



Article

Contrasting Seasonal Daytime CO₂ Fluxes in Tropical Irrigation Tanks Under Variable Hydrological and Physicochemical Conditions

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Abstract

Ancient irrigation tanks are a defining component of Sri Lanka's freshwater landscape, but their CO₂ flux dynamics remain poorly characterized and are underrepresented in carbon databases. This study quantified hourly daytime CO₂ fluxes and examined associations between CO₂ flux and environmental variables in Thalangama Tank (TG) and Huruluwewa Tank (HW), which are situated in contrasting hydroclimatic zones. An automated floating chamber was deployed monthly in each tank between January 2025 and January 2026 to capture the monsoon seasons, while water quality parameters and hydro-meteorological data were monitored simultaneously. TG, a small and shallow tank located in the Wet Zone, showed predominantly positive daytime CO₂ fluxes across the sampled campaigns, and no significant seasonal dynamics were observed. In contrast, HW, a large but shallow Dry Zone tank, showed both daytime CO₂ uptake and emission, and daytime CO₂ flux varied significantly among seasons. Daytime net emission was observed during the first inter-monsoon and northeast monsoon periods, while CO₂ uptake was observed during the southwest monsoon and second inter-monsoon periods. At HW, daytime CO₂ flux was strongly associated with the ionic gradient, moderated by strong hydrometeorological forcing. Conversely, CO₂ flux in TG was weakly related to the ionic gradient but associated with the metabolic balance and rainfall variation. These contrasting patterns suggest that hydrometeorological and physicochemical conditions are important factors associated with daytime CO₂ exchange in tropical irrigation tanks. Also emphasize the potential for significant temporal variability in CO₂ flux among tropical artificial freshwater systems.

Keywords: CO₂ flux; tropical freshwater systems; irrigation tanks; flux dynamics; carbon cycle



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1. Introduction

Inland lentic freshwater ecosystems, including lakes, ponds, and reservoirs, are widely recognized as active components of the global carbon cycle rather than passive conduits merely transporting carbon from land to the ocean [1]. These inland waters receive carbon inputs from terrestrial landscapes and generate internal carbon through primary production. Of this total carbon pool, a significant fraction is released to the atmosphere as CO₂, with the overall magnitude and flux patterns dictated by the specific water body type and its unique biogeochemical processes. Furthermore, clarifying these underlying mechanisms

provides a foundation for mitigating these fluxes [2]. Recent coupled terrestrial-aquatic global models demonstrate a significant increase in atmospheric carbon transport via inland waters compared to the pre-industrial era; remarkably, inland waters recycle and export an amount equivalent to nearly half of the global terrestrial carbon sink annually [3]. Omitting these aquatic fluxes introduces substantial bias into regional and global carbon budgets, ultimately undermining the accuracy of global climate policy decisions.

Inland water bodies comprise both natural and anthropogenic systems. While both systems are heavily influenced by human activities, artificial systems are uniquely characterized by intentional hydrological management tailored to specific socio-economic purposes. Anthropogenic activities have been shown to significantly alter carbon dioxide (CO₂) emissions from inland waters [4]. Because water management practices vary widely by region, understanding region-specific flux patterns in these artificial systems is critical. However, current global models of inland water carbon cycling rely predominantly on data from temperate and boreal regions, leaving small, shallow, and highly regulated systems such as those subjected to artificial water level drawdowns, periodic flushing, and controlled extraction significantly underrepresented [2,5,6]. This data scarcity is particularly acute in tropical regions, limiting our understanding of region-specific flux dynamics and their underlying biogeochemical drivers [7,8]. Consequently, upscaling CO₂ fluxes from data-rich regions to the tropics introduces profound uncertainties, as the climatic and biogeochemical regimes between these zones differ fundamentally.

The available studies in tropical freshwater show different variations in flux patterns and the drivers. Deep natural lakes show a net CO₂ sink in annual observations, driven by phytoplankton productivity in the water column [9]. Also, flux sink-source patterns of natural lakes are different from artificial water bodies [10]. Tropical lakes also show a positive correlation between surface water temperature and carbon dioxide flux [11]. These tropical inland waters have distinct physical, chemical, and biological characteristics compared to freshwater systems in other regions. These systems may have high metabolic rates because of significant nutrient supply to the mixed layer and rapid vertical exchange within the water column [12]. Confirming this, case studies from tropical South American reservoirs and Asian hydropower systems indicate that CO₂ emissions can be locally high and strongly modulated by water-level fluctuations, stratification dynamics, and watershed disturbance [13,14]. Yet, global syntheses reveal mixed patterns and highlight that climatic-zone differences are not straightforward; for example, some recent reservoir meta-analyses find weaker differences among climate zones than earlier work, partly because eutrophic temperate reservoirs can emit as much or more than their tropical counterparts [15]. Importantly, most existing data from the tropics come from natural lakes and large hydropower or flood-control reservoirs [7,16–18], whereas small, agricultural, shallow water bodies, often highly productive and intensively managed, remain strongly underrepresented in global CO₂ flux datasets.

