

Original Research

Received 07 June 2026

Revised 22 July 2026

Accepted 05 Aug 2026

Natural Resources for Human Health 2026, Vol.6(15s):1005–1033

KEYWORDS:

Dissolved inorganic carbon, Carbon isotopes, Chemical weathering, Water quality, Sediment geochemistry, Cauvery River.

Rock–Sediment–Water Controls on Dissolved Inorganic Carbon, $\delta^{13}\text{C}$ and Water Quality in the Cauvery River, India

K. Vybhav^{1*}, K. N. Prakash Narasimha²

¹Department of Mines and Geology, Ballari, Karnataka, India.

ORCID Id: 0000-0002-6461-770X

²Department of Studies in Earth Science, University of Mysore, Manasagangotri, Mysuru, Karnataka, India (Retired Professor)

Corresponding Author: K. Vybhav, Department of Mines and Geology, Ballari, Karnataka, India.

E-mail: k.vybhav@gmail.com

ABSTRACT: Rivers draining silicate terrains carry carbon fixed by rock weathering to the ocean, yet rocks, sediments, water and dissolved carbon are rarely studied together, and the suitability of the same water for people is usually assessed separately. We combined whole-rock ($n = 10$), bed-load sediment ($n = 15$) and river-water chemistry ($n = 15$) with dissolved inorganic carbon (DIC) and its stable carbon isotope composition ($\delta^{13}\text{C}$ -DIC; $n = 11$) along the lower Cauvery River, southern India. Gneiss-dominated rocks and immature sands (CIA 42–61) record plagioclase weathering, and the water plots at the silicate end-member (Ca/Na 0.14–0.31), yet bicarbonate balances only about one-third of the cation charge because of large chloride inputs from irrigation, effluents and evaporation. All river stations meet the Indian acceptable limits for chloride, calcium, magnesium and hardness, and TDS stays below the permissible limit, but magnesium hazard exceeds 50% at 12 of 14 stations, a risk for irrigated soils. DIC (8.3–40.9 mg C L⁻¹) follows the weathering solute load, while $\delta^{13}\text{C}$ -DIC rises downstream from -9.5‰ to -1.3‰ (2.7‰ per 100 km; $r = 0.84$). As carbonate is absent, this enrichment records progressive exchange with the atmosphere and CO₂ evasion in the dam-regulated channel; an equilibration model gives an e-folding length of 190 ± 54 km. Treating all cations as weathering products would overestimate CO₂ consumption about threefold. We propose a Rock–Sediment–Water–Carbon (RSWC) framework, including water-quality screening, for use in other river basins.

1. INTRODUCTION

Rivers are the main conduit linking the terrestrial, oceanic and atmospheric carbon reservoirs. Globally they deliver roughly 0.4 Pg C yr⁻¹ of organic carbon and a comparable amount of dissolved inorganic carbon (DIC) to the ocean, while inland waters return a large fraction of terrestrially fixed carbon to the atmosphere as CO₂ (Ludwig et al., 1996; Cole et al., 2007; Tranvik et al., 2009; Aufdenkampe et al., 2011; Raymond et al., 2013). On geological time-scales, chemical weathering of silicate minerals by carbonic acid, followed by carbonate precipitation in the ocean, is the principal long-term sink of atmospheric CO₂ and a thermostat for Earth's climate (Walker et al., 1981; Berner et al., 1983). Quantifying how much river DIC originates from silicate weathering, from carbonate dissolution, from respired soil CO₂ or from the atmosphere is therefore central to both the short-term carbon budget and the long-term weathering feedback (Meybeck, 1987; Gaillardet et al., 1999; Hartmann et al., 2009).

The stable isotope composition of DIC ($\delta^{13}\text{C}$ -DIC) is the most widely used tracer of these sources. DIC produced by silicate weathering with soil CO₂ beneath C₃ vegetation carries $\delta^{13}\text{C}$ values of about -17 to -21‰ , carbonate dissolution by the same

acid yields about -8 to -12‰ , and DIC in isotopic equilibrium with atmospheric CO_2 is close to 0‰ at tropical temperatures (Mook et al., 1974; Zhang et al., 1995; Clark and Fritz, 1997; Telmer and Veizer, 1999). The trouble is that these fields overlap, and once carbon reaches the channel its isotopic label keeps changing through CO_2 evasion, exchange with the atmosphere, photosynthesis and respiration (Doctor et al., 2008; Polsenae and Abril, 2012). A value of about -8‰ may therefore point to carbonate weathering, or equally to silicate-derived DIC that has partly equilibrated with the air. Telling the two apart needs independent evidence of what the river is weathering, and that evidence sits in the rocks of the catchment and in the sediment the river carries.

In India, DIC and $\delta^{13}\text{C}$ -DIC have been studied mainly in Himalayan rivers (Galy and France-Lanord, 1999; Singh et al., 2005), in rivers draining the Deccan basalts (Das et al., 2005) and in national-scale surveys of monsoonal rivers (Krishna et al., 2019). Solute-based weathering budgets exist for the Kaveri (Cauvery) basin (Pattanaik et al., 2013), and sediment geochemistry of the Kaveri floodplain has been used to infer source-area weathering (Singh and Rajamani, 2001). To our knowledge no study has yet followed a single reach from source rock, through bed-load sediment, to the dissolved load and its carbon isotopes, and there is no simple workflow for doing so in other basins.

The Cauvery suits this purpose well. It drains Archaean–Proterozoic granulites, charnockites and migmatitic gneisses of the Southern Granulite Terrain with little carbonate; its lower course lies in the semi-arid rain shadow of the Western Ghats; and it is among the most regulated rivers in India, with the Mettur reservoir, a chain of anicuts and barrages, and an intensively irrigated delta. Here we (i) characterise rock, sediment and water chemistry along the Tamil Nadu reach, (ii) quantify spatial variations of DIC and $\delta^{13}\text{C}$ -DIC, (iii) test how far lithology and weathering intensity explain the carbon signal, (iv) compare the Cauvery with other Indian and world rivers, and (v) propose a transferable Rock–Sediment–Water–Carbon (RSWC) framework.

The lower Cauvery is also the main source of drinking and irrigation water for the towns and farmland of central and eastern Tamil Nadu. The weathering processes that set its carbon chemistry also control the salts that matter for health and agriculture, so we additionally assess the river water against drinking-water standards and irrigation-quality indices.

2. MATERIALS AND METHODS

2.1. Study area

The Cauvery rises at Talakaveri (≈ 1350 m a.s.l.) in the Western Ghats of Karnataka and flows ≈ 800 km east-south-east to the Bay of Bengal near Poompuhar, draining a basin of $81,155$ km² across Karnataka, Tamil Nadu, Kerala and Puducherry (CWC, 2025). In Tamil Nadu the river enters over the Hogenakkal falls, is impounded at Mettur, receives the Bhavani, Noyyal and Amaravathi tributaries, and widens into a sandy braided channel below Karur. At Mukkombu (Upper Anicut) it bifurcates into the Coleroon (Kollidam) and the Cauvery proper, and below the Grand Anicut it divides into the distributary and canal network of the delta (Figure 1).

The reach studied lies in the Cauvery Shear System, a ≈ 60 km wide, E–W trending Proterozoic shear belt separating the northern granulite blocks from the Madurai Block (Drury et al., 1984). Exposed lithologies are hornblende–biotite and quartzofeldspathic gneisses, migmatites, charnockites, pegmatites, layered anorthosite–gabbro–ultramafic bodies (Sittampundi, Bhavani) and minor calc-silicate and crystalline limestone bands; Cretaceous–Tertiary sediments and Quaternary alluvium cover the delta. The climate is tropical semi-arid, with a bimodal rainfall regime (south-west monsoon, June–September; north-east monsoon, October–December) and mean air temperature of ≈ 26 °C (13.5 – 41 °C). Discharge in the Tamil Nadu reach is controlled by reservoir releases for irrigation.

2.2. Sampling

Rock, bed-load sediment and surface-water samples were collected at ≈ 25 – 30 km intervals along the river in Tamil Nadu (Table 1). Ten representative rock samples from eight outcrops (gneiss, pegmatite, charnockite) were taken for petrography and whole-rock chemistry. Bed-load sediment was collected at 15 stations and homogenised by coning and quartering. Surface water was collected at the same 15 stations in pre-cleaned 1 L polyethylene bottles during post-monsoon, monsoon and winter campaigns; the values reported here are station means over the three seasons. Samples for DIC and $\delta^{13}\text{C}$ -DIC were filtered, collected without headspace in 60–100 mL Tarsons bottles, poisoned with saturated HgCl_2 and stored at 4 °C. DIC and $\delta^{13}\text{C}$ -DIC were determined at 11 geo-referenced stations (S4–S14). pH, EC and DO were determined in the laboratory on the stored samples, together with the major ions.

To avoid ambiguity in the source dataset, where water/sediment identifiers (C1–C15, upstream to downstream) and isotope identifiers (C2–C12, downstream to upstream) run in opposite directions, all stations are re-coded S1–S15 in downstream order; the cross-walk is given in Table 1.

2.3. Analytical methods

Thin sections were examined with Leitz Laborlux Pol and Lawrence and Mayo polarising microscopes. Major and trace elements of rock and sediment powders ($<63 \mu\text{m}$) were determined by wavelength-dispersive XRF (Bruker S4 Pioneer) at the National Centre for Earth Science Studies, Thiruvananthapuram, on fused glass beads (1 g sample + 5 g Li-tetraborate/metaborate flux) for majors and pressed pellets for traces, calibrated against international reference materials. Loss on ignition was measured at 950°C . Water samples were analysed for pH, EC, turbidity, total alkalinity, HCO_3^- , Cl^- , SO_4^{2-} , Ca^{2+} , Mg^{2+} , Na^+ , K^+ and TDS following IS 3025 procedures at an ISO 9001/14001-certified laboratory (Mysuru). DIC was measured by coulometry (UIC CM-140) at ISRO–NRSC, Hyderabad. $\delta^{13}\text{C}$ -DIC was measured on CO_2 liberated with $\approx 99\%$ H_3PO_4 using a Delta V Plus isotope-ratio mass spectrometer at the Wadia Institute of Himalayan Geology, Dehradun; results are reported in ‰ relative to VPDB, with reproducibility better than 0.1% (1σ).

2.4. Geochemical indices and calculations

Weathering intensity was expressed as the Chemical Index of Alteration (Nesbitt and Young, 1982), the Plagioclase Index of Alteration (Fedo et al., 1995), the Chemical Index of Weathering (Harnois, 1988), the Weathering Index of Parker (Parker, 1970) and the Index of Compositional Variability (Cox et al., 1995), using molar proportions:

$$\text{CIA} = 100 \times \text{Al}_2\text{O}_3 / (\text{Al}_2\text{O}_3 + \text{CaO}^* + \text{Na}_2\text{O} + \text{K}_2\text{O}) \quad (1)$$

$$\text{ICV} = (\text{Fe}_2\text{O}_3 + \text{K}_2\text{O} + \text{Na}_2\text{O} + \text{CaO} + \text{MgO} + \text{TiO}_2) / \text{Al}_2\text{O}_3 \quad (\text{wt}\%) \quad (2)$$

where CaO^* is silicate-bound CaO . Whole-rock CIA is reported without the apatite/carbonate correction, which is inappropriate for mafic rocks with $\text{CaO} > \text{Na}_2\text{O}$. Element mobility in sediment relative to the parent was expressed by the mass-transfer coefficient τ (Brimhall and Dietrich, 1987; Anderson et al., 2002), with Al as the immobile reference and the mean of the eight felsic–intermediate rocks as parent (excluding the charnockite R4 and ultramafic-affinity gneiss R10):

$$\tau_j = (C_{j,\text{sed}} / C_{j,\text{parent}}) \times (C_{\text{Al,parent}} / C_{\text{Al,sed}}) - 1 \quad (3)$$

The stoichiometric CO_2 -consumption potential of each rock, Φ (mol CO_2 per kg rock), was computed as the charge equivalents of base cations that would be released by complete carbonic-acid weathering to kaolinite (each equivalent consumes one mole of CO_2 ; Gaillardet et al., 1999):

$$\Phi = 2 n(\text{CaO}) + 2 n(\text{MgO}) + 2 n(\text{Na}_2\text{O}) + 2 n(\text{K}_2\text{O}) \quad (\text{mol kg}^{-1}) \quad (4)$$

Water chemistry was converted to molar units to calculate Na-normalised ratios (Ca/Na , Mg/Na , HCO_3^-/Na) for comparison with the silicate, carbonate and evaporite end-members of Gaillardet et al. (1999), the Gibbs (1970) ratio $\text{Na}/(\text{Na}+\text{Ca})$, the Na/Cl ratio and the fraction of total cation charge ($\text{TZ}^+ = 2\text{Ca} + 2\text{Mg} + \text{Na} + \text{K}$, meq L^{-1}) balanced by bicarbonate ($\text{HCO}_3^-/\text{TZ}^+$). Carbonate speciation was calculated at 25°C using the constants of Plummer and Busenberg (1982) ($\text{pK}_0 = 1.468$, $\text{pK}_1 = 6.352$, $\text{pK}_2 = 10.329$), neglecting activity corrections at these ionic strengths:

$$\text{DIC}_{\text{calc}} = [\text{HCO}_3^-] (1 + [\text{H}^+]/\text{K}_1 + \text{K}_2/[\text{H}^+]) ; \quad \text{pCO}_2 = [\text{HCO}_3^-][\text{H}^+] / (\text{K}_1 \text{K}_0) \quad (5)$$

Because pH values are seasonal means measured in the laboratory after transport, DIC_{calc} and pCO_2 were used as a consistency check rather than as primary data (Section 3.5). Sources of $\delta^{13}\text{C}$ -DIC were evaluated with a two end-member model between silicate-weathering DIC produced by soil CO_2 (δ_{sil}) and DIC in isotopic equilibrium with atmospheric CO_2 (δ_{eq}):

$$f_{\text{eq}} = (\delta^{13}\text{C}_{\text{DIC}} - \delta_{\text{sil}}) / (\delta_{\text{eq}} - \delta_{\text{sil}}) \quad (6)$$

with $\delta_{\text{sil}} = -19\%$ (cf. $-18.7 \pm 2\%$ in silicate-dominated Western Ghats rivers; Das et al., 2005) and $\delta_{\text{eq}} = -0.6\%$ (atmospheric $\text{CO}_2 \approx -8.5\%$ plus $\epsilon(\text{HCO}_3^- - \text{CO}_2(\text{g})) \approx +7.9\%$ at 25°C ; Mook et al., 1974; Zhang et al., 1995). A sensitivity case with $\delta_{\text{sil}} = -14\%$ represents soil CO_2 with a substantial C_4 (crop, grass) contribution. Uncertainty in f_{eq} was propagated by Monte Carlo simulation (20,000 draws) with $\delta_{\text{sil}} \sim \text{N}(-19, 2)\%$, $\delta_{\text{eq}} \sim \text{U}(-1.5, +0.5)\%$ and an analytical error of $\pm 0.1\%$.

The downstream isotopic evolution was described with a first-order equilibration model, in which DIC relaxes towards the atmosphere-equilibrated value with distance x :

$$\delta^{13}\text{C}(x) = \delta_{\text{eq}} - (\delta_{\text{eq}} - \delta_0) \exp(-x / L) \quad (7)$$

where δ_0 is the value at S4 and L is an e-folding equilibration length; δ_{eq} was fixed at -0.6‰ . δ_0 and L were estimated by non-linear least squares and their uncertainty by 2000 bootstrap resamples (Efron and Tibshirani, 1993). The anion balance was expressed as the fractions of TZ^+ balanced by HCO_3^- , by Cl^- and by a residual comprising SO_4^{2-} , NO_3^- , unmeasured anions and analytical error. CO_2 consumption was evaluated for three scenarios: (A) all base cations attributed to carbonic-acid weathering ($Q \times \text{TZ}^+$), (B) bicarbonate-based ($Q \times \text{HCO}_3^-$) and (C) silicate-derived bicarbonate only ($0.9 Q \times \text{HCO}_3^-$; Pattanaik et al., 2013), where Q is annual discharge. Downstream distance was calculated as the cumulative great-circle distance between consecutive stations, a lower bound on channel length. Relationships were tested with Pearson (r) and Spearman (ρ) coefficients; with $n = 11$, $|r| \geq 0.60$ corresponds to $p < 0.05$. All calculations were scripted in Python (pandas, SciPy) and are provided as supplementary code.

