above the feldspar join line, indicating plagioclase with CIA values >50.

- The A-C-N plot shows a single line for the plagioclase weathering trend, indicating that the parent rocks' plagioclases are low to intermediately weathered. The sediments display a linear trend with high CaO values and are enriched in Al_2O_3 suggesting that the sediments gradually reduce albite and are enriched in the weathering of anorthite parent material
- The A-CNK-FM shows all the sediment samples lie below the feldspar region indicating the presence of garnet and biotite and provides evidence of the existence of these minerals indicating that the underlying rock formations are mostly composed of igneous and metamorphic rocks.

The Noyyal River basin illustrates the intricate interaction between natural and human-induced processes that control the mobility and accumulation of surface material. The transportation of surface material in the Noyyal River basin from its provenance to its sink is an intricate process that is affected by geological, hydrological, land use, climate, and human variables. Comprehending this process is crucial for efficient river basin management and reducing the consequences of sediment-related problems such as inundation, deterioration of water quality, and accumulation of sediment in reservoirs.

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DATA AVAILABILITY STATEMENT

The author confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

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