Irrigation Tanks in Sri Lanka, also known as *wewa*, are part of the ancient cascade systems. These manmade water bodies are engineered and several centuries old. The cascade systems consist of village-scale ponds to large shallow reservoirs, which have been developed over centuries to capture and redistribute monsoonal runoff for paddy cultivation and domestic use. Beyond irrigation, they support multiple ecosystem functions, including groundwater recharge, local microclimate regulation, and wetland habitat provision, and collectively form one of the most widespread wetland types in the country [19]. Their shallow depths, high perimeter-to-area ratios, strong coupling to cultivated catchments, and exposure to external pressures [20] suggest that they may be biogeochemically active and potentially important sites of CO₂ exchange, yet quantitative flux data are sparse.

Annual rainfall determines three climatic zones in Sri Lanka: the Wet Zone, Intermediate Zone, and Dry Zone. Each zone receives rainfall differently under the influence of monsoon-driven seasonal climate. The Southwest Monsoon (SWM), from May to September, and the Northeast Monsoon (NEM), from December to February, are the two main monsoon seasons. The country also receives substantial rainfall during the First Inter Monsoon (FIM), from March to April, and the Second Inter Monsoon (SIM), from October to November. These climatic seasons create contrasting hydrological environments across the island. The Dry Zone contains most of the country's ancient irrigation tanks, while the Wet Zone also includes several historic tanks. Differences in water availability led to different water-management practices in these systems. This makes it important to understand how climatic seasons influence carbon flux patterns in these contrasting environments.

This study selected two ancient, actively managed irrigation tanks representing the Wet Zone and Dry Zone of Sri Lanka. It aims to compare seasonal and diurnal CO₂ flux patterns between these two tanks and to identify the dominant environmental variables governing flux variability in each system. By examining tanks under contrasting hydroclimatic and water management conditions, the study also seeks to determine which factors are important when monitoring CO₂ flux dynamics of manmade shallow tropical freshwater systems.

2. Materials and Methods

2.1. Study Sites

The *Thalangama* tank (TG) was built around 1412–1467 AD in the *Diyawanna Oya* River basin. This tank is situated in a wet zone as indicated in Figure 1, annually receives 2500 mm of rainfall, and the mean annual temperature is 27.4 °C. This tank has high inflow during the South West Monsoon season (May to September). The most intense rainfall is recorded in the second inter-monsoon period (October to November). The catchment area is characterized by a mix of urban, agricultural, and natural land uses. The *Huruluwewa* Tank (HW), which is located in the dry zone, has a history dating back to 325–352 AD. It is situated in the *Yan Oya River* basin and receives 1750 mm of mean annual rainfall. The mean annual temperature in the area is 28.0 °C. This tank is mainly fed by the second inter-monsoon and the north-east monsoon (October to February). The catchment area of HW is dominated by traditional rural agro-ecological land use patterns. Both tanks are used for irrigation and managed by the Department of Irrigation, Sri Lanka. Table 1 shows basic hydrological details of both tanks.

Table 1. Description of study sites.

	<i>Thalangama</i> Tank	<i>Huruluwewa</i> Tank
Latitude	6°53'16.99'' N	8° 13'0' N
Longitude	79°56'50.10'' E	80° 43'0'' E
Catchment area *	2.51 km ²	199.56 km ²
High flood level above MSL *	6.18 m	132.88 m
Water spared area at Full supply level *	0.083 km ²	35.21 km ²
Maximum depth *	3.65 m	8.38 m
Mean depth	3.00 m **	5.60 m ***

Data sources: * Department of Irrigation, Sri Lanka, ** [21] *** [22].