Drinking-water suitability was assessed against the acceptable and permissible limits of the Indian standard IS 10500 (BIS, 2012) and the WHO (2017) guidelines. Total hardness was calculated as $\text{TH} = 2.497 \text{ Ca} + 4.118 \text{ Mg}$ (mg L^{-1} as CaCO_3). Irrigation suitability was assessed, with ions in meq L^{-1} , using the sodium adsorption ratio $\text{SAR} = \text{Na} / \sqrt{((\text{Ca} + \text{Mg})/2)}$ and the US Salinity Laboratory classification (Richards, 1954); sodium percentage, $\% \text{Na} = 100 (\text{Na} + \text{K}) / (\text{Ca} + \text{Mg} + \text{Na} + \text{K})$ (Wilcox, 1955); the Kelly ratio, $\text{KR} = \text{Na} / (\text{Ca} + \text{Mg})$ (Kelly, 1940); magnesium hazard, $\text{MH} = 100 \text{ Mg} / (\text{Ca} + \text{Mg})$ (Szabolcs and Darab, 1964); and residual sodium carbonate, $\text{RSC} = (\text{HCO}_3^- + \text{CO}_3^{2-}) - (\text{Ca} + \text{Mg})$ (Eaton, 1950).

3. RESULTS AND DISCUSSION

3.1. Rock chemistry and weathering reactivity

Gneisses consist of quartz, plagioclase, K-feldspar, biotite and hornblende with opaque accessories; plagioclase is variably sericitised and epidotised, and feldspars along fractures alter to sericite and kaolinite. Charnockite contains orthopyroxene, plagioclase, K-feldspar and quartz; pegmatite contains quartz, feldspar, muscovite and biotite. Whole-rock compositions (Table 2) span SiO_2 46.8–74.3 wt%, Al_2O_3 4.8–20.1 wt%, CaO 0.6–11.3 wt% and MgO 0.2–22.8 wt%. On Harker diagrams CaO ($r = -0.88$), MgO (-0.82) and $\text{Fe}_2\text{O}_3^{\text{T}}$ (-0.87) decrease with SiO_2 , whereas Na_2O and K_2O scatter (Figure 2), consistent with a calc-alkaline, peraluminous to metaluminous tonalite–granite suite. The charnockite (R4) and the mafic gneiss R10 are Mg–Fe–Cr–Ni-rich (Cr 1294–1935 ppm; Ni 385–978 ppm). Unaltered-rock CIA values cluster at 44–52 for felsic gneisses and pegmatite and fall to 17.6–24.2 for the mafic samples; the stoichiometric CO_2 -consumption potential Φ is 2.9–5.8 mol kg^{-1} for felsic–intermediate rocks but 10.9–15.7 mol kg^{-1} for the mafic lithologies.

Plotting CIA against Φ separates the lithologies into two reactivity classes (Figure 3). Felsic gneisses and pegmatite cluster at CIA 44–52 and Φ 2.9–5.8 mol kg^{-1} , whereas the charnockite R4 and mafic gneiss R10 combine low CIA with Φ of 10.9–15.7 mol kg^{-1} and the highest $\text{MgO} + \text{Fe}_2\text{O}_3$ contents.

Read together, the rocks and sediments show that weathering in the lower Cauvery is mostly a matter of plagioclase breakdown. Rocks lie on the feldspar join (CIA ≈ 50), sediments are displaced only 5–10 CIA units toward Al_2O_3 , and Na is depleted at every station, as petrography also shows (sericitisation and kaolinisation of plagioclase). The accompanying loss of K (mean $\tau_{\text{K}} -0.38$) is larger than expected from K-feldspar stability and probably reflects hydraulic sorting: fine micas and altered K-feldspar are winnowed from the bed load, leaving quartz and coarse plagioclase (Singh and Rajamani, 2001). Ca and Mg behave differently. They are enriched where charnockite and mafic rocks crop out and depleted in the quartz-rich middle reach, which shows that bed-load chemistry is set as much by local provenance and sorting as by weathering intensity. This has consequences for the carbon budget, since the mafic lithologies, although volumetrically minor, have two to five times the CO_2 -consumption potential of the gneisses ($\Phi = 10.9\text{--}15.7$ vs $2.9\text{--}5.8 \text{ mol kg}^{-1}$) and weather faster; analogous weatherability contrasts between basalt and granite underpin the high CO_2 consumption of basaltic catchments (Dessert et al., 2003; Das et al., 2005).

3.2. Bed-load sediment: weathering intensity and provenance

Bed-load sediments contain 64.9–84.6 wt% SiO₂ and 8.2–14.6 wt% Al₂O₃ (Table 3). Reported CIA ranges from 41.7 to 61.4 (mean 53.7), PIA from 40.8 to 62.0 and ICV from 0.77 to 1.84 (mean 1.12), indicating chemically immature, first-cycle sands derived from weak to moderate weathering (Figure 4a). Recalculation with the McLennan (1993) CaO correction raises CIA slightly (mean 56.8) without changing the spatial pattern. On the A–CN–K diagram, rocks lie on or below the plagioclase–K-feldspar join and sediments plot just above it, displaced toward the A apex along a trend parallel to the A–CN edge (Figure 5*). This indicates preferential loss of Ca and Na from plagioclase, the first stage of the Nesbitt and Young (1984) weathering trend, with little illite or kaolinite formation.

Downstream patterns are systematic (Figure 4b). Stations S2–S4 below Mettur and the river-mouth station S15 are the least weathered and most immature (CIA 41.7–49.2; ICV 1.30–1.84), and are rich in Fe, Mg, Ti and Cr (Cr up to 223 ppm; Al₂O₃/TiO₂ down to 4.4 at S15), reflecting supply of pyroxene, amphibole and Fe–Ti oxides from charnockitic and mafic sources. The middle reach (S5–S9) carries quartz-rich, mature sands (SiO₂/Al₂O₃ 9.1–10.2; ICV 0.77–0.95; Cr 54–72 ppm) with the highest CIA (56–59). Relative to the gneissic parent, Na and K are depleted at every station (τ_{Na} –0.08 to –0.52; τ_K –0.19 to –0.83), whereas Ca and Mg are enriched upstream and at the mouth (τ_{Mg} up to +3.1) and depleted in the mature middle reach (τ_{Ca} –0.20 to –0.32). Al₂O₃/TiO₂ ratios (mean 20.5) and the provenance diagrams of the source study indicate felsic–intermediate sources with a variable mafic component.

The sediment indices place the basin in a regime of low to moderate chemical weathering with relatively rapid physical erosion of fresh rock (CIA 42–61, ICV > 1 at 8 of 15 stations). This is consistent with semi-arid climate, the incision of the Cauvery across uplifted Western Ghats and shear-zone topography, and with the conclusion that the Kaveri floodplain sediments preserve source-rock signatures with limited recycling (Singh and Rajamani, 2001).

3.3. River-water chemistry and solute sources

Excluding the river-mouth station, station-mean waters are neutral to alkaline (pH 5.85–9.54; mean 8.0), with EC 225–817 $\mu\text{S cm}^{-1}$ and TDS 178–714 mg L^{–1} (Table 4). Cations are ordered Na⁺ > Ca²⁺ $\approx$ Mg²⁺ > K⁺ by mass and anions HCO₃[–] $\approx$ Cl[–] > SO₄^{2–}; carbonate alkalinity is absent. In molar terms Na⁺ dominates (Na/(Na+Ca) = 0.62–0.79 in meq). All river stations fall in the rock-dominance field of the Gibbs diagram, displaced toward higher Na/(Na+Ca) (Figure 6a). In Na-normalised mixing space they cluster at the silicate end-member (Ca/Na 0.14–0.31; Mg/Na 0.17–0.51), two orders of magnitude from the carbonate end-member (Figure 6b). HCO₃[–]/Na ratios (0.55–1.02), however, lie below the silicate end-member ($\approx$ 2; Figure 6c), bicarbonate balances only 29–42% of the total cation charge (HCO₃[–]/TZ⁺ mean 0.34), and molar Na/Cl ratios (0.73–1.60; mean 1.14) are close to halite and seawater (Figure 6d). Station S15 (Poompuhar) is saline and marine-influenced (TDS 1355 mg L^{–1}; EC 3328 $\mu\text{S cm}^{-1}$; Mg 455 mg L^{–1}; Na 2021 mg L^{–1}) and is excluded from weathering calculations.

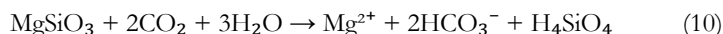
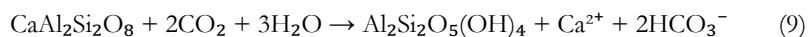
Four stations (S6, S8, S11, S13) have mean pH below 6.4 and roughly half the solute load of the others (mean TDS 247 vs 507 mg L^{–1}; HCO₃[–] 91 vs 143 mg L^{–1}). pH is strongly correlated with EC ($r = 0.92$), Ca²⁺ (0.90) and HCO₃[–] (0.81) across the isotope stations (Figure 7).

The anion balance is summarised in Figure 8. At the river stations HCO₃[–] balances on average 34% of the total cation charge, Cl[–] 44% and the residual (SO₄^{2–}, NO₃[–], unmeasured anions) 23%. At S7 bicarbonate and chloride together exceed TZ⁺, leaving no residual. HCO₃[–]/TZ⁺ is not significantly related to Cl[–] concentration ($r = -0.33$, $p = 0.25$) and remains at about half the world-average value at every river station.

Projected onto the basin, the water chemistry shows little change in cation make-up but clear downstream changes in solute load (Figure 9). Na⁺ + K⁺ supply 43–63% of the cation charge at every station, with the largest share at Kandiyur Bridge (S11). Mg²⁺ is highest at the dilute, low-pH stations S6 and S8 (40–41%). TDS is highest at S5, S7, S9 and S10 (535–714 mg L^{–1}) and lowest at S8, S11 and S13 (178–201 mg L^{–1}). Chloride is the largest single anion at ten of the eleven stations; only at Thiruvanchuli (S12) does bicarbonate lead (42%).

The dissolved load tells the other half of the story. The Na-normalised ratios place every river station at the silicate end-member (Figure 6b), consistent with the absence of significant carbonate in rocks and sediments and with the solute budget of Pattanaik et al. (2013), who attributed more than 90% of the Kaveri ionic load to silicate weathering. Na-dominance in the water mirrors

Na depletion in the sediment: plagioclase weathering transfers Na^+ (and Ca^{2+}) to solution and HCO_3^- is produced in stoichiometric proportion, e.g.



If all cations were weathering-derived through carbonic acid, $\text{HCO}_3^-/\text{TZ}^+$ would approach 1. The observed 0.29–0.42 and $\text{Na}/\text{Cl} \approx 1.1$ show that about two-thirds of the cation charge is balanced by Cl^- (and SO_4^{2-}), which rock weathering cannot supply in a granulite terrain. Plausible sources are irrigation return flow and evaporative concentration of reservoir and canal water in a semi-arid climate, urban and industrial effluents, fertilisers, and saline groundwater; $\approx 30\%$ of global riverine Na, Cl and SO_4 has been attributed to anthropogenic inputs (Meybeck, 2003; see also Sarin et al., 1989). Station-by-station correlations between sediment and water chemistry are weak ($|r| \leq 0.36$): the dissolved load integrates weathering over the whole upstream catchment and is modulated by reservoir releases, whereas bed load reflects local supply and sorting. The link between rock, sediment and water is therefore visible in the processes (plagioclase-dominated silicate weathering, Na-rich solutes, Na-depleted sands) rather than in station-by-station correlations. For that reason the framework proposed below works with process indices instead of raw concentrations.

3.4. Water quality for drinking and irrigation

Because the lower Cauvery supplies drinking water to riverside towns and irrigates the delta, the station data were screened against drinking-water standards and irrigation indices (Table 5; Figure 10). At the fourteen river stations, Cl^- (57–163 mg L^{-1}), Ca^{2+} (14–35 mg L^{-1}), Mg^{2+} (12–27 mg L^{-1}), total hardness (88–195 mg L^{-1} as CaCO_3) and total alkalinity (119–178 mg L^{-1}) are all within the BIS (2012) acceptable limits. TDS exceeds the acceptable limit of 500 mg L^{-1} at five stations (S1, S5, S7, S9 and S10; up to 714 mg L^{-1}) but remains well below the permissible limit of 2000 mg L^{-1} , and Na^+ (44–82 mg L^{-1}) stays below the WHO (2017) taste threshold of 200 mg L^{-1} . Station-mean pH lies outside the 6.5–8.5 range at twelve stations; because these values were measured in the laboratory and partly reflect degassing (Section 3.5), pH should be confirmed in the field before compliance is judged.

For irrigation, SAR (1.7–3.0) and RSC (negative at every station) show no sodicity or residual-carbonate hazard, and the waters fall in the C1–C3/S1 classes of the US Salinity Laboratory diagram, mostly C2S1 (Richards, 1954). Sodium percentage (43–63%) lies mainly in the permissible class (Wilcox, 1955), with Kandiur Bridge (S11) in the doubtful class, and the Kelly ratio reaches or exceeds 1 at S1–S4 and S11. The main concern is magnesium. Mg^{2+} makes up 42–73% of the divalent cations and exceeds the 50% hazard threshold (Szabolcs and Darab, 1964) at twelve of the fourteen stations, which over time can weaken soil structure and lower crop yields. The Mg excess comes from the weathering of the pyroxene- and amphibole-bearing charnockite and mafic gneiss identified in Section 3.1, so the agricultural quality of the river water is itself an outcome of basin lithology. The river-mouth station S15 is unsuitable for drinking or irrigation (TDS 1355 mg L^{-1} , Na^+ 2021 mg L^{-1} , total hardness 2601 mg L^{-1} ; C4S4), reflecting seawater ingress.

3.5. DIC and the carbonate system

DIC ranges from 8.26 mg C L^{-1} at Kandiur Bridge (S11) to 40.9 mg C L^{-1} at Karuvelampalayam (S5), with a mean of 21.8 ± 8.3 mg C L^{-1} (1.81 mmol L^{-1} ; Table 6; Figure 11a). Seasonal ranges reported for the full station set are 6.7–18.0 mg C L^{-1} (post-monsoon), 6–9 mg C L^{-1} (monsoon) and 18.1–60.5 mg C L^{-1} (winter), i.e. strong dilution during high flow. DIC correlates positively with pH ($r = 0.66$, $p = 0.03$), EC (0.68, $p = 0.02$) and Ca^{2+} (0.70, $p = 0.02$) and, by rank, with K^+ ($q = 0.66$) and TDS ($q = 0.60$), but not with distance downstream ($r = -0.41$, $p = 0.21$) (Figure 7). Measured DIC is on average 0.89 times the HCO_3^- -C derived from seasonal-mean alkalinity (range 0.44–1.69).

DIC is highest where the weathering solute load is highest: it correlates with EC, Ca^{2+} , K^+ and pH, and the low-DIC stations (S6, S11, S13) are those with half the solute load. Mean DIC (1.8 mmol L^{-1}) is roughly twice the world-average river bicarbonate (≈ 0.96 mmol L^{-1} ; Livingstone, 1963) and comparable to large silicate-carbonate rivers, despite the lack of carbonate, because

evaporative concentration and low runoff in the rain shadow raise solute concentrations. The strong seasonal contrast (6–9 mg C L⁻¹ in the monsoon vs up to 60 mg C L⁻¹ in winter) reflects dilution by reservoir releases and monsoon runoff.

Running the speciation calculation also turned up a data-quality problem that other studies may share. At stations with pH > 8.8, calculated pCO₂ is 41–272 μatm, below atmospheric (≈410 μatm), implying CO₂ uptake by photosynthesis; DO at these stations is 7.2–10.7 mg L⁻¹, consistent with active primary production. At the four stations with pH < 6.4, the same equations give pCO₂ of 5 × 10⁴ to 1.3 × 10⁵ μatm and DIC_{calc} 2.6–7.3 times the measured DIC, values not physically plausible for an open, well-mixed river. Because these low pH values coincide with low TDS and are strongly collinear with EC and Ca²⁺, they probably reflect dilute (monsoon-weighted) samples and/or laboratory pH measurement after degassing or storage. For this reason we interpret DIC and δ¹³C directly and use pCO₂ only in a qualitative sense. Field pH with a calibrated electrode, and a routine comparison of DIC_{meas} with DIC_{calc} (accepting ratios of 0.5–2) should be standard practice (Table 7).