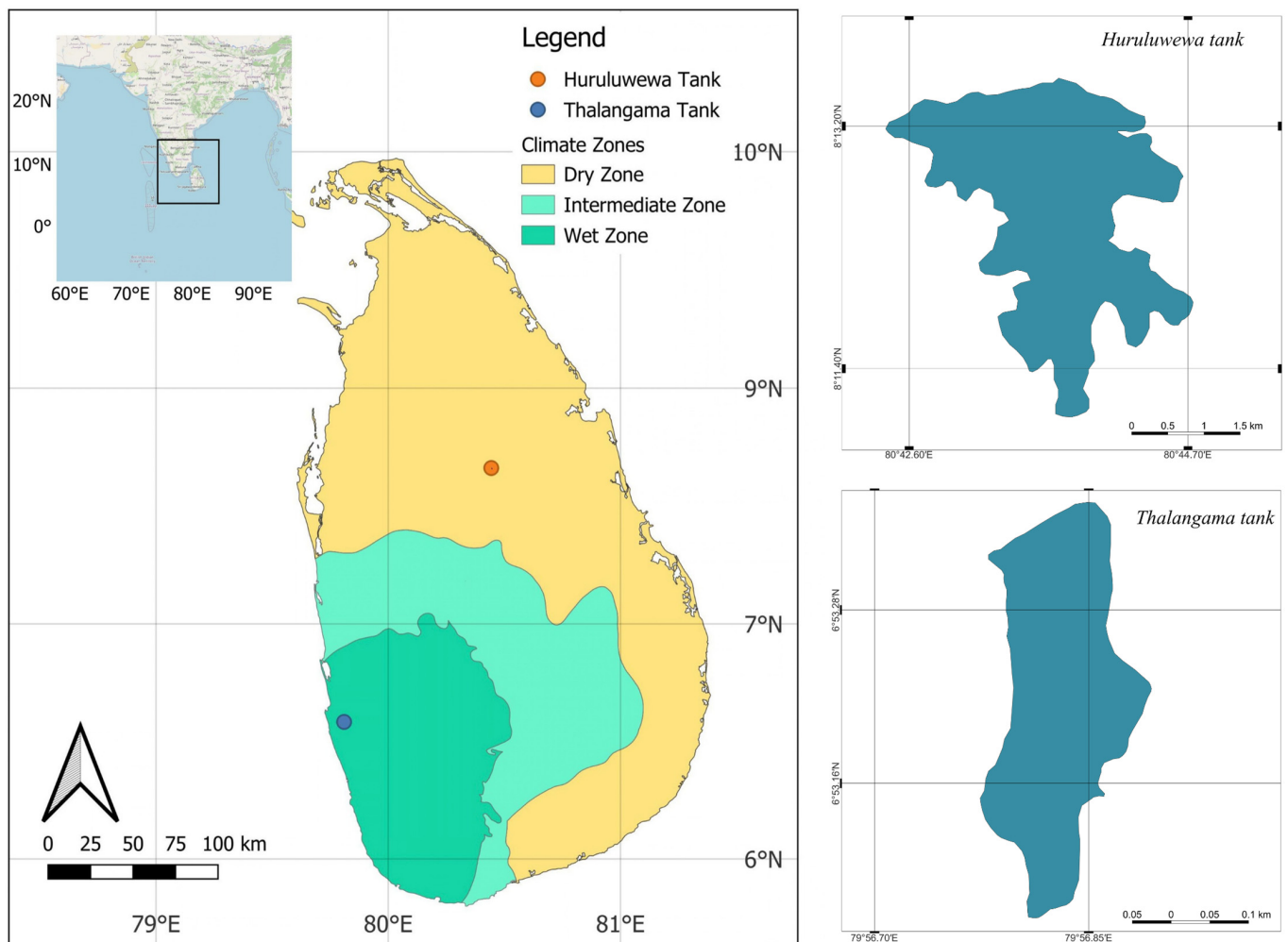


Figure 1. Location of the two study sites. The main map shows the island-wide distribution of three climatic zones: Dry Zone (yellow), Intermediate Zone (light green), and Wet Zone (dark green), with the locations of the two study tanks indicated by colored dots. *Huruluwewa* Tank is situated in the North-Central Dry Zone (Orange color dot), while *Thalangama* Tank is located in the southwestern Wet Zone (Blue color dot). The blue inset maps show the digitized outlines and spatial morphology of *Huruluwewa* and *Thalangama* tanks, with separate scale bars indicating their approximate dimensions. Boundary layers were obtained from the National Spatial Data Infrastructure, Sri Lanka. (<https://www.nsd.gov.lk> accessed on 11 July 2026). Base map obtained from OpenStreetMap ©OpenStreetMap Distributed under the Open Data Commons Open Database License (ODbL) v1.0 (for further information, please see <https://www.openstreetmap.org/copyright/en>, accessed on 11 July 2026). The final map was produced using QGIS Desktop version 3.34.5.

2.2. Quantification of CO₂ Flux

The floating chamber method was used to quantify hourly carbon dioxide flux. Mini loggers were used to automate the chamber [23], and a Non-Dispersive Infrared (NDIR) sensor (SCD30, Sensirion AG, Switzerland) was used to quantify the CO₂ concentration inside the chamber in 2 min interval [24,25]. The sensor was force-calibrated with a reference using ambient air in a 2 ms⁻¹ windy environment as described by the manufacturer. The automated floating chamber (AFC) was constructed using transparent acrylic sheets with dimensions of 0.30 m in width, height, and length, and mounted on a Styrofoam base with dimensions of 0.91 m in length, 0.60 m in width, and 0.0635 m in height to ensure buoyancy. The chamber was insulated using aluminum double bubble wrap, aiming to minimize the influence of external temperature. The bottom opening of the chamber, which was in contact with the water surface, had an area of 0.0625 m². Fluxes were measured at hourly

intervals. Each cycle included a 40 min gas accumulation period inside the sealed chamber, followed by a 20 min flushing period to reset the internal air. A PVC pipe with a diameter of 16 mm and a length of 1.5 m was attached to the chamber, aiming to prevent air pressure buildup inside the chamber. An air pump was operated on a separate power supply, while sensors and the microcontroller were powered by a separate Li-ion 18,650 battery pack.