3.6. Sources and downstream evolution of δ¹³C-DIC

δ¹³C-DIC ranges from −9.52‰ at Sittar Kovil (S4) to −1.34‰ at Panniyur (S14) (mean −5.54 ± 2.49‰). It increases significantly downstream (Figure 11b): δ¹³C = −8.4‰ + 2.74‰ per 100 km (*r* = 0.84, *p* = 0.001; *Q* = 0.75, *p* = 0.007). δ¹³C is also negatively correlated with turbidity (*r* = −0.63) and with the SiO₂/Al₂O₃ ratio of co-located bed load (*r* = −0.62), but not with DIC, pH, HCO₃[−] or individual cations (*|r|* ≤ 0.37). In the δ¹³C–DIC plane most samples lie between the carbonate-weathering/silicate-dilution field and the atmospheric-equilibration field, and S13 and S14 fall within the latter (Figure 12a); δ¹³C and 1/DIC are unrelated (*r* = 0.14, *p* = 0.68; Figure 12b).

Standardising the sediment, water and carbon variables along the river reveals three segments (Figure 13). Below Mettur (S1–S4) the bed load is immature and Cr-rich (ICV 1.12–1.81; Cr 127–204 ppm), the water has average solute loads, and δ¹³C-DIC is at its lightest (−9.5‰ at S4). Through the middle reach (S5–S9) sands are quartz-rich and mature (SiO₂/Al₂O₃ 9.1–10.2; Cr 54–72 ppm), TDS peaks (714 mg L⁻¹ at S7), and DIC reaches its maximum (40.9 mg C L⁻¹ at S5). In the delta (S10–S14) sediments return to lower SiO₂/Al₂O₃ and higher Cr, high-solute and dilute stations alternate, and δ¹³C-DIC climbs to −1.3‰. S15 stands apart as a marine-influenced end-member.

The same stations on the basin map (Figure 14) show how the solid and carbon phases change along the reach. In A–CN–K–FM space the upstream bed load at Sittar Kovil (S4) is the most mafic (FM 32%, A 33%). The quartz-rich middle-reach sands (S6–S9) have the highest Al share (44–47%). The FM fraction rises again towards the delta (23–29% at S10–S14). The carbon pies change more strongly: the atmosphere-equilibrated share of the DIC isotopic signal grows from about half at S4 to more than 90% at S13–S14, while DIC concentration changes irregularly.

On their own, the Cauvery δ¹³C values (−9.5 to −1.3‰) would place much of the DIC in the carbonate-weathering field, or suggest a marine or atmospheric source. The rock and sediment data rule out the first: there is no carbonate signal in the rock suite, in the sediments (low CaO, no LOI–CaO covariance) or in the water (Ca/Na ≤ 0.31). A marine source is ruled out for S4–S14 by their low, non-marine Na/Cl and Mg/Na; only S15 is marine-influenced. The progressive ¹³C enrichment downstream (Figure 11b), without a matching change in DIC or solute ratios and without conservative mixing (Figure 12b), suggests instead that silicate-derived DIC is being modified within the river.

Three processes can enrich DIC in ¹³C along a regulated tropical river. (1) Kinetic CO₂ evasion from CO₂-supersaturated water removes isotopically light CO₂ and leaves the residual DIC enriched by several per mil over tens of kilometres (Doctor et al., 2008; Polsenaere and Abril, 2012). (2) Isotopic exchange with atmospheric CO₂ moves δ¹³C-DIC toward ≈0‰ at 25–30 °C; this is favoured by the long residence time, shallow depth and large surface area of the braided sandy channel, the Mettur reservoir and the anicut/barrage pools. (3) Photosynthetic uptake of ¹²C-enriched CO₂ in clear, nutrient-rich, slow-flowing water raises δ¹³C, pH and DO. The negative correlation of δ¹³C with turbidity (*r* = −0.63) supports processes (2) and (3), because clear water permits primary production and indicates quiescent, well-exchanged flow. The two end-member model (Eq. 6; Figure 15) quantifies the result: 52% of the DIC isotopic signal at S4 and 95–96% at S13–S14 (mean 73%) corresponds to atmosphere-equilibrated carbon, or 33–95% (mean 63%) if soil CO₂ carries a significant C₄ component. These fractions describe isotopic re-equilibration, not an atmospheric origin of the carbon mass: the bicarbonate itself was produced by silicate weathering (Eqs. 8–10), whose carbon derives ultimately from atmospheric CO₂ via soil respiration, but the isotopic label of that pathway has been progressively overprinted in the channel.

The equilibration model (Eq. 7) describes the same trend with a physically bounded curve (Figure 16). The fit gives $\delta_0 = -8.6 \pm 1.0\text{‰}$ and $L = 190 \pm 54$ km (bootstrap 90% range 127–359 km), with $R^2 = 0.65$ compared with 0.70 for the linear fit; over the sampled reach the two are statistically indistinguishable. The length scale matters for interpretation: 90% equilibration would require ≈ 440 km of transport, about twice the sampled reach, so most of the channel carries DIC that is only partly re-equilibrated. S13 and S14 plot above the curve, suggesting that the distributary channels and anicut pools of the delta add local exchange or photosynthesis. The Monte Carlo analysis confirms that the downstream rise in f_{eq} is robust to end-member uncertainty (Figure 15): median f_{eq} increases from 51% (90% interval 40–59%) at S4 to 95–96% (90–100%) at S13–S14, and the intervals of the upstream and delta stations do not overlap.

Seen this way, the isotope data no longer conflict with the evidence that silicate weathering supplies the DIC. It also follows that reading a $\delta^{13}\text{C}$ –DIC diagram in isolation, as is often done, would have led to the wrong source attribution here.

3.7. CO₂ consumption

At the mean bicarbonate concentration of the river stations (128 mg L^{-1} ; 2.10 mmol L^{-1}), and with $\geq 90\%$ of cations silicate-derived, each cubic kilometre of discharge exports $\approx 2 \times 10^9$ mol of carbon fixed from atmospheric/soil CO₂ by weathering. The basin-scale silicate-weathering drawdown of $25.4 (\pm 0.8) \times 10^9 \text{ mol CO}_2 \text{ yr}^{-1}$ ($3.2\text{--}3.8 \times 10^5 \text{ mol km}^{-2} \text{ yr}^{-1}$; Pattanaik et al., 2013) therefore corresponds to $\approx 12\text{--}13 \text{ km}^3 \text{ yr}^{-1}$ of water at our concentrations. However, because about two-thirds of the cation charge is balanced by non-carbonic anions, flux estimates that equate all base cations with carbonic-acid weathering would overestimate CO₂ consumption in the Cauvery by up to a factor of ≈ 3 . Discharge-weighted sampling at gauged stations is needed to turn these per-volume figures into a robust flux.

Figure 17 shows the three flux scenarios as functions of discharge. Matching the basin drawdown of Pattanaik et al. (2013) requires $12.1\text{--}13.4 \text{ km}^3 \text{ yr}^{-1}$ under the bicarbonate-based scenarios (B, C) but only $4.1 \text{ km}^3 \text{ yr}^{-1}$ if all base cations are treated as carbonic-acid weathering (A). At a given discharge, scenario A exceeds scenario C by a factor of 3.3, which is the error incurred in this basin by ignoring the chloride-balanced cation load.

3.8. Comparison with other rivers

Table 8 and Figure 18 set the Cauvery beside other Indian and world rivers. Four differences are worth drawing out.

Isotopically heavy DIC for a silicate basin. Silicate-dominated rivers typically carry $\delta^{13}\text{C}$ –DIC of -14 to -21‰ : Western Ghats rivers draining Deccan basalt ($-18.7 \pm 2\text{‰}$; Das et al., 2005), the southern tributaries of the Brahmaputra (-13.6 to -17.2‰ ; Singh et al., 2005) and upland silicate tributaries of the Ottawa River ($\approx -16\text{‰}$; Telmer and Veizer, 1999). Carbonate-influenced rivers are heavier: Krishna mainstream -8.5 to -15‰ , Xijiang karst -14.8 to -8.3‰ (mean -11.2‰ ; Gao and Wang, 2015), lowland Ottawa tributaries $\approx -8\text{‰}$. The Cauvery (mean -5.5‰ , down to -1.3‰) is heavier than all of these and resembles only the south-east Indian monsoonal rivers as a group ($-3.5 \pm 2.3\text{‰}$; Krishna et al., 2019) and summer, lake-equilibrated St Lawrence water (-13.1 to -2.4‰ ; Hélie et al., 2002). Values near 0‰ in North Himalayan rivers reflect a different process, input of metamorphic CO₂ (up to $+3.9\text{‰}$; Galy and France-Lanord, 1999). We attribute the Cauvery signature to low runoff, long water residence behind dams and barrages, and high water temperature, which together maximise atmospheric exchange and in-stream production.

High DIC despite no carbonate. Mean DIC (21.8 mg C L^{-1}) exceeds that of the Xijiang karst river ($1.63 \text{ mmol L}^{-1} \approx 19.6 \text{ mg C L}^{-1}$) and the world average, and is lower than the SE Indian river mean ($37.4 \pm 6.3 \text{ mg C L}^{-1}$; Krishna et al., 2019), which includes Cauvery and other rain-shadow rivers draining granulites. In humid silicate catchments (e.g. Western Ghats, Brahmaputra; TDS $102\text{--}203 \text{ mg L}^{-1}$) concentrations are much lower. The difference is climatic and hydrological (evaporation, low runoff), not lithological.

A chloride-rich solute budget. HCO_3^- balances $\approx 34\%$ of cation charge in the Cauvery, compared with $\approx 67\%$ for the world-average river (Livingstone, 1963), and Cl^- (mean 97 mg L^{-1}) is about twelve times the world average (7.8 mg L^{-1}). Himalayan and Deccan rivers are HCO_3^- -dominated. This contrast is diagnostic of intensively irrigated, semi-arid basins and must be corrected for before cation-based weathering fluxes are calculated.

Moderate weathering rates in an old cratonic terrain. Silicate weathering in the Kaveri ($9.4 \text{ t km}^{-2} \text{ yr}^{-1}$; $3.2\text{--}3.8 \times 10^5 \text{ mol CO}_2 \text{ km}^{-2} \text{ yr}^{-1}$; Pattanaik et al., 2013) is lower than in the Brahmaputra ($\approx 6 \times 10^5 \text{ mol km}^{-2} \text{ yr}^{-1}$ basin-wide; $\approx 19 \times 10^5$ in the Eastern Syntaxis; Singh et al., 2005) but substantial for a low-relief, semi-arid granulite terrain. Our bed-load indices (CIA 42–61) confirm that weathering is supply-limited by fresh-rock exposure rather than transport-limited by thick saprolite.

For comparative studies, the Cauvery is a reference case for regulated, semi-arid, silicate (granulite–gneiss) rivers, such as the Krishna, Godavari, Penner and Palar and rivers of other cratonic, irrigated regions, where isotopes, solutes and sediments each give an incomplete and potentially misleading picture on their own.

3.9. A transferable Rock–Sediment–Water–Carbon (RSWC) framework

The steps followed above can be written as a five-module framework (Figure 19; Table 7). Each module relies on routinely measured data and yields normalised indices that can be compared between basins; each also constrains the module that follows.

- M1 – Rock (source). Classify lithologies (petrography, XRF), compute unaltered-rock CIA, mafic index and the stoichiometric CO_2 -consumption potential Φ (Eq. 4). Output: the expected cation ratios and the weatherability ranking of the lithologies. Test: does any lithology contain carbonate (CaO–LOI covariance, calcite in thin section)?
- M2 – Sediment (residue). Compute CIA, PIA, ICV, WIP and τ (Eq. 3) relative to the M1 parent. Output: which cations were removed (e.g. Na, Ca from plagioclase) and whether bed load reflects weathering or sorting (ICV > 1 and $\text{SiO}_2/\text{Al}_2\text{O}_3$ trends). Test: are τ values consistent with the ions enriched in water?
- M3 – Water (solute). Apply the Gibbs diagram, Na-normalised end-member mixing (Gaillardet et al., 1999), Na/Cl and $\text{HCO}_3^-/\text{TZ}^+$. Output: the silicate/carbonate/evaporite apportionment of cations and the fraction of charge balanced by non-carbonic anions (anthropogenic, rain, sulphuric acid). A forward model ($X_{\text{sil}} = X - X_{\text{rain/anthropogenic}} - X_{\text{carb}}$; Galy and France-Lanord, 1999) can be added where rain chemistry is known. Screen drinking and irrigation suitability (BIS, 2012; Richards, 1954).
- M4 – Carbon speciation and QA. Calculate DIC_{calc} and pCO_2 (Eq. 5) from HCO_3^- , pH and temperature; flag samples with DIC_{meas}/DIC_{calc} outside 0.5–2; derive CO_2 drawdown as $Q \times \text{HCO}_3^-_{\text{sil}}$, normalised by area. Output: whether the river is a CO_2 source or sink and a quality-screened DIC data set.
- M5 – Isotope source apportionment. Using end-members constrained by M1–M3 (only include carbonate if M1–M3 show it), compute f_{eq} (Eq. 6) or a three-component mass balance; evaluate the downstream $\delta^{13}\text{C}$ slope (‰ per 100 km) as an index of in-river equilibration or degassing; test conservative mixing with $\delta^{13}\text{C}$ vs $1/\text{DIC}$. Output: the share of DIC carrying source versus in-river (equilibration, degassing, photosynthesis) signatures.

The central idea is that the isotopes (M5) are interpreted only within the limits set by the lithological and weathering evidence (M1–M3). In the Cauvery this is what prevents ^{13}C -enriched DIC being attributed to carbonate weathering. Applied elsewhere, the same sequence identifies when heavy $\delta^{13}\text{C}$ reflects carbonate, metamorphic CO_2 or atmospheric exchange, and when cation-based CO_2 drawdown must be corrected for non-carbonic acids or anthropogenic salts. The indices of Table 7 — Φ , CIA/ICV, τ_{Na} , Ca/Na, $\text{HCO}_3^-/\text{TZ}^+$, Na/Cl, DIC_{meas}/DIC_{calc}, f_{eq} and the $\delta^{13}\text{C}$ downstream slope — together give a compact basin fingerprint, so that rivers of very different size can be compared.

3.10. Limitations and recommendations

(i) Water chemistry is presented as seasonal means, whereas DIC and $\delta^{13}\text{C}$ may represent individual campaigns; seasonally paired sampling is needed to test hydrological control on $\delta^{13}\text{C}$. (ii) pH quality limits pCO_2 estimates (Section 3.5). (iii) SO_4^{2-} , SiO_2 and NO_3^- were measured but are not reported per station in the source dataset; including them would allow the Si/ HCO_3^- silicate proxy of Das et al. (2005) and a sulphuric-acid weathering correction. (iv) $\delta^{13}\text{C}$ of DOC/POC, $\delta^{18}\text{O}$ – δD of water and discharge at each station would allow evaporation, respiration and degassing to be separated quantitatively (Polsenaere and Abril, 2012). (v) Coordinates for S1–S3 and S15 should be added so that the full 15-station transect can be mapped and modelled. We do not think any of these alters the main conclusions, because they rest on several independent data sets that point the same way.

4. CONCLUSIONS

- Rocks along the lower Cauvery are calc-alkaline, peraluminous–metaluminous gneisses with subordinate charnockite and pegmatite; mafic lithologies have 2–5 times the CO₂-consumption potential of felsic gneisses.
- Bed-load sediments are immature to moderately weathered (CIA 42–61; ICV 0.77–1.84), depleted in Na and K relative to the parent, and locally enriched in Mg–Ca–Cr from charnockitic/mafic sources; weathering is dominated by plagioclase breakdown.
- River water is rock-dominated with silicate-type cation ratios, but only about one-third of cation charge is balanced by HCO₃[−]; chloride from irrigation, effluents and evaporative concentration is a major non-weathering input.
- DIC (8.3–40.9 mg C L^{−1}) is controlled by the weathering solute load and by seasonal dilution; δ¹³C-DIC (−9.5 to −1.3‰) becomes heavier downstream by 2.7‰ per 100 km, recording progressive atmospheric exchange, CO₂ evasion and photosynthesis in a regulated channel rather than carbonate weathering.
- All river stations meet the BIS (2012) acceptable limits for chloride, calcium, magnesium and hardness, and TDS is within the permissible limit, but magnesium hazard exceeds 50% at twelve of fourteen stations, a lithology-driven risk for irrigated soils; the river mouth is unsuitable because of seawater ingress.
- Compared with Himalayan, Deccan, karst and temperate rivers, the Cauvery combines silicate-controlled but Cl-rich water with anomalously ¹³C-enriched DIC, making it a reference case for regulated semi-arid cratonic rivers.
- The RSWC framework, in which rock and sediment evidence constrains isotopic source apportionment and a speciation-based QA step screens the data, provides a transferable, index-based protocol for other river basins.

Funding

This work was funded by the Indian Space Research Organisation (ISRO) under the project “Hydrogeochemistry of Cauvery river basin – Carbon flux studies” (sanction ref. S/E SG, ECSA/AOSG & ISRO/IGBP/NCP/project funds/10-2012 (3), dated 15.10.2012).

Acknowledgement

We thank the National Centre for Earth Science Studies (NCESS), Thiruvananthapuram, for XRF analyses; ISRO–NRSC, Hyderabad, for DIC analyses; and the Wadia Institute of Himalayan Geology, Dehradun, for δ¹³C-DIC measurements. We also thank the Department of Studies in Earth Science, University of Mysore, for laboratory and petrographic facilities.

Author contributions

Vybhav K.: Conceptualization, Methodology, Investigation (field sampling), Formal analysis, Visualization, Writing – original draft. K. N. Prakash Narasimha: Conceptualization, Supervision, Methodology, Validation, Writing – review & editing.

Conflict of interest

The authors declare no conflict of interest.

Ethics statements

Not applicable. This study did not involve human participants or animals.

Data availability

All data used are tabulated in Tables 1–6 and the supplementary files (rock, sediment and water data; Python scripts for indices, speciation, mixing and figures).

REFERENCES

- [1] Anderson, S.P., Dietrich, W.E., Brimhall, G.H., 2002. Weathering profiles, mass-balance analysis, and rates of solute loss: linkages between weathering and erosion in a small, steep catchment. *Geological Society of America Bulletin* 114, 1143–1158.
- [2] Aufdenkampe, A.K., Mayorga, E., Raymond, P.A., Melack, J.M., Doney, S.C., Alin, S.R., Aalto, R.E., Yoo, K., 2011. Riverine coupling of biogeochemical cycles between land, oceans, and atmosphere. *Frontiers in Ecology and the Environment* 9, 53–60.
- [3] Berner, R.A., Lasaga, A.C., Garrels, R.M., 1983. The carbonate-silicate geochemical cycle and its effect on atmospheric carbon dioxide over the past 100 million years. *American Journal of Science* 283, 641–683.
- [4] BIS, 2012. Indian Standard Drinking Water — Specification (Second Revision), IS 10500:2012. Bureau of Indian Standards, New Delhi.
- [5] Brimhall, G.H., Dietrich, W.E., 1987. Constitutive mass balance relations between chemical composition, volume, density, porosity, and strain in metasomatic hydrochemical systems: results on weathering and pedogenesis. *Geochimica et Cosmochimica Acta* 51, 567–587.
- [6] Clark, I.D., Fritz, P., 1997. *Environmental Isotopes in Hydrogeology*. Lewis Publishers, Boca Raton.
- [7] Cole, J.J., Prairie, Y.T., Caraco, N.F., McDowell, W.H., Tranvik, L.J., Striegl, R.G., Duarte, C.M., Kortelainen, P., Downing, J.A., Middelburg, J.J., Melack, J., 2007. Plumbing the global carbon cycle: integrating inland waters into the terrestrial carbon budget. *Ecosystems* 10, 172–185.
- [8] Cox, R., Lowe, D.R., Cullers, R.L., 1995. The influence of sediment recycling and basement composition on evolution of mudrock chemistry in the southwestern United States. *Geochimica et Cosmochimica Acta* 59, 2919–2940.
- [9] CWC (Central Water Commission), 2025. Basin boundaries of India (basin_cwc), Hydrological Layer. India-WRIS, Ministry of Jal Shakti, Government of India. Available at <https://indiawris.gov.in>.
- [10] Das, A., Krishnaswami, S., Bhattacharya, S.K., 2005. Carbon isotope ratio of dissolved inorganic carbon (DIC) in rivers draining the Deccan Traps, India: sources of DIC and their magnitudes. *Earth and Planetary Science Letters* 236, 419–429.
- [11] Dessert, C., Dupré, B., Gaillardet, J., François, L.M., Allègre, C.J., 2003. Basalt weathering laws and the impact of basalt weathering on the global carbon cycle. *Chemical Geology* 202, 257–273.
- [12] Doctor, D.H., Kendall, C., Sebestyen, S.D., Shanley, J.B., Ohte, N., Boyer, E.W., 2008. Carbon isotope fractionation of dissolved inorganic carbon (DIC) due to outgassing of carbon dioxide from a headwater stream. *Hydrological Processes* 22, 2410–2423.
- [13] Drury, S.A., Harris, N.B.W., Holt, R.W., Reeves-Smith, G.J., Wightman, R.T., 1984. Precambrian tectonics and crustal evolution in South India. *Journal of Geology* 92, 3–20.
- [14] Eaton, F.M., 1950. Significance of carbonates in irrigation waters. *Soil Science* 69, 123–133.
- [15] Efron, B., Tibshirani, R.J., 1993. *An Introduction to the Bootstrap*. Chapman & Hall, New York.
- [16] Fedo, C.M., Nesbitt, H.W., Young, G.M., 1995. Unraveling the effects of potassium metasomatism in sedimentary rocks and paleosols, with implications for paleoweathering conditions and provenance. *Geology* 23, 921–924.
- [17] Gaillardet, J., Dupré, B., Louvat, P., Allègre, C.J., 1999. Global silicate weathering and CO₂ consumption rates deduced from the chemistry of large rivers. *Chemical Geology* 159, 3–30.
- [18] Galy, A., France-Lanord, C., 1999. Weathering processes in the Ganges–Brahmaputra basin and the riverine alkalinity budget. *Chemical Geology* 159, 31–60.
- [19] Gao, Q., Wang, Z., 2015. Dissolved inorganic carbon in the Xijiang River: concentration and stable isotopic composition. *Environmental Earth Sciences* 73, 253–266.
- [20] Gibbs, R.J., 1970. Mechanisms controlling world water chemistry. *Science* 170, 1088–1090.
- [21] Harnois, L., 1988. The CIW index: a new chemical index of weathering. *Sedimentary Geology* 55, 319–322.
- [22] Hartmann, J., Jansen, N., Dürr, H.H., Kempe, S., Köhler, P., 2009. Global CO₂-consumption by chemical weathering: what is the contribution of highly active weathering regions? *Global and Planetary Change* 69, 185–194.
- [23] Hélie, J.-F., Hillaire-Marcel, C., Rondeau, B., 2002. Seasonal changes in the sources and fluxes of dissolved inorganic carbon through the St. Lawrence River — isotopic and chemical constraint. *Chemical Geology* 186, 117–138.
- [24] Kelly, W.P., 1940. Permissible composition and concentration of irrigation waters. *Proceedings of the American Society of Civil Engineers* 66, 607–613.

- [25] Krishna, M.S., Viswanadham, R., Prasad, M.H.K., Kumari, V.R., Sarma, V.V.S.S., 2019. Export fluxes of dissolved inorganic carbon to the northern Indian Ocean from the Indian monsoonal rivers. *Biogeosciences* 16, 505–519.
- [26] Lehner, B., Grill, G., 2013. Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. *Hydrological Processes* 27, 2171–2186.
- [27] Livingstone, D.A., 1963. Chemical composition of rivers and lakes. In: *Data of Geochemistry*, 6th ed. U.S. Geological Survey Professional Paper 440-G.
- [28] Ludwig, W., Probst, J.-L., Kempe, S., 1996. Predicting the oceanic input of organic carbon by continental erosion. *Global Biogeochemical Cycles* 10, 23–41.
- [29] McLennan, S.M., 1993. Weathering and global denudation. *Journal of Geology* 101, 295–303.
- [30] Meybeck, M., 1987. Global chemical weathering of surficial rocks estimated from river dissolved loads. *American Journal of Science* 287, 401–428.
- [31] Meybeck, M., 2003. Global occurrence of major elements in rivers. In: Drever, J.I. (Ed.), *Treatise on Geochemistry*, Vol. 5. Elsevier, Oxford, pp. 207–223.
- [32] Mook, W.G., Bommerson, J.C., Staverman, W.H., 1974. Carbon isotope fractionation between dissolved bicarbonate and gaseous carbon dioxide. *Earth and Planetary Science Letters* 22, 169–176.
- [33] Nesbitt, H.W., Young, G.M., 1982. Early Proterozoic climates and plate motions inferred from major element chemistry of lutites. *Nature* 299, 715–717.
- [34] Nesbitt, H.W., Young, G.M., 1989. Formation and diagenesis of weathering profiles. *Journal of Geology* 97, 129–147.
- [35] Nesbitt, H.W., Young, G.M., 1984. Prediction of some weathering trends of plutonic and volcanic rocks based on thermodynamic and kinetic considerations. *Geochimica et Cosmochimica Acta* 48, 1523–1534.
- [36] Parker, A., 1970. An index of weathering for silicate rocks. *Geological Magazine* 107, 501–504.
- [37] Pattanaik, J.K., Balakrishnan, S., Bhutani, R., Singh, P., 2013. Estimation of weathering rates and CO₂ drawdown based on solute load: significance of granulites and gneisses dominated weathering in the Kaveri River basin, Southern India. *Geochimica et Cosmochimica Acta* 121, 611–636.
- [38] Plummer, L.N., Busenberg, E., 1982. The solubilities of calcite, aragonite and vaterite in CO₂–H₂O solutions between 0 and 90 °C, and an evaluation of the aqueous model for the system CaCO₃–CO₂–H₂O. *Geochimica et Cosmochimica Acta* 46, 1011–1040.
- [39] Polsenaere, P., Abril, G., 2012. Modelling CO₂ degassing from small acidic rivers using water pCO₂, DIC and δ¹³C-DIC data. *Geochimica et Cosmochimica Acta* 91, 220–239.
- [40] Raymond, P.A., Hartmann, J., Lauerwald, R., Sobek, S., McDonald, C., Hoover, M., Butman, D., Striegl, R., Mayorga, E., Humborg, C., Kortelainen, P., Dürr, H., Meybeck, M., Ciais, P., Guth, P., 2013. Global carbon dioxide emissions from inland waters. *Nature* 503, 355–359.
- [41] Richards, L.A. (Ed.), 1954. *Diagnosis and Improvement of Saline and Alkali Soils*. Agriculture Handbook 60. United States Department of Agriculture, Washington, DC.
- [42] Sarin, M.M., Krishnaswami, S., Dilli, K., Somayajulu, B.L.K., Moore, W.S., 1989. Major ion chemistry of the Ganga–Brahmaputra river system: weathering processes and fluxes to the Bay of Bengal. *Geochimica et Cosmochimica Acta* 53, 997–1009.
- [43] Singh, P., Rajamani, V., 2001. REE geochemistry of recent clastic sediments from the Kaveri floodplains, southern India: implication to source area weathering and sedimentary processes. *Geochimica et Cosmochimica Acta* 65, 3093–3108.
- [44] Singh, S.K., Sarin, M.M., France-Lanord, C., 2005. Chemical erosion in the eastern Himalaya: major ion composition of the Brahmaputra and δ¹³C of dissolved inorganic carbon. *Geochimica et Cosmochimica Acta* 69, 3573–3588.
- [45] Szabolcs, I., Darab, C., 1964. The influence of irrigation water of high sodium carbonate content on soils. In: *Proceedings of the 8th International Congress of Soil Science, Transactions II*. ISSS, Bucharest, pp. 803–812.
- [46] Taylor, S.R., McLennan, S.M., 1985. *The Continental Crust: Its Composition and Evolution*. Blackwell, Oxford.
- [47] Telmer, K., Veizer, J., 1999. Carbon fluxes, pCO₂ and substrate weathering in a large northern river basin, Canada: carbon isotope perspectives. *Chemical Geology* 159, 61–86.
- [48] Tranvik, L.J., Downing, J.A., Cotner, J.B., et al., 2009. Lakes and reservoirs as regulators of carbon cycling and climate. *Limnology and Oceanography* 54, 2298–2314.

- [49] Walker, J.C.G., Hays, P.B., Kasting, J.F., 1981. A negative feedback mechanism for the long-term stabilization of Earth's surface temperature. *Journal of Geophysical Research* 86, 9776–9782.
- [50] WHO, 2017. *Guidelines for Drinking-water Quality*, 4th edition incorporating the first addendum. World Health Organization, Geneva.
- [51] Wilcox, L.V., 1955. *Classification and Use of Irrigation Waters*. Circular 969. United States Department of Agriculture, Washington, DC.
- [52] Zhang, J., Quay, P.D., Wilbur, D.O., 1995. Carbon isotope fractionation during gas–water exchange and dissolution of CO₂. *Geochimica et Cosmochimica Acta* 59, 107–114.

- Table S1: complete rock, sediment and water data sets (from the source thesis tables).
- Code S1: Python scripts (data.py, analysis.py, figures.py, newfig.py, basinio.py, basinmap.py, piemaps.py) reproducing all indices, statistics and figures.
- Table S2: seasonal pH, EC, major-ion and DIC ranges (post-monsoon, monsoon, winter).

Tables

Table 1. Sampling stations (downstream order), identifier cross-walk to the source dataset and coordinates.

Station	Water/sediment ID	Isotope ID	Location	Lat (°N)	Long (°E)	Distance (km)
S1	C1	–	Pannavadi	n.r.	n.r.	–
S2	C2	–	Kudagal	n.r.	n.r.	–
S3	C3	–	Konaivaikal	n.r.	n.r.	–
S4	C4	C12	Sitthar Kovil	11.1511	77.7734	0
S5	C5	C11	Karuvelampalayam	11.1525	77.8854	12
S6	C6	C10	Kelakuthavitupalayam	11.0758	78.0487	32
S7	C7	C9	Sriramasamudram	10.9626	78.2112	54
S8	C8	C8	Kulithalai	10.9388	78.4315	78
S9	C9	C7	Mutharasanallur	10.8641	78.6533	104
S10	C10	C6	Appakudathan Temple	10.8354	78.8626	127
S11	C11	C5	Kandiyur Bridge	10.8644	79.0897	152
S12	C12	C4	Thiruvanchuli	10.9493	79.3282	179
S13	C13	C3	Suryanar Kovil	11.0264	79.4831	198
S14	C14	C2	Panniyur	11.1365	79.5914	215
S15	C15	–	Poompuhar	n.r.	n.r.	–

n.r., not reported in the source dataset. Distance is cumulative great-circle distance from S4 (lower bound on channel length). Coordinates converted from degrees–minutes–seconds.

Table 2. Whole-rock major (wt%) and selected trace (ppm) element composition, CIA and stoichiometric CO₂-consumption potential Φ (mol kg⁻¹).

Sample	Rock	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃ ^T	MgO	CaO	Na ₂ O	K ₂ O	CIA	Φ	Cr	Ni
R1	Gneiss	72.32	15.11	0.51	0.18	0.58	2.67	8.12	51.5	2.9	7	4
R2	Pegmatite	74.33	15.16	0.55	0.21	2.56	5.30	1.48	50.3	3.0	13	3
R3	Gneiss	71.22	15.18	1.99	1.25	3.11	4.63	1.52	50.4	3.5	36	17
R4	Charnockite	48.78	4.78	9.61	22.78	11.34	0.97	0.21	17.6	15.7	1294	385
R5	Gneiss	65.17	18.88	0.21	0.17	0.71	2.99	11.30	50.6	3.7	10	3
R6	Gneiss	70.73	15.65	1.89	0.63	2.93	4.49	2.80	49.9	3.4	11	4
R7	Gneiss	59.31	20.10	4.00	1.39	8.47	5.64	0.00	44.9	5.5	59	15
R8	Gneiss	60.65	18.78	5.00	2.24	5.68	4.94	1.08	48.9	5.0	27	20
R9	Gneiss	58.76	18.44	4.87	2.33	6.95	5.65	1.68	43.7	5.8	22	11
R10	Gneiss	46.82	5.95	19.42	14.51	8.92	1.14	0.52	24.2	10.9	1935	978

Complete data (TiO₂, MnO, P₂O₅, LOI, V, Cu, Zn, Ga, Rb, Sr, Y, Zr, Ba, La) in Supplementary Table S1. CIA is molar and uncorrected (see text).

Table 3. Bed-load sediment chemistry, weathering indices and mass-transfer coefficients.