First, we omitted the first five minutes and the last five minutes of CO₂ concentration readings from each 40 min chamber deployment, as these intervals were affected by noise associated with the flushing procedure. The sensor includes built-in humidity and temperature compensation, so the influence of varying humidity and temperature on the CO₂ readings is minimal. CO₂ concentration was recorded in ppm by the microprocessor. We applied a three-point moving average to the raw data to reduce background noise. The smoothed data were then fitted using ordinary least squares linear regression of CO₂ concentration (ppm) against elapsed time (seconds) to estimate the slope. Hourly gas fluxes were subsequently calculated using the following equation:

$$FCO_2 = \frac{V}{RTA} \times \frac{dC}{dt} \times 3600 \mu\text{mol m}^{-2} \text{ h}^{-1}$$

FCO_2 = CO₂ Flux ($\mu\text{mol m}^{-2} \text{ h}^{-1}$)

$\frac{dC}{dt}$ = Rate of change in CO₂ concentration over time ($\mu\text{mol m}^{-3} \text{ s}^{-1}$)

T = Ambient temperature (K)

R = Universal gas constant ($\text{m}^3 \text{ atm K}^{-1} \text{ mol}^{-1}$)

A = Chamber area in contact with water (m^2)

V = Chamber volume (m^3)

The same chamber was deployed at each lake at monthly intervals from January 2025 to January 2026. The placement was over an area of 2 m of water depth, and daytime hourly fluxes were quantified. A flux measurement campaign consisted of a five- to eight-hour monitoring period. The chamber was deployed at the same location during each visit. The number of observed flux hours during some field visits was limited due to transportation delays and challenges encountered during instrument deployment. For one tank, a total of 12 flux measurement campaign days were conducted covering First Inter Monsoon (FIM), South West Monsoon (SWM), Second Inter Monsoon (SIM), and North East Monsoon (NEM) rainfall seasons of Sri Lanka.

2.3. Monitoring of Hourly Environmental Parameters

Water quality parameters, including dissolved oxygen (DO), electrical conductivity (EC), total dissolved solids (TDS), pH, water temperature, and atmospheric pressure, were recorded using a Hanna HI9829 multiparameter (Nusfalau, Romania) at hourly intervals. In each hour, five readings of solar radiation were randomly recorded using a TES1333R solar power meter (Taipei, Taiwan), and the mean solar radiation was obtained. Wind speed was recorded with a handheld anemometer. Air temperature and relative humidity were recorded using a Palma II Hygrothermometer, SK SATO (Tokyo, Japan).

2.4. Monitoring of Water Quality Variables

Chlorophyll-a concentration, turbidity, nitrate nitrogen, total phosphorus, and total alkalinity were measured once during each flux monitoring campaign. These measurements were considered representative of the campaign-day water conditions for descriptive and campaign-scale analyses. For each campaign, three surface water samples were collected consecutively for each analysis at the chamber deployment location and processed independently. The arithmetic mean of the three replicate measurements was used as the campaign-scale value for descriptive and campaign-scale statistical analyses.

For chlorophyll-a analysis, surface-water samples were collected in 0.5 L high-density polyethylene (HDPE) bottles, protected from light, and transported to the laboratory at 4 °C. Samples were filtered through glass fiber filters (nominal pore size 0.7 µm). Pigments retained on the filters were extracted in 90% acetone and stored for 24 h in darkness at 4 °C. Extracts were subsequently centrifuged at 3500 rpm for 20 min, and absorbance (Wavelengths: 750 nm, 664 nm, 647 nm, 630 nm) was measured with a Shimadzu UV-2700 spectrophotometer against a 90% acetone blank. Chlorophyll-a concentration was calculated using the spectrophotometric equations developed by Jeffrey and Humphrey. Ref. [26] with absorbance readings were corrected for background scattering at 750 nm.

Turbidity was measured in situ at each sampling point using a Hach DR/890 colorimeter (Hach Company, Loveland, CO, USA) following manufacturer protocols. The instrument was calibrated daily using Hach TurbCal calibration standards spanning the expected range (0–400 NTU), and measurements were taken in triplicate at approximately 0.2 m depth below the water surface, avoiding areas of visible sediment resuspension or surface scum. Reported values represent the mean of triplicate readings.

Total alkalinity was determined in situ by acid-base titration immediately after sample collection, with 0.2 N sulfuric acid (H₂SO₄) and a mixed bromocresol green methyl red indicator endpoint (pH ≈ 4.5), following APHA Standard Method 2320 B. Samples were collected in clean 100 mL glass beakers, and titration was performed within 15 min of collection to minimize CO₂ exchange with the atmosphere. Alkalinity is reported as mg L⁻¹ as CaCO₃.

Water samples for nitrate nitrogen and total phosphorus analysis were collected in HDPE bottles, transported to the laboratory in the dark at approximately 4 °C, and analysed within 24 h. Nitrate nitrogen was determined using the Hach NitraVer 5 powder pillow method (Hach Company, Loveland, CO, USA). The method detection limit is 0.01 mg L⁻¹. Total phosphorus was determined following sample acid persulfate digestion using the Hach PhosVer 3 ascorbic-acid colorimetric method (Hach Company, Loveland, CO, USA). The method detection limit is 0.01 mg L⁻¹. All colorimetric analyses were performed using the Hach DR/890 colorimeter (Hach Company, Loveland, CO, USA).