Stn	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	Na ₂ O	K ₂ O	CIA	PIA	ICV	SiO ₂ / Al ₂ O ₃	Al ₂ O ₃ / TiO ₂	τ_{Na}	τ_{K}	Cr
S1	75.1	11.4	6.08	2.46	1.46	0.40	61.4	62.0	1.12	6.59	13.1	-0.52	-0.83	204
S2	67.4	13.1	4.36	5.97	2.72	2.17	43.5	42.3	1.43	5.14	15.4	-0.22	-0.19	155
S3	64.9	11.9	7.41	6.44	2.34	1.32	41.7	40.8	1.81	5.46	11.2	-0.26	-0.45	175
S4	74.3	10.6	4.45	3.17	2.60	1.14	49.2	49.1	1.30	6.99	15.2	-0.08	-0.47	127
S5	82.3	8.7	2.77	1.58	1.70	1.17	56.4	57.6	0.95	9.41	19.9	-0.26	-0.34	72
S6	83.6	8.6	1.92	1.38	1.58	1.14	57.9	59.5	0.79	9.77	34.2	-0.30	-0.35	67
S7	82.7	9.0	2.18	1.63	1.77	1.23	56.1	57.4	0.85	9.14	33.5	-0.26	-0.33	69
S8	84.6	8.4	1.78	1.29	1.48	1.24	58.3	60.2	0.77	10.04	31.2	-0.34	-0.28	54
S9	84.0	8.2	2.15	1.28	1.37	1.23	58.9	61.0	0.83	10.19	25.8	-0.37	-0.27	54
S10	70.0	13.0	4.29	3.09	2.77	1.70	52.5	52.9	1.07	5.40	17.3	-0.19	-0.36	119
S11	78.7	10.2	3.28	2.07	2.16	1.47	53.7	54.4	1.03	7.75	13.7	-0.20	-0.29	97
S12	71.3	13.2	3.74	3.06	3.22	1.80	51.4	51.6	1.04	5.39	17.6	-0.08	-0.33	127

Stn	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	Na ₂ O	K ₂ O	CIA	PIA	ICV	SiO ₂ / Al ₂ O ₃	Al ₂ O ₃ / TiO ₂	τ _{Na}	τ _K	Cr
S13	71.8	13.5	3.81	2.46	2.35	1.73	57.7	59.2	0.89	5.32	26.0	-0.34	-0.37	112
S14	67.2	14.6	4.96	2.83	2.47	1.85	57.1	58.5	0.96	4.60	29.2	-0.36	-0.38	153
S15	69.9	10.3	7.69	3.44	2.04	1.23	49.2	49.1	1.84	6.80	4.4	-0.25	-0.41	223

Major oxides in wt%, Cr in ppm. CIA, PIA and ICV as reported in the source dataset; τ relative to the mean felsic gneiss parent with Al immobile (Eq. 3).

Table 4. Station-mean surface-water chemistry (mean of post-monsoon, monsoon and winter) and derived molar ratios.

Stn	Station	pH	EC	TDS	HCO ₃ ⁻	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	Cl ⁻	Na/Cl	HCO ₃ ⁻ /TZ ⁺
S1	Pannavadi	8.62	518	516	126.9	27.9	25.6	80.6	8.43	148.8	0.83	0.29
S2	Kudagal	8.69	538	467	145.2	27.3	22.5	79.6	8.76	99.8	1.23	0.34
S3	Konaivaikal	8.62	522	457	125.9	30.3	19.1	80.0	7.73	113.2	1.09	0.31
S4	Sitthar Kovil	8.29	817	459	156.7	34.5	20.7	79.9	11.03	103.3	1.19	0.36
S5	Karuvelampalayam	9.25	746	564	122.6	35.3	15.8	70.1	8.70	112.3	0.96	0.32
S6	Kelakuthavitupalayam	6.32	383	412	98.1	14.1	23.4	49.3	3.70	76.2	1.00	0.33
S7	Sriramasamudram	9.48	767	714	145.8	31.7	22.2	77.6	7.03	162.9	0.73	0.34
S8	Kulithalai	5.95	348	201	83.5	15.3	23.9	44.3	4.70	68.8	0.99	0.29
S9	Mutharasanallur	8.89	757	545	158.4	34.2	26.7	82.5	7.40	94.8	1.34	0.34
S10	Appakudathan Temple	9.54	787	535	130.5	27.6	21.4	63.5	6.70	86.6	1.13	0.35
S11	Kandiyur Bridge	6.01	316	195	96.3	15.4	12.1	65.6	3.73	64.7	1.56	0.33
S12	Thiruvanchuli	8.81	561	402	162.0	32.0	23.7	59.6	9.48	57.2	1.60	0.42
S13	Suryanar Kovil	5.85	224	178	86.8	15.8	16.2	46.2	6.10	67.6	1.05	0.33
S14	Panniyur	8.00	502	411	154.8	31.7	23.1	77.3	10.93	99.2	1.20	0.36
S15	Poompuhar	8.42	3328	1355	341.8	292.0	454.5	2020.5	7.30	348.6	8.94	0.04

EC in μS cm⁻¹; concentrations in mg L⁻¹. Na/Cl molar; HCO₃⁻/TZ⁺ is the fraction of total cation charge balanced by bicarbonate. S15 is marine-influenced.

Table 5. Drinking- and irrigation-water quality indices of the Cauvery stations.

Stn	TDS	TH	Cl ⁻	Na ⁺	pH	SAR	%Na	KR	MH (%)	RSC	USSL class
S1	516	175	149	81	8.62	2.65	52	1.00	60	-1.42	C2S1
S2	467	161	100	80	8.69	2.73	53	1.08	58	-0.84	C2S1
S3	457	154	113	80	8.62	2.81	54	1.13	51	-1.01	C2S1
S4	459	171	103	80	8.29	2.66	52	1.02	50	-0.85	C3S1
S5	564	153	112	70	9.25	2.46	52	1.00	42	-1.05	C2S1
S6	412	131	76	49	6.32	1.87	46	0.82	73	-1.02	C2S1
S7	714	170	163	78	9.48	2.59	51	0.99	54	-1.02	C3S1
S8	201	137	69	44	5.95	1.65	43	0.71	72	-1.36	C2S1
S9	545	195	95	82	8.89	2.57	49	0.92	56	-1.30	C3S1
S10	535	157	87	63	9.54	2.20	48	0.88	56	-1.00	C3S1
S11	195	88	65	66	6.01	3.04	63	1.62	56	-0.18	C2S1
S12	402	177	57	60	8.81	1.95	44	0.73	55	-0.89	C2S1
S13	178	106	68	46	5.85	1.95	51	0.95	63	-0.70	C1S1
S14	411	174	99	77	8.00	2.55	51	0.97	55	-0.94	C2S1
S15	1355	2601	349	2020	8.42	17.24	63	1.69	72	-46.37	C4S4

TDS, total hardness (TH, as CaCO₃), Cl⁻ and Na⁺ in mg L⁻¹; RSC in meq L⁻¹. BIS (2012) acceptable/permissible limits: TDS 500/2000, TH 200/600, Cl⁻ 250/1000, pH 6.5–8.5; WHO (2017) Na⁺ taste threshold 200. SAR, sodium adsorption ratio (Richards, 1954); %Na, sodium percentage (Wilcox, 1955); KR, Kelly ratio (Kelly, 1940); MH, magnesium hazard (Szabolcs and Darab, 1964); RSC, residual sodium carbonate (Eaton, 1950).

Table 6. Dissolved inorganic carbon, $\delta^{13}\text{C}$ -DIC and derived carbonate-system and mixing parameters.

Stn	Isotope ID	Station	Lat	Long	Dist. (km)	DIC (mg C L ⁻¹)	$\delta^{13}\text{C}$ (‰)	HCO ₃ ⁻ C	DIC/HCO ₃ ⁻ C	pCO ₂ (µatm)	f _{eq} % (C ₄ case)
S4	C12	Sitthar Kovil	11.1511	77.7734	0	25.29	-9.52	30.8	0.82	870	52 (33)
S5	C11	Karuvelampalayam	11.1525	77.8854	12	40.90	-5.95	24.1	1.69	75	71 (60)
S6	C10	Kelakuthavitupalayam	11.0758	78.0487	32	15.56	-8.14	19.3	0.81	>50,000*	59 (44)
S7	C9	Sriramasamudram	10.9626	78.2112	54	18.40	-5.91	28.7	0.64	52	71 (60)
S8	C8	Kulithalai	10.9388	78.4315	78	19.58	-7.13	16.4	1.19	>101,000*	65 (51)

Stn	Isotope ID	Station	Lat	Long	Dist. (km)	DIC (mg C L ⁻¹)	$\delta^{13}\text{C}$ (‰)	HCO_3^- C	DIC/ HCO_3^- C	pCO ₂ (µatm)	f _{eq} % (C ₄ case)
S9	C7	Mutharasanallur	10.8641	78.6533	104	26.39	-6.25	31.2	0.85	221	69 (58)
S10	C6	Appakudathan Temple	10.8354	78.8626	127	26.18	-4.35	25.7	1.02	41	80 (72)
S11	C5	Kandiyur Bridge	10.8644	79.0897	152	8.26	-4.84	18.9	0.44	>101,000*	77 (68)
S12	C4	Thiruvanchuli	10.9493	79.3282	179	21.31	-5.97	31.9	0.67	272	71 (60)
S13	C3	Suryanar Kovil	11.0264	79.4831	198	16.60	-1.52	17.1	0.97	>132,000*	95 (93)
S14	C2	Panniyur	11.1365	79.5914	215	21.11	-1.34	30.5	0.69	1676	96 (94)

* Calculated pCO₂ physically implausible; attributed to pH measurement artefacts (Section 3.5). f_{eq} from Eq. (6) with $\delta_{\text{sil}} = -19\text{‰}$ (and -14‰ in brackets).

Table 7. The RSWC framework: modules, inputs, key indices and diagnostic thresholds for application to other basins.

Module	Inputs	Indices / equations	Diagnostic interpretation	Cauvery result
M1 Rock	Petrography, whole-rock XRF	CIA _{rock} ; mafic index; Φ (Eq. 4); carbonate test	$\Phi > 10 \text{ mol kg}^{-1} \rightarrow$ high-reactivity mafic source; any CaO–LOI covariance $\rightarrow$ carbonate present	Φ 2.9–5.8 (felsic), 10.9–15.7 (mafic); no carbonate
M2 Sediment	Bed-load XRF	CIA, PIA, ICV, WIP, τ_{ij} (Eq. 3), Al ₂ O ₃ /TiO ₂	CIA < 60 & ICV > 1 $\rightarrow$ weathering-limited, fresh supply; $\tau_{\text{Na}} < 0 \rightarrow$ plagioclase weathering	CIA 42–61; ICV 0.77–1.84; $\tau_{\text{Na}} -0.27$
M3 Water	Major ions, TDS	Gibbs ratio; Ca/Na, Mg/Na, HCO ₃ ⁻ /Na; Na/Cl; HCO ₃ ⁻ /TZ ⁺	Ca/Na < 0.5 & Mg/Na < 0.5 $\rightarrow$ silicate; HCO ₃ ⁻ /TZ ⁺ < 0.7 $\rightarrow$ non-carbonic anion input; Na/Cl $\approx$ 1 $\rightarrow$ salt input	Silicate; HCO ₃ ⁻ /TZ ⁺ 0.34; Na/Cl 1.1
M4 Carbon & QA	DIC, alkalinity, field pH, T, Q	DIC _{calc} , pCO ₂ (Eq. 5); DIC _{meas} /DIC _{calc} ; flux = Q $\times$ HCO ₃ ⁻ _{sil}	Ratio outside 0.5–2 $\rightarrow$ reject/re-measure pH; pCO ₂ > 410 µatm $\rightarrow$ CO ₂ source	7 of 11 stations pass; high-pH stations CO ₂ -undersaturated
M5 Isotopes	$\delta^{13}\text{C}$ -DIC (+ DOC/POC $\delta^{13}\text{C}$ if available)	f _{eq} (Eq. 6) with Monte Carlo; equilibration length L (Eq. 7); $\delta^{13}\text{C}$ vs 1/DIC	Positive slope with no mixing line $\rightarrow$ in-river equilibration/degassing; use carbonate end-member only if M1–M3 allow	+2.74‰/100 km; L = 190 $\pm$ 54 km; f _{eq} 51–96% (MC)

Table 8. Comparison of the Cauvery with other rivers.

River / region	Dominant lithology / setting	DIC or HCO_3^-	$\delta^{13}\text{C-DIC}$ (‰)	Other indicators	Source
Cauvery, lower reach (this study)	Granulite, gneiss, charnockite; semi-arid, regulated	8.3–40.9 mg C L^{-1} (mean 21.8)	–9.5 to –1.3 (mean –5.5)	$\text{HCO}_3^-/\text{TZ}^+$ 0.34; Na/Cl 1.1; CIA _{sed} 42–61	This study
Kaveri basin	Granulite–gneiss	HCO_3^- 27–79% of anions (monsoon)	–	>90% silicate ions; CO_2 3.2–3.8 $\times 10^5$ mol km^{-2} yr^{-1}	Pattanaik et al. (2013)
SE Indian monsoonal rivers	Peninsular cratonic	37.4 $\pm$ 6.3 mg C L^{-1}	–3.5 $\pm$ 2.3	All-India DIC 3.4–73.6 mg C L^{-1}	Krishna et al. (2019)
Deccan Traps rivers (Krishna, Bhima, W. Ghats)	Basalt $\pm$ dispersed carbonate	–	–20.7 to –8.5 (W. Ghats –18.7 $\pm$ 2)	Si/ HCO_3 0.10–0.55	Das et al. (2005)
Brahmaputra	Himalayan, mixed silicate–carbonate	TDS 102–203 mg L^{-1}	Main channel –14.3 to –10.1	CO_2 $\approx 6 \times 10^5$ mol km^{-2} yr^{-1}	Singh et al. (2005)
Ganga–Brahmaputra (Nepal Himalaya)	Tethyan, High Himalaya	–	≈ 0 , up to +3.9 (North Himalaya)	Metamorphic CO_2 input	Galy and France-Lanord (1999)
Ottawa River, Canada	Shield silicate + lowland carbonate	–	≈ -16 (silicate) to ≈ -8 (carbonate)	61% DIC from respiration; 30% evaded	Telmer and Veizer (1999)
St Lawrence, Canada	Great Lakes-fed carbonate/silicate	–	–13.1 to –2.4	Mean pCO_2 ≈ 1300 ppmv	Hélie et al. (2002)
Xijiang (Pearl), China	Karst carbonate	750–2400 $\mu\text{mol L}^{-1}$	–14.8 to –8.3 (mean –11.2)	Flood dilution of DIC	Gao and Wang (2015)
World average river	–	HCO_3^- 58.4 mg L^{-1} (0.96 mmol L^{-1})	–	$\text{HCO}_3^-/\text{TZ}^+$ ≈ 0.67 ; Cl^- 7.8 mg L^{-1}	Livingstone (1963)

Figure 1

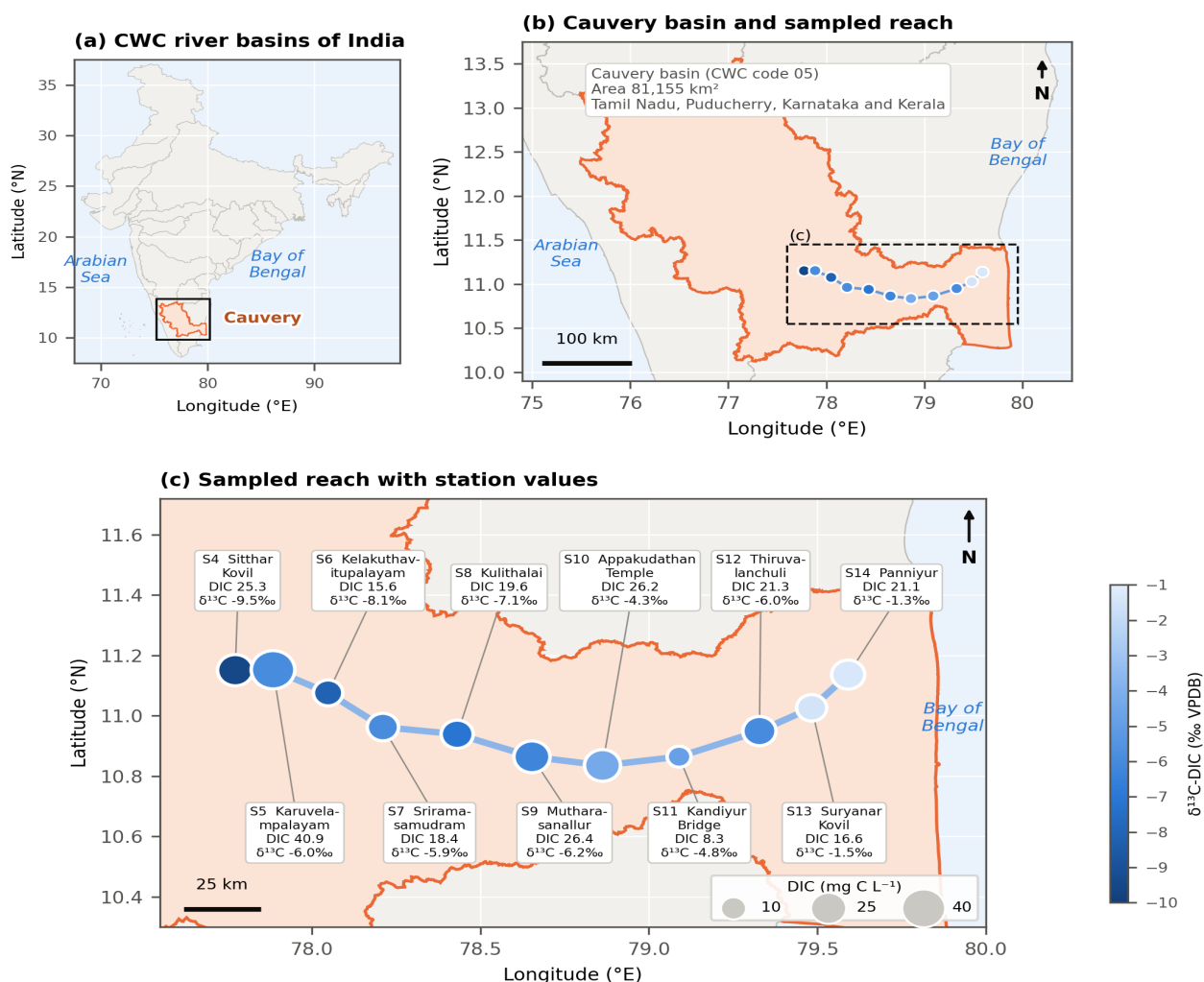


Figure 1. Location of the study. (a) River basins of India from the Central Water Commission basin layer (CWC, 2025), with the Cauvery basin highlighted. (b) The Cauvery basin (CWC basin code 05; 81,155 km²) and the geo-referenced sampling stations. (c) The sampled reach, with measured DIC (symbol size, mg C L⁻¹) and $\delta^{13}\text{C}$ -DIC (colour, ‰ VPDB) labelled at each station (data in Table 6). All eleven stations fall inside the CWC basin polygon. The line joining stations is schematic and does not trace the channel. S1–S3 (upstream, near Mettur) and S15 (Poompuhar) are not shown because their coordinates were not recorded.