2.5. Carbon Species Quantification

Water samples were collected in amber colored 100 mL glass bottles during flux measurement campaigns in March, August, October, and December to quantify total organic carbon (TOC) and total inorganic carbon (TIC). All samples were transported and stored at 4 °C. Quantification was performed within seven days of sample collection using the Elementar Vario TOC cube (Elementar Analysensysteme GmbH, Germany). Before the measurements, the instrument was calibrated with TOC standard calibration solutions (0 ppm, 50 ppm, 100 ppm). Three analytical replicates were performed per sample.

2.6. Hydrological Data

Water levels and Rainfall data of the HW tank were obtained from the official records of the Divisional Irrigation Engineer's Office, *Huruluwewa*, Sri Lanka. Data for the TG tank were obtained from the automatic gauges at the TG tank managed by the Center for Urban Water, Sri Lanka Land Development Corporation, Sri Lanka.

2.7. Statistical Analysis

All statistical analyses were performed in R (version 4.5.2; R Core Team, Vienna, Austria, 2026). Before analysis, CO₂ flux data and environmental variables were assessed for normality using the Shapiro–Wilk test and visual inspection of Q–Q plots. Descriptive statistics, including mean, standard deviation, range, and the proportion of positive and negative flux values, were calculated separately for each site to characterize central ten-

dependency and directional flux behavior over the study period. Pairwise Pearson correlation coefficients were calculated separately according to the native temporal resolution of each environmental variable to assess the strength and direction of bivariate associations with CO₂ flux at each tank. Hourly measured physicochemical and meteorological variables, including water temperature, air temperature, wind speed, relative humidity, pH, electrical conductivity, total dissolved solids, salinity, atmospheric pressure, dissolved oxygen, and solar radiation, were paired with corresponding hourly CO₂ flux observations. Variables measured once per sampling campaign, including total phosphate, nitrate nitrogen, alkalinity, turbidity, chlorophyll-a, water depth, and rainfall, were paired with the mean daytime CO₂ flux calculated for the corresponding campaign day. Statistical significance was evaluated at $\alpha = 0.05$.

Seasonal variation in hourly daytime CO₂ flux was assessed separately for HW and TG using linear mixed-effects models. Season was specified as a fixed categorical effect, and sampling campaign date was included as a random intercept to account for repeated hourly chamber observations collected during each campaign. A first-order autoregressive [AR(1)] residual correlation structure was specified for sequential hourly observations within campaign date. For each tank, the AR(1) model was compared with a random-intercept-only model using Akaike's information criterion (AIC) and Bayesian information criterion (BIC); the model with lower information criteria was retained for inference. Seasonal significance was evaluated from analysis of variance of the selected model. Accordingly, the individual hourly flux observations were treated as repeated measurements nested within campaign dates rather than as independent replicates.

Principal component analysis (PCA) [27] was performed for TG and HW separately using only environmental variables measured at the same hourly temporal resolution as CO₂ flux. The candidate hourly variables were water temperature, air temperature, wind speed, relative humidity, pH, electrical conductivity, total dissolved solids, salinity, atmospheric pressure, dissolved oxygen, and solar radiation. Before conducting PCA, multicollinearity among the candidate environmental variables was assessed using pairwise Pearson correlations and variance inflation factors (VIF). Then, selected variables were assembled for a multivariate data matrix. The suitability of the data matrix for PCA was assessed using two complementary tests. First, Bartlett's test of sphericity was applied to the correlation matrix to confirm that inter-variable correlations were significantly different from an identity matrix ($p < 0.05$). Second, the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy was computed both globally and for each variable (MSAi). An iterative variable selection procedure was applied: the variable with the lowest MSAi value below 0.50 was removed in each iteration, and the KMO was recalculated on the reduced matrix. This process was repeated until all remaining variables had $MSAi \geq 0.50$. Then, PCA was conducted with the selected variables. Components were extracted and rotated using the varimax method to improve the interpretability of the loading structure. The number of components retained was determined by the Kaiser criterion (eigenvalue > 1) and verified with a scree plot. The resulting Principal components were correlated with CO₂ flux using Spearman's rank correlation to assess the relationship between each principal component and tank CO₂ dynamics.

2.8. Calculation of Carbon Species

The relative distribution of dissolved inorganic carbon (DIC) among dissolved carbon dioxide and carbonic acid (CO₂*), bicarbonate (HCO₃[−]), and carbonate (CO₃^{2−}) was estimated from hourly measurements of surface water pH and temperature. The calculation provides the fractional speciation of the inorganic carbon pool and does not quantify absolute DIC concentration.

The proportion of each species as a fraction of total DIC was calculated using the following equations.

$$\begin{aligned}\text{CO}_2^* \alpha_0 &= \frac{[\text{H}^+]^2}{[\text{H}^+]^2 + [\text{H}^+]K_1 + K_1K_2} \\ \text{HCO}_3^- \alpha_1 &= \frac{[\text{H}^+]K_1}{[\text{H}^+]^2 + [\text{H}^+]K_1 + K_1K_2} \\ \text{CO}_3^{2-} \alpha_2 &= \frac{K_1K_2}{[\text{H}^+]^2 + [\text{H}^+]K_1 + K_1K_2}\end{aligned}$$

where $[\text{H}^+] = 10^{-\text{pH}}$, and K_1 and K_2 are the first and second apparent dissociation constants of carbonic acid, respectively. Since K_1 and K_2 are temperature-dependent, both constants were corrected to each hourly measured water temperature using the following equations [28].

$$\begin{aligned}\text{p}K_1 &= \frac{3404.71}{T_K} + 0.032786 \times T_K - 14.8435 \\ \text{p}K_2 &= \frac{2902.39}{T_K} + 0.02379 \times T_K - 6.4980\end{aligned}$$

Here, T_K is the absolute temperature in Kelvin.

2.9. Calculation of Trophic State

The trophic state of each tank was assessed for each sampling campaign using Carlson's chlorophyll-a-based trophic state index, TSI(Chl). The index was calculated from the campaign-level chlorophyll-a concentration using the following equation,

$$\text{TSI(Chl)} = 9.81 \ln[\text{Chl-a}] + 30.6$$

where [Chl-a] is the chlorophyll-a concentration in $\mu\text{g L}^{-1}$. Campaigns were classified as oligotrophic ($\text{TSI} < 40$), mesotrophic ($40 \leq \text{TSI} < 50$), eutrophic ($50 \leq \text{TSI} < 70$), or hypereutrophic ($\text{TSI} \geq 70$). For each tank, the mean campaign-level TSI(Chl) was calculated as the arithmetic mean of its available campaign-specific values.

3. Results

3.1. Magnitude and Temporal Dynamics of CO_2 Flux

CO_2 flux quantification showed contrasting patterns between the HW and TG irrigation tanks. HW exhibited a mean flux of $90 \mu\text{mol m}^{-2} \text{h}^{-1}$ (range: -2509 to $4359 \mu\text{mol m}^{-2} \text{h}^{-1}$, $n = 77$), with 51.8% of measurements showing negative flux, implying intake of atmospheric CO_2 into the water column. TG hourly fluxes were consistent with a mean flux of $2421 \mu\text{mol m}^{-2} \text{h}^{-1}$ (range: -839 to $7835 \mu\text{mol m}^{-2} \text{h}^{-1}$, $n = 84$), with only 5.9% of measurements exhibiting CO_2 uptake by the water column. Mean hourly flux measured in each flux quantification campaign per month is shown in Figure 2. Quantified hourly fluxes are provided in Supplementary Tables S1 and S2.

Mixed-effects models incorporating campaign date as a random intercept and an AR(1) residual correlation structure were preferred over random intercept-only models for both tanks. For HW, the AR(1) model had lower AIC and BIC values (AIC = 1194.13; BIC = 1210.16) than the random intercept-only model (AIC = 1210.77; BIC = 1224.51). Season had a statistically significant effect on hourly daytime CO_2 flux at HW ($F_{3,8} = 9.17$, $p = 0.0057$). For TG, the AR(1) model was likewise preferred (AIC = 1419.95; BIC = 1436.54) over the random-intercept-only model (AIC = 1433.31; BIC = 1447.53). However, season did not significantly affect hourly daytime CO_2 flux at TG ($F_{3,9} = 0.34$, $p = 0.7982$).