Figure 2

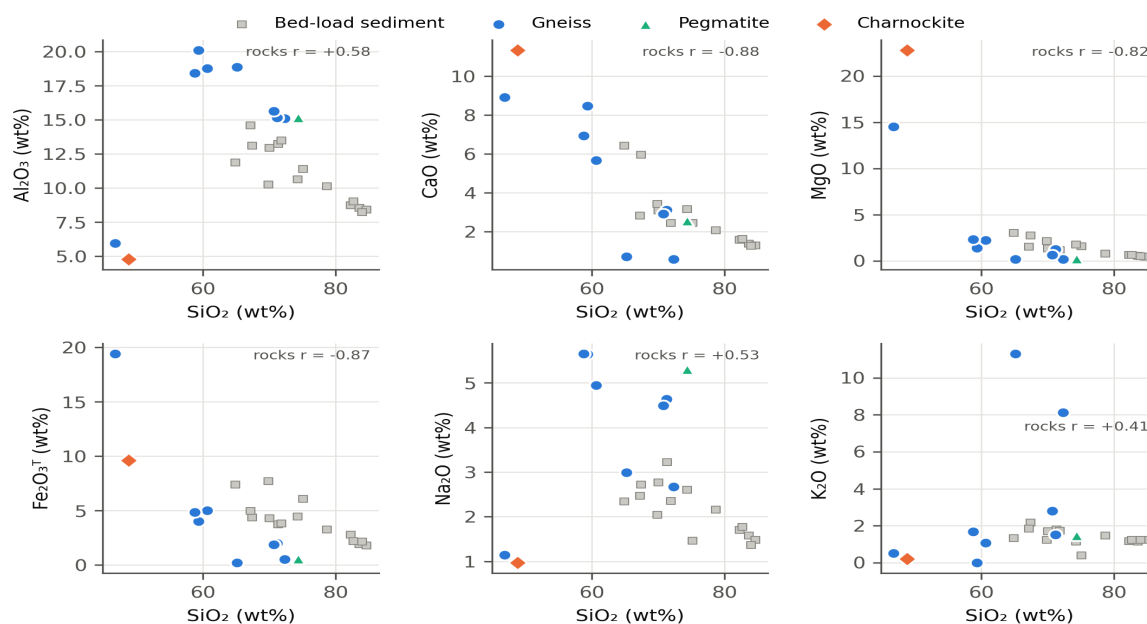


Figure 2. Harker variation diagrams for rocks (coloured symbols by lithology) and bed-load sediments (grey squares) of the lower Cauvery. The r values refer to rocks only. Sediments are displaced to high SiO_2 by quartz enrichment and lie within the rock array for CaO , MgO and Fe_2O_3^T , indicating a mixed felsic–mafic provenance.

Figure 3

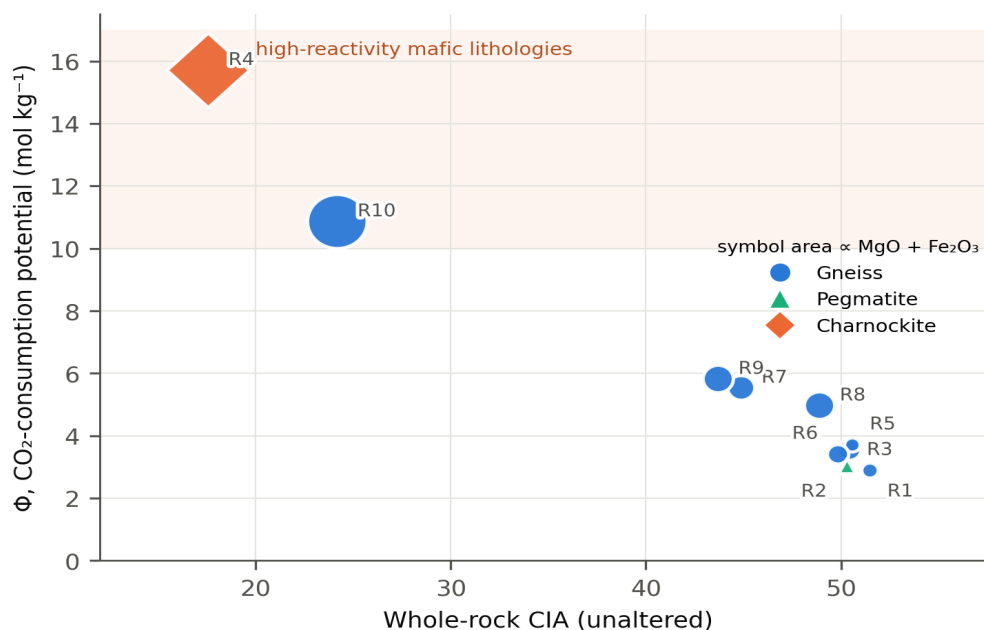


Figure 3. Whole-rock CIA (Nesbitt and Young, 1982) versus stoichiometric CO_2 -consumption potential Φ (Eq. 4; after Gaillardet et al., 1999) for the rock samples. Symbol area is proportional to $\text{MgO} + \text{Fe}_2\text{O}_3$ (wt%). The shaded band marks the high-reactivity mafic lithologies

Figure 4

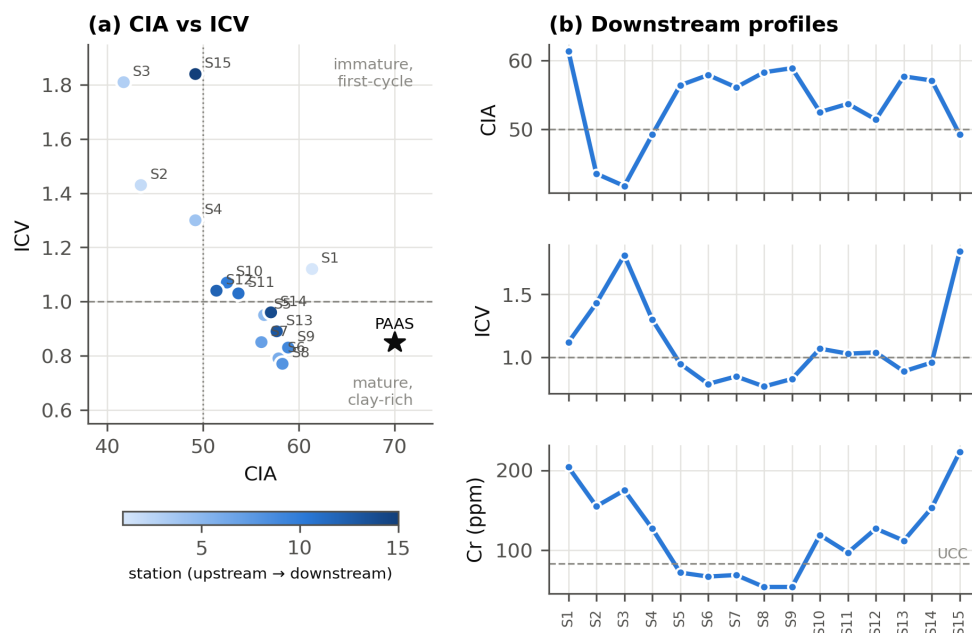


Figure 4. (a) CIA versus ICV for bed-load sediments, coloured by position along the river; PAAS is shown for reference (Taylor and McLennan, 1985). (b) Downstream profiles of CIA, ICV and Cr; dashed lines mark CIA = 50 (fresh feldspar), ICV = 1 and the upper-continental-crust Cr content.

Figure 5

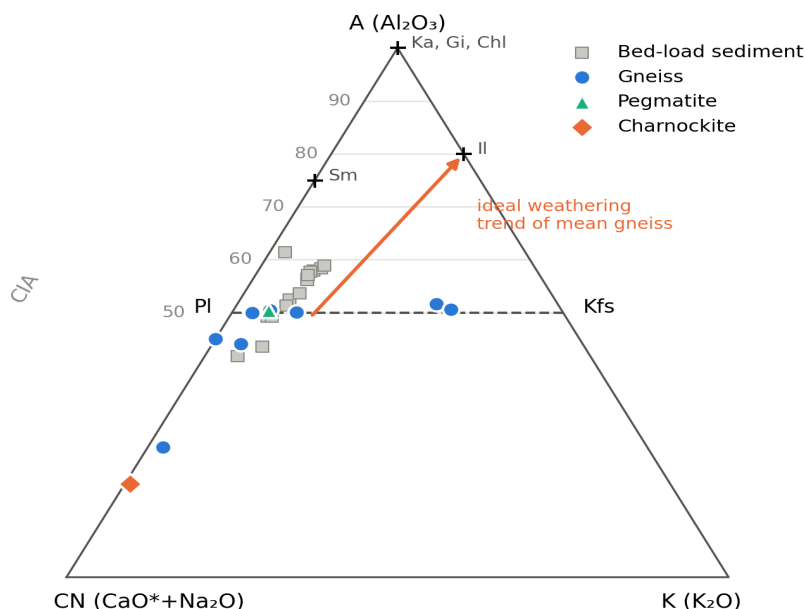


Figure 5. A–CN–K ternary diagram (molar) for rocks and bed-load sediments. The CIA scale is on the left edge; Pl, plagioclase; Kfs, K-feldspar; Sm, smectite; Il, illite; Ka, Gi, Chl, kaolinite, gibbsite, chlorite. The arrow shows the ideal weathering trend from the mean felsic gneiss.

Figure 6

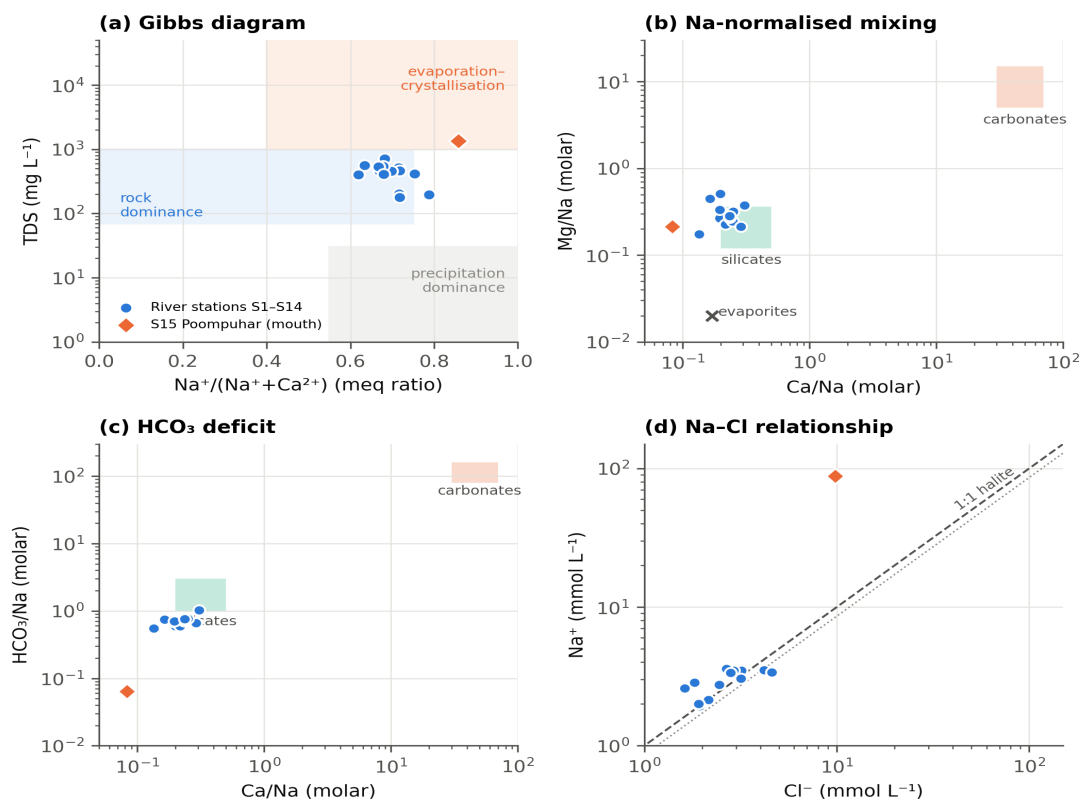


Figure 6. Controls on river-water chemistry. (a) Gibbs diagram (fields schematic, after Gibbs, 1970). (b, c) Na-normalised molar mixing diagrams with silicate, carbonate and evaporite end-members after Gaillardet et al. (1999). (d) Na⁺ versus Cl⁻ with the 1:1 halite line (dashed) and the seawater ratio (dotted). S15 is the river-mouth station.

Figure 7

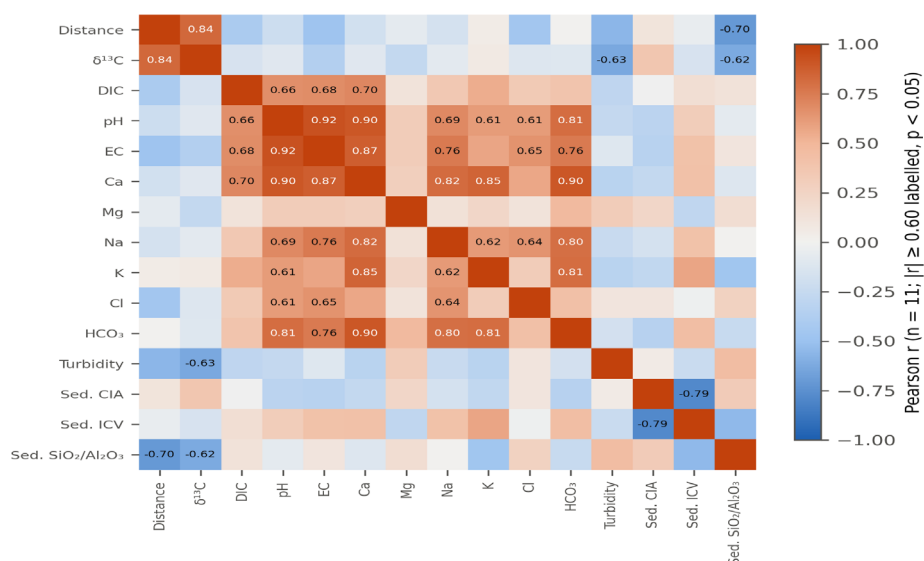


Figure 7. Pearson correlation matrix of carbon, water and co-located bed-load sediment variables at the 11 isotope stations. Coefficients with |r| ≥ 0.60 (p < 0.05) are labelled.