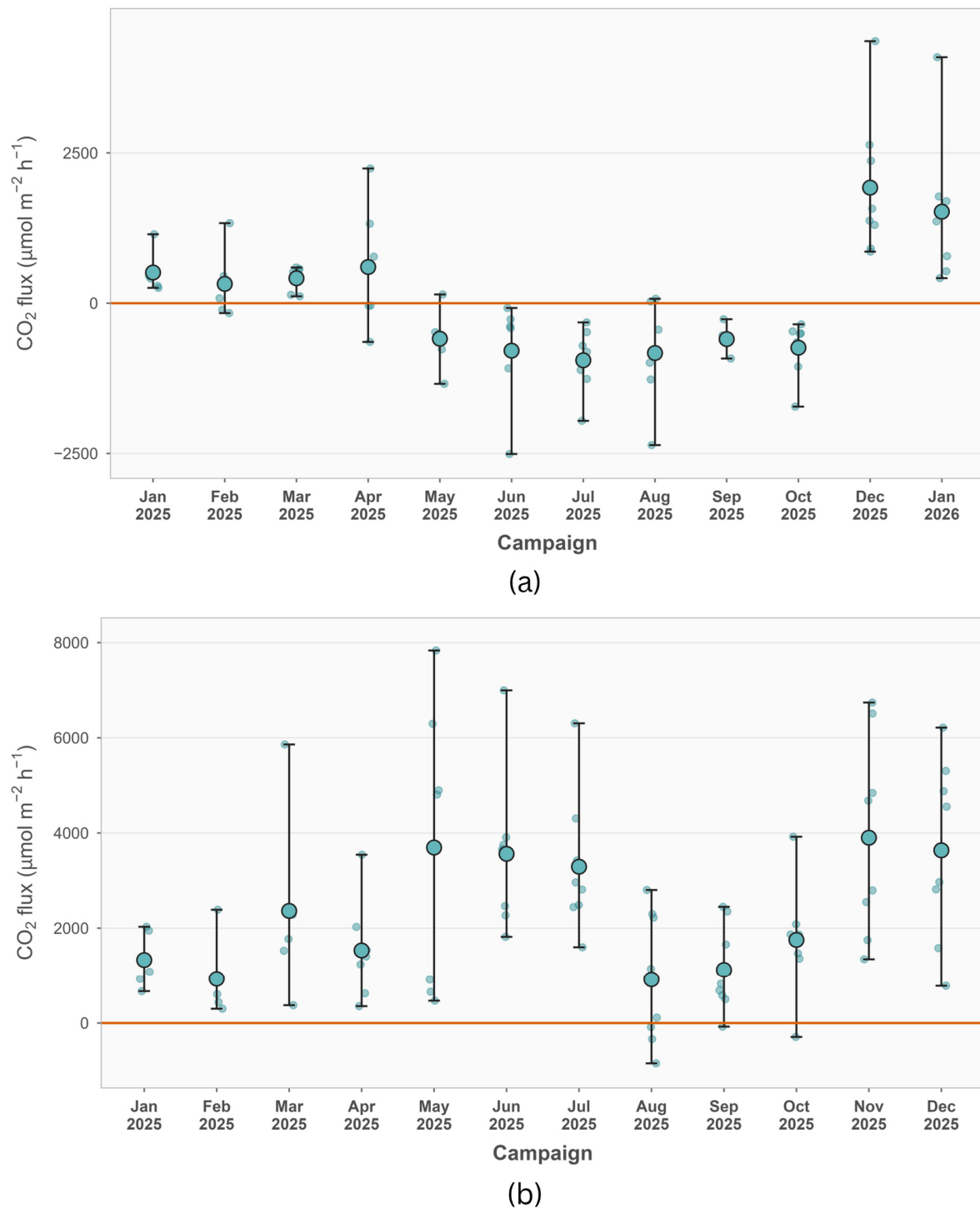


Figure 2. Campaign-level daytime CO₂ flux in (a) Huruluwewa Tank (HW) and (b) Thalangama Tank (TG). Large teal circles indicate the mean CO₂ flux across hourly observations collected during each daytime monitoring campaign, while vertical black bars show the within-day minimum-to-maximum range. Small semi-transparent teal circles represent individual hourly observations and are displayed to illustrate within-day variability. The orange horizontal line denotes zero CO₂ flux, with positive and negative values indicating net CO₂ emission and uptake, respectively. Campaigns are labelled by month and year. Daytime monitoring was not conducted at HW in November 2025 because of adverse weather conditions. The number of hourly observations differed among campaigns owing to field- and weather-related constraints.

Post hoc pairwise seasonal comparisons were conducted only for HW because the overall seasonal effect was significant. Tukey-adjusted post hoc comparisons identified

significant differences between the SWM and NEM seasons (estimate = -1866 , SE = 335, df = 7.88, $t = -5.57$, $p = 0.0025$) and between the SIM and NEM seasons (estimate = -1849 , SE = 538, df = 6.86, $t = -3.44$, $p = 0.0436$), while remaining pairwise contrasts were not statistically significant ($p > 0.05$).

The highest mean hourly flux of HW was recorded in NEM ($1173.51 \pm 1149.46 \mu\text{mol m}^{-2} \text{h}^{-1}$, $n = 26$), while the highest uptake was recorded in SWM ($-765.51 \pm 637.34 \mu\text{mol m}^{-2} \text{h}^{-1}$, $n = 31$). The SIM period also showed net CO_2 uptake ($-740.17 \pm 448.84 \mu\text{mol m}^{-2} \text{h}^{-1}$, $n = 8$). Similar to NEM, FIM showed net positive flux, but the mean flux was comparatively lower ($508.56 \pm 736.82 \mu\text{mol m}^{-2} \text{h}^{-1}$, $n = 12$). All seasons in TG showed net positive flux as shown in Figure 3. (FIM: $1877.67 \pm 1534.36 \mu\text{mol m}^{-2} \text{h}^{-1}$, $n = 12$, SWM: $2486.15 \pm 2086.69 \mu\text{mol m}^{-2} \text{h}^{-1}$, $n = 39$, SIM: $2898.68 \pm 2019.00 \mu\text{mol m}^{-2} \text{h}^{-1}$, $n = 15$, NEM: $2242.6717 \pm 1849.26 \mu\text{mol m}^{-2} \text{h}^{-1}$, $n = 18$).