Figure 8

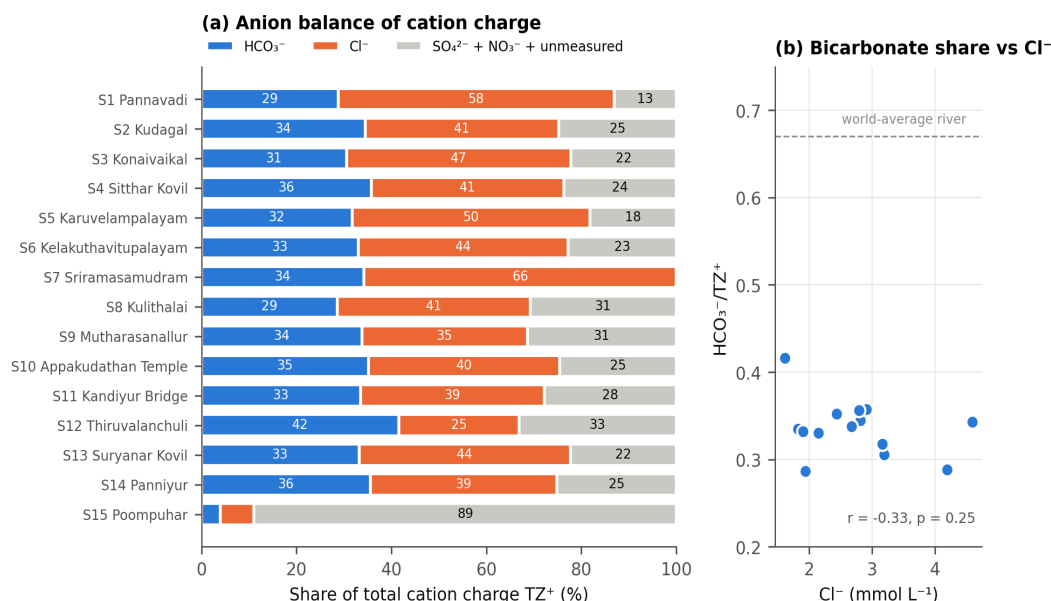


Figure 8. (a) Fractions of total cation charge ($TZ^+ = 2Ca + 2Mg + Na + K$) balanced by HCO_3^- , Cl^- and the residual at each station (values in %). (b) HCO_3^-/TZ^+ versus Cl^- for S1–S14; the dashed line is the world-average river computed from Livingstone (1963).

Figure 9

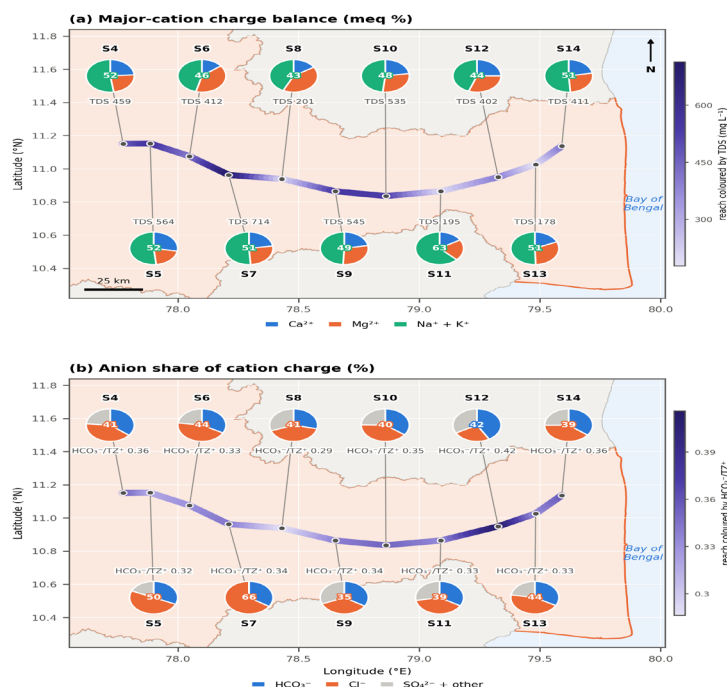


Figure 9. River-water chemistry at the geo-referenced stations on the CWC Cauvery basin layer (CWC, 2025). (a) Major-cation composition as percentages of total cation charge (meq); the sampled reach is coloured by TDS. (b) Fractions of total cation charge balanced by HCO_3^- , Cl^- and the residual (SO_4^{2-} , NO_3^- , unmeasured); the reach is coloured by HCO_3^-/TZ^+ . Numbers in the pies give the largest share; labels give the station value. Data from Table 4.

Figure 10

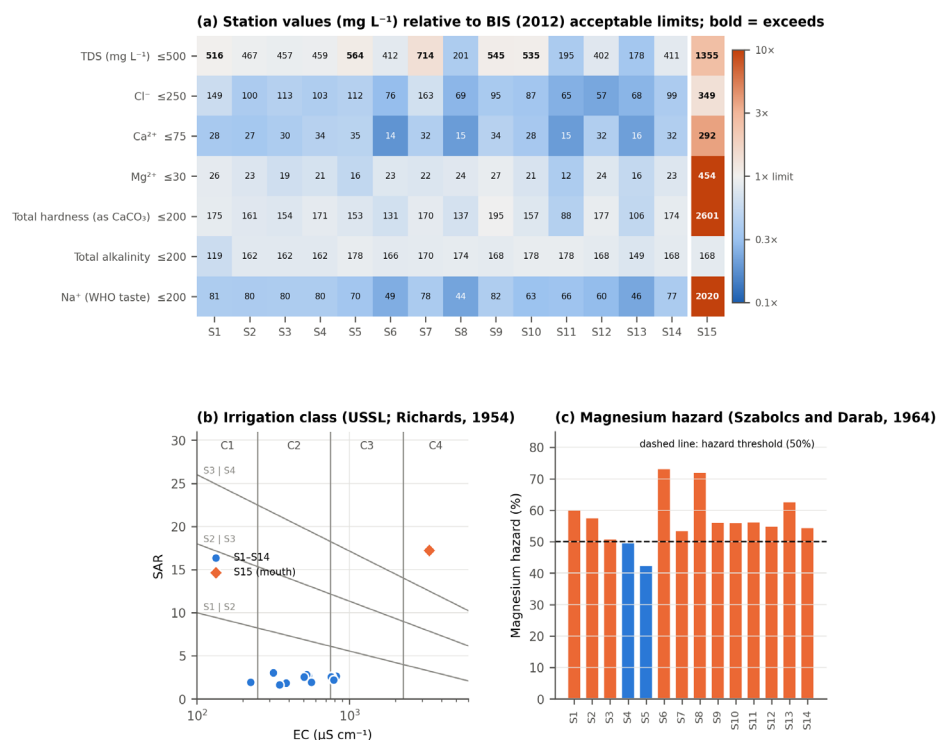


Figure 10. Drinking- and irrigation-water quality of the Cauvery stations. (a) Measured concentrations relative to the BIS (2012) acceptable limits (Na^+ against the WHO, 2017, taste threshold); colours show the ratio to the limit on a logarithmic scale and bold values exceed it. (b) US Salinity Laboratory classification (Richards, 1954). (c) Magnesium hazard (Szabolcs and Darab, 1964) with the 50% threshold. Data from Tables 4 and 5

Figure 11

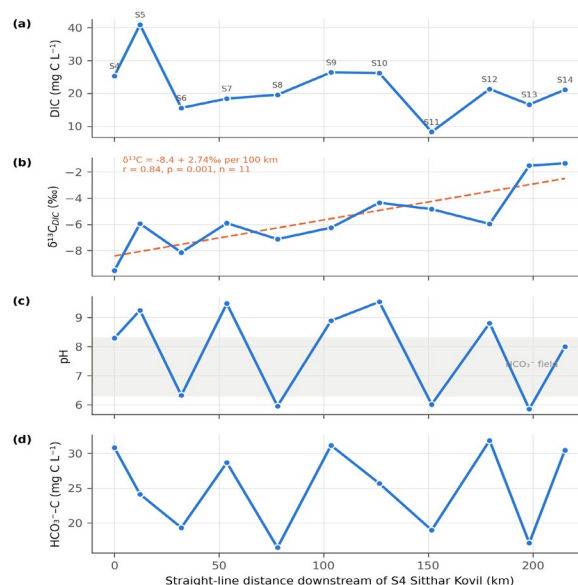


Figure 11. Downstream variation of (a) DIC, (b) $\delta^{13}\text{C}$ -DIC with least-squares regression, (c) station-mean pH (the shaded band is the pH range in which HCO_3^- dominates DIC) and (d) HCO_3^- -C from alkalinity, plotted against straight-line distance from S4

Figure 12

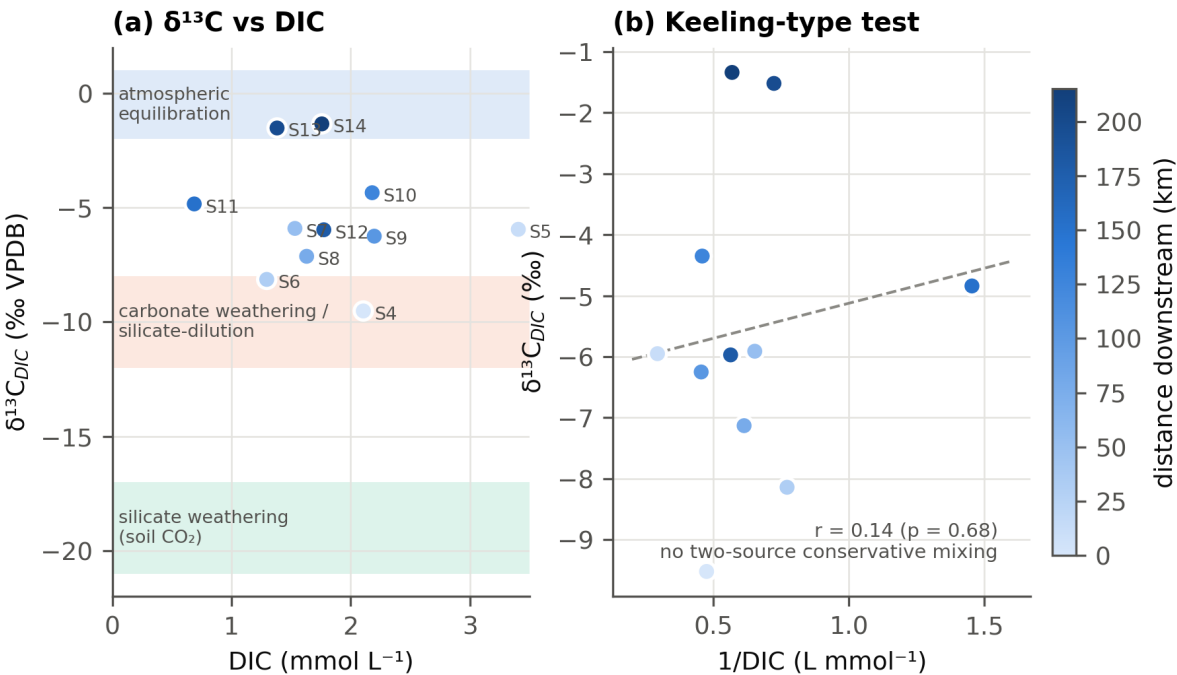


Figure 12. (a) $\delta^{13}\text{C}$ -DIC versus DIC with typical source fields (after Telmer and Veizer, 1999; Clark and Fritz, 1997). (b) $\delta^{13}\text{C}$ -DIC versus $1/\text{DIC}$; the absence of a linear relationship rules out simple conservative mixing of two sources. Colour shows distance downstream

Figure 13

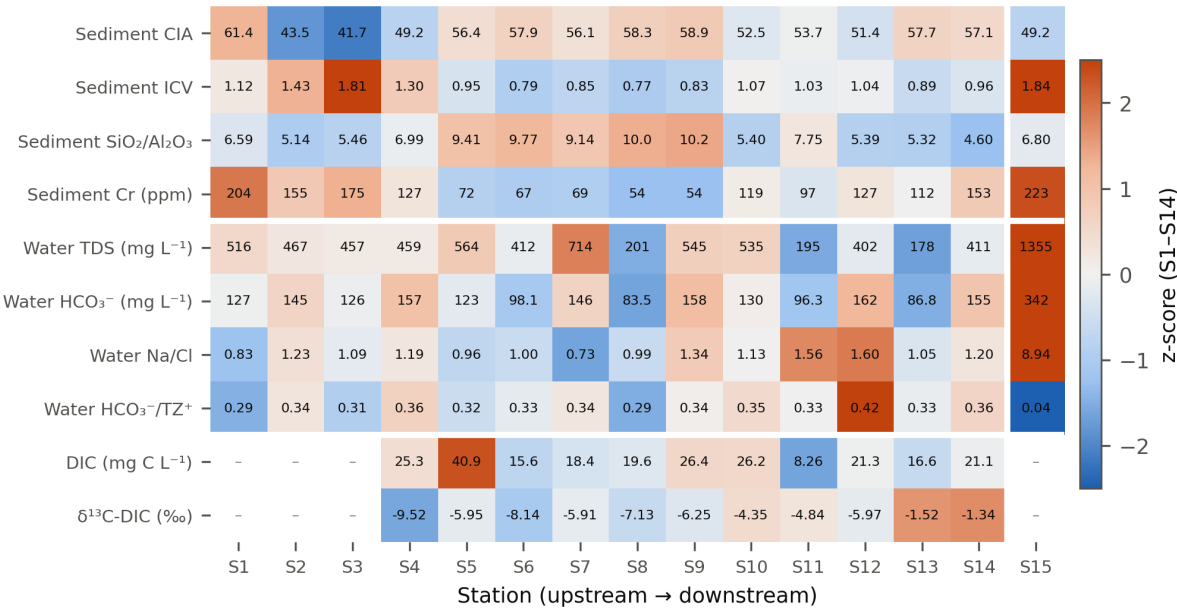


Figure 13. Longitudinal fingerprint of the lower Cauvery. Cells show measured values; colours are z-scores computed over S1–S14 (S15 scaled on the same basis and clipped at ± 3). Sediment indices after Nesbitt and Young (1982) and Cox et al. (1995); $\text{HCO}_3^-/\text{TZ}^+$ and Na/Cl are molar.

Figure 14

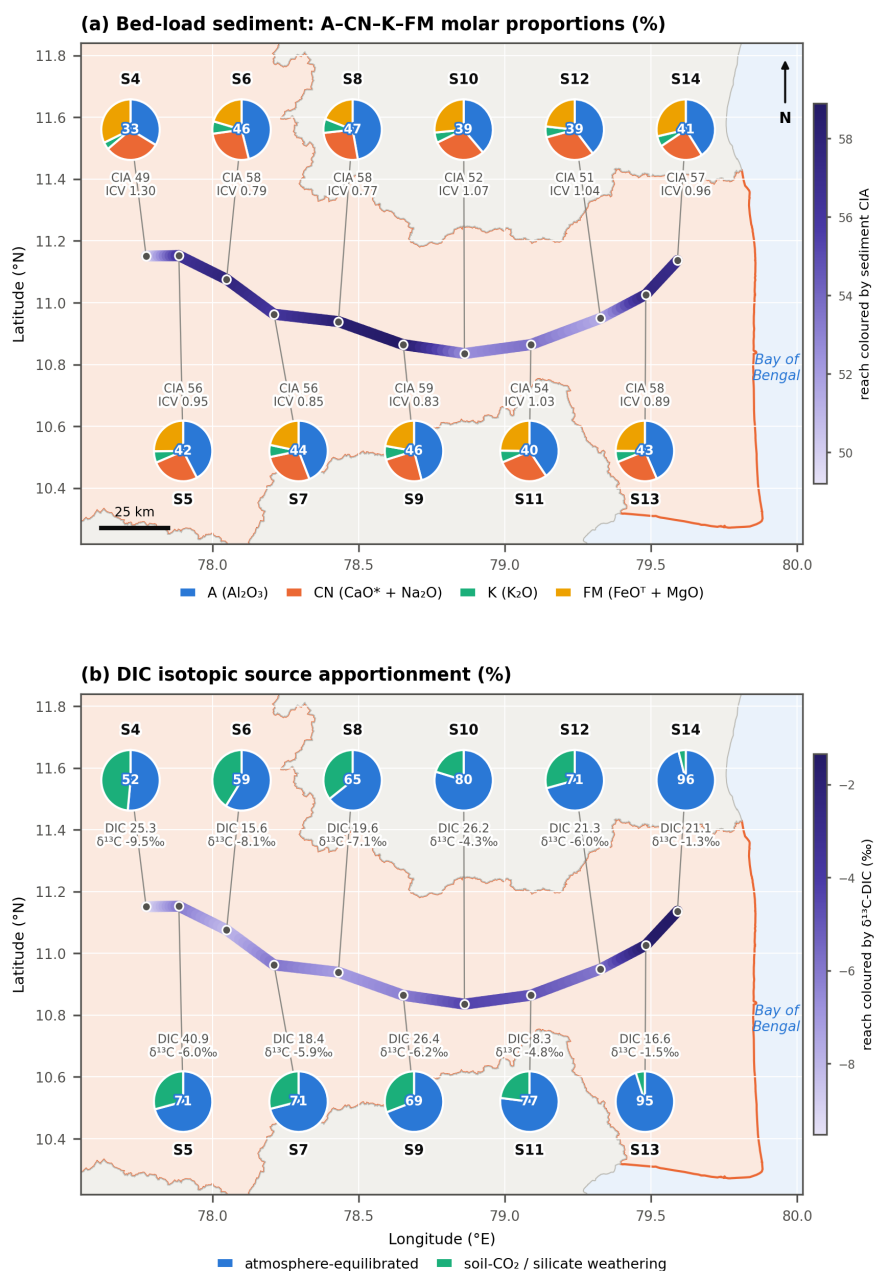


Figure 14. Sediment chemistry and carbon sources on the CWC Cauvery basin layer (CWC, 2025). (a) Molar A–CN–K–FM proportions of bed-load sediment (after Nesbitt and Young, 1989), labelled with CIA and ICV; the reach is coloured by CIA. (b) Isotopic apportionment of DIC between atmosphere-equilibrated carbon and soil-CO₂/silicate-weathering carbon (Eq. 6; end-members after Mook et al., 1974; Zhang et al., 1995; Das et al., 2005), labelled with DIC and $\delta^{13}\text{C-DIC}$; the reach is coloured by $\delta^{13}\text{C-DIC}$. Data from Tables 3 and 5.

Figure 15

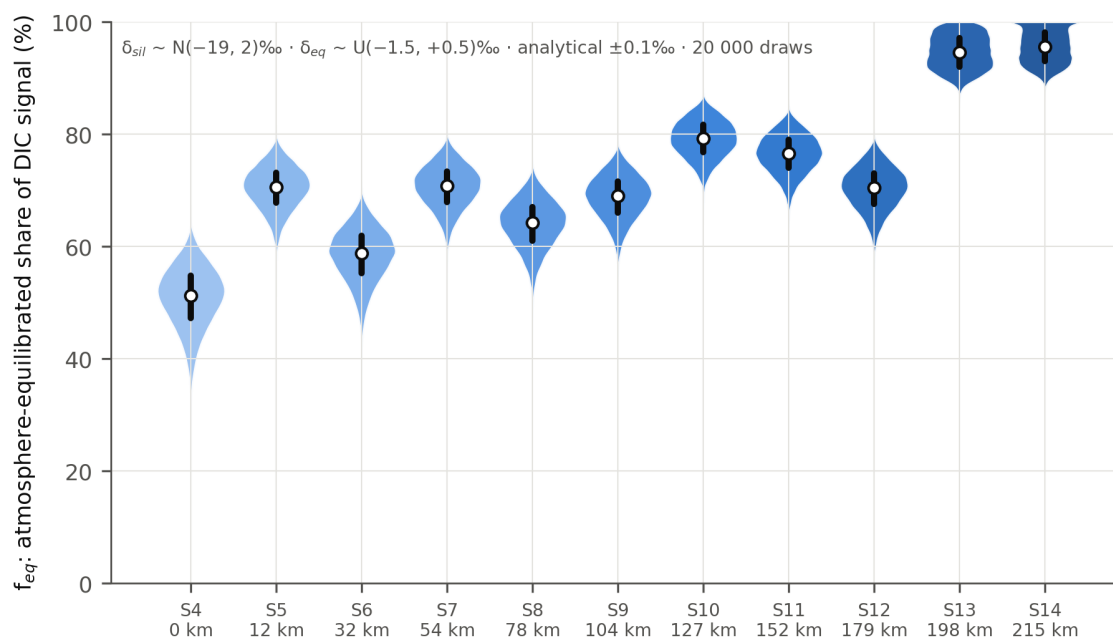


Figure 15. Monte Carlo distributions (20,000 draws) of f_{eq} , the share of the $\delta^{13}\text{C}$ -DIC signal attributable to atmosphere-equilibrated carbon (Eq. 6), at each station. End-member distributions are shown in the panel; violins show the full distribution, bars the interquartile range and circles the median. Silicate end-member after Das et al. (2005); equilibrium fractionation after Mook et al. (1974) and Zhang et al. (1995).

Figure 16

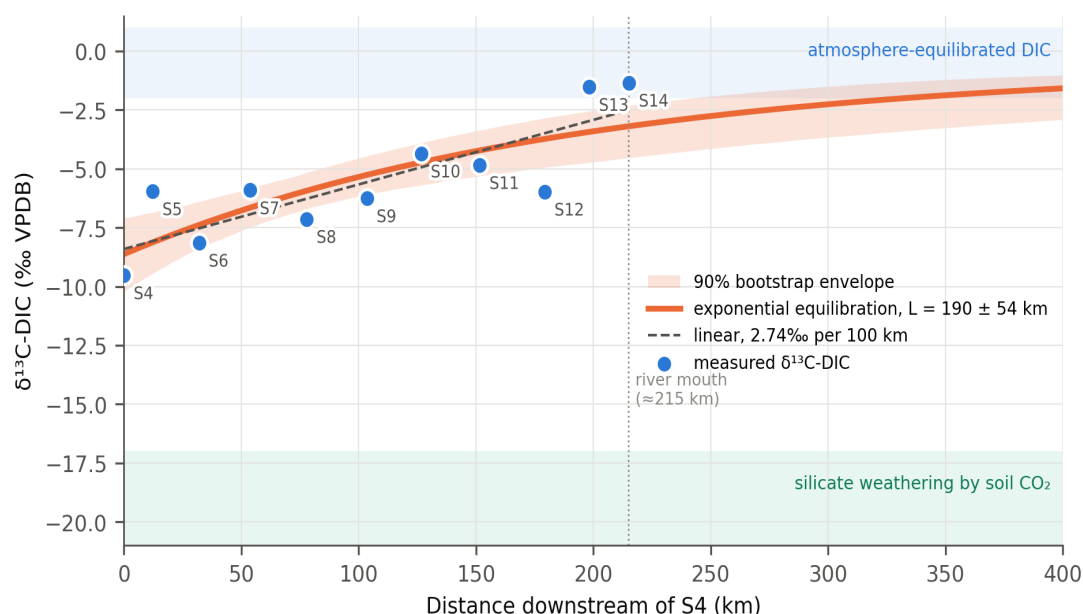


Figure 16. Downstream evolution of $\delta^{13}\text{C}$ -DIC fitted with the first-order equilibration model (Eq. 7; orange, with 90% bootstrap envelope) and a linear model (dashed). Shaded bands show the silicate-weathering (soil CO_2) and atmosphere-equilibrated end-members (Mook et al., 1974; Zhang et al., 1995; Das et al., 2005). The model is extrapolated beyond the river mouth only to illustrate the equilibration length scale.

Figure 17

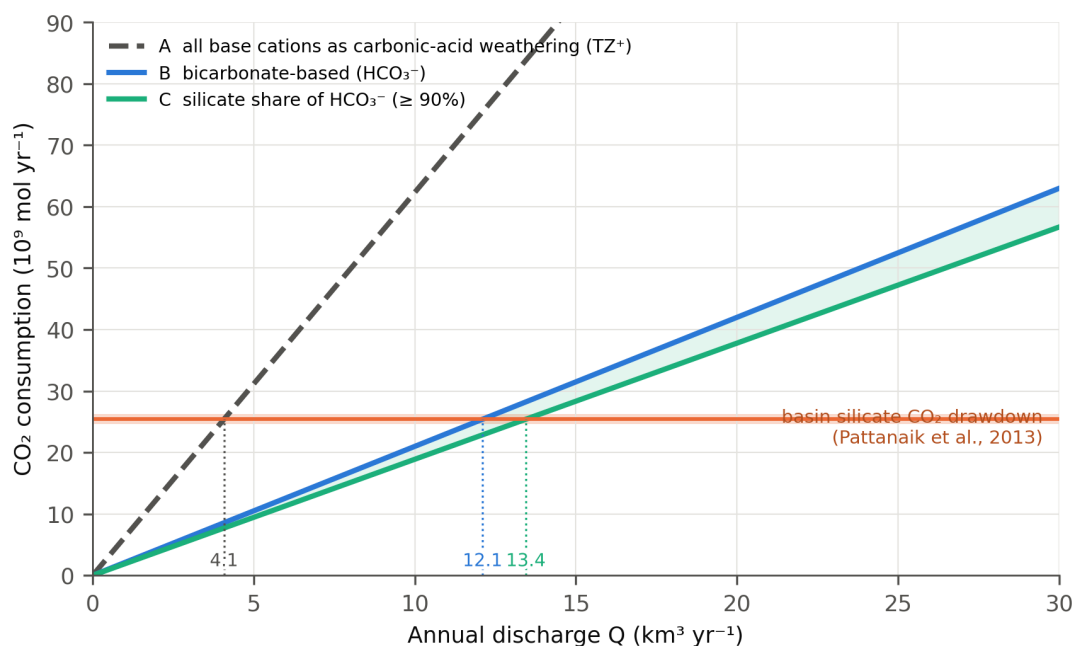


Figure 17. CO₂ consumption as a function of annual discharge for three scenarios based on the mean composition of stations S1–S14: (A) all base cations (TZ⁺), (B) HCO₃[−], (C) silicate-derived HCO₃[−] (≥90%). The horizontal band is the basin-scale silicate-weathering drawdown of Pattanaik et al. (2013); dotted lines mark the discharge at which each scenario matches it.

Figure 18

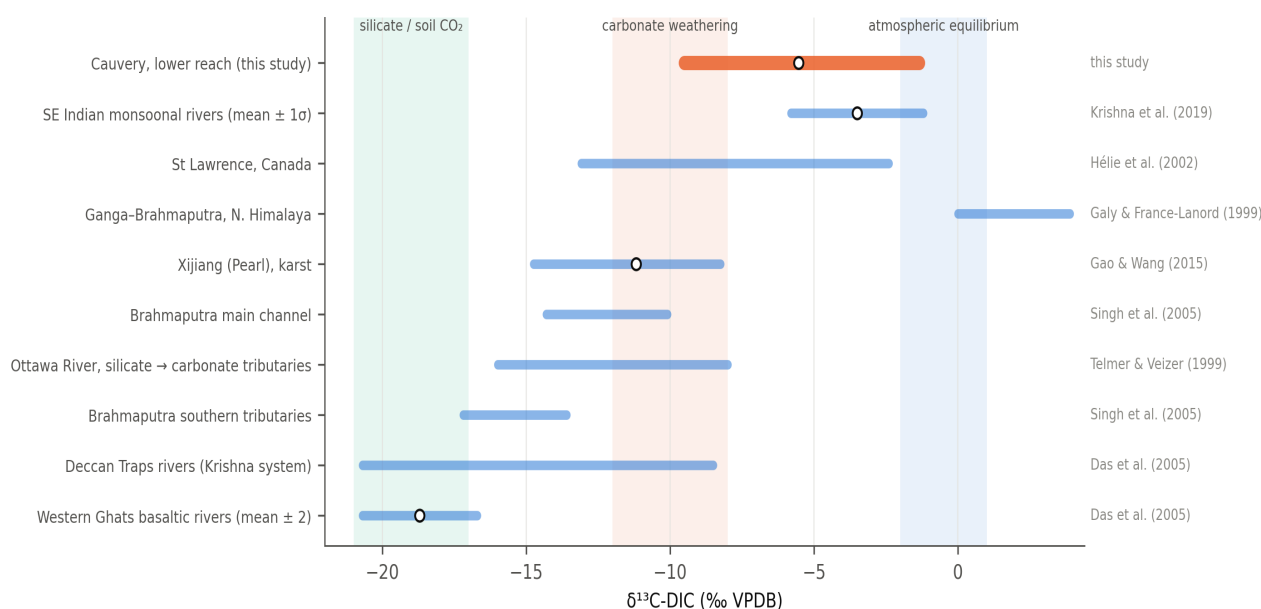


Figure 18. Ranges of $\delta^{13}\text{C-DIC}$ in the lower Cauvery compared with other rivers (circles: reported means). Data from Galy and France-Lanord (1999), Telmer and Veizer (1999), Hélie et al. (2002), Das et al. (2005), Singh et al. (2005), Gao and Wang (2015) and Krishna et al. (2019). Background bands show typical source fields (Clark and Fritz, 1997; Telmer and Veizer, 1999).

Figure 19

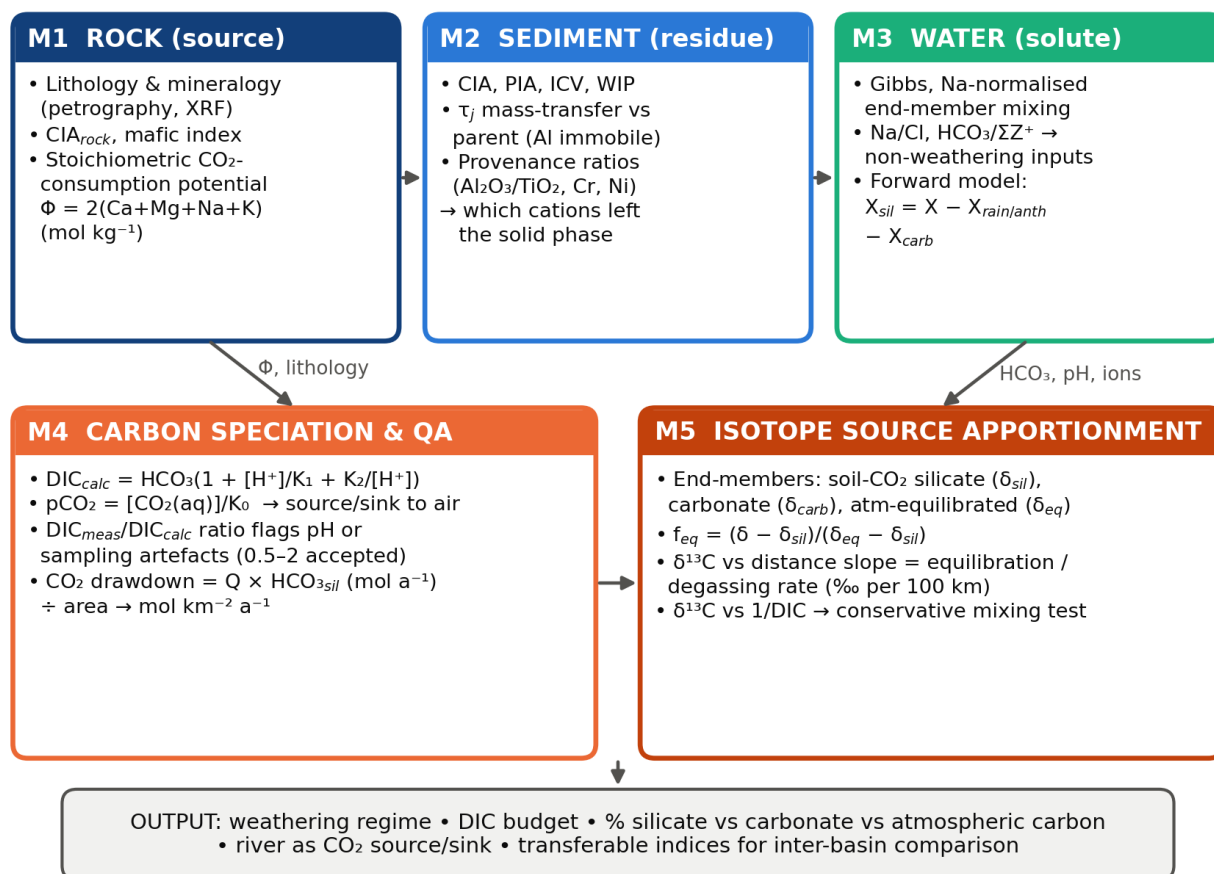


Figure 19. The Rock–Sediment–Water–Carbon (RSWC) framework. Modules M1–M3 constrain the lithological and weathering sources; M4 checks the internal consistency of the carbonate system and derives fluxes; M5 apportions δ¹³C-DIC using end-members admitted by M1–M3. Equations are given in Section 2.4 and diagnostic thresholds in Table 7.

Supplementary material