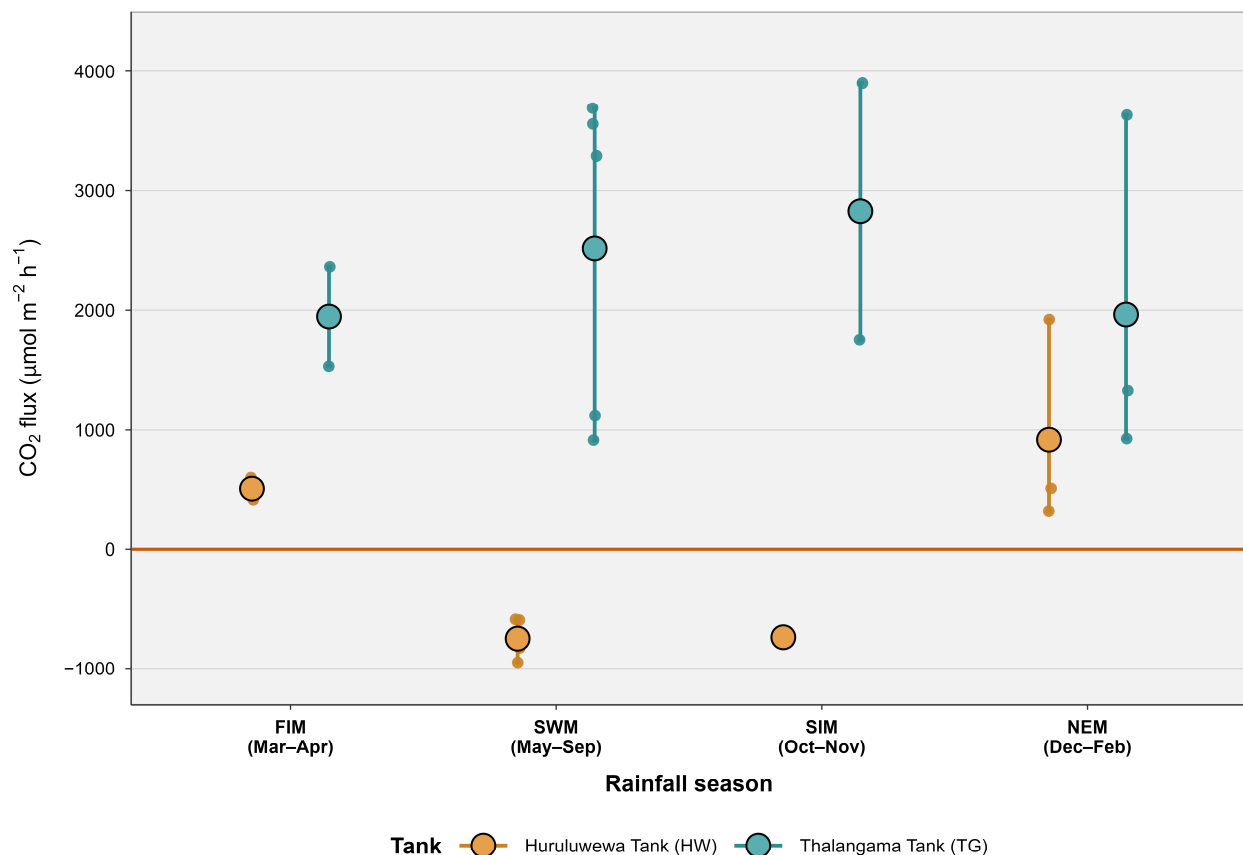


Figure 3. Seasonal campaign-level daytime CO_2 flux in Thalangama Tank (TG; teal) and Huruluwewa Tank (HW; orange). Large circles represent seasonal means calculated from independent monitoring-campaign means, whereas smaller circles represent individual campaign-level mean fluxes. Vertical bars denote the minimum–maximum range among campaign means within each rainfall season. Rainfall seasons are classified as FIM (March–April), SWM (May–September), SIM (October–November), and NEM (December–February). The orange horizontal line indicates zero CO_2 flux; values above and below this line represent net CO_2 emission and uptake, respectively. The number of independent campaigns contributing to each seasonal estimate is displayed above the range bar. No monitoring was conducted at HW in November 2025 because of adverse weather conditions.

3.2. Dynamics of Environmental Variables

The carbon species analysis showed that TIC dominated the measured carbon pool in the surface water of HW and TG (Figure 4). HW recorded the highest mean TC ($20.15 \pm 4.63 \text{ mg/L}$), TIC ($15.55 \pm 3.96 \text{ mg/L}$), and TOC ($4.60 \pm 0.96 \text{ mg/L}$) compared to TG (TC: $10.74 \pm 0.79 \text{ mg/L}$; TIC: $8.00 \pm 0.77 \text{ mg/L}$; TOC: $2.73 \pm 0.77 \text{ mg/L}$). The TOC:

TIC ratio, a useful indicator of the relative contribution of organic versus inorganic carbon sources. In HW, the ratio was lowest in August (0.25) and highest in December (0.41). Similar to HW, in TG, the lowest ratio was observed in August (0.25), but the highest ratio was observed in October (0.50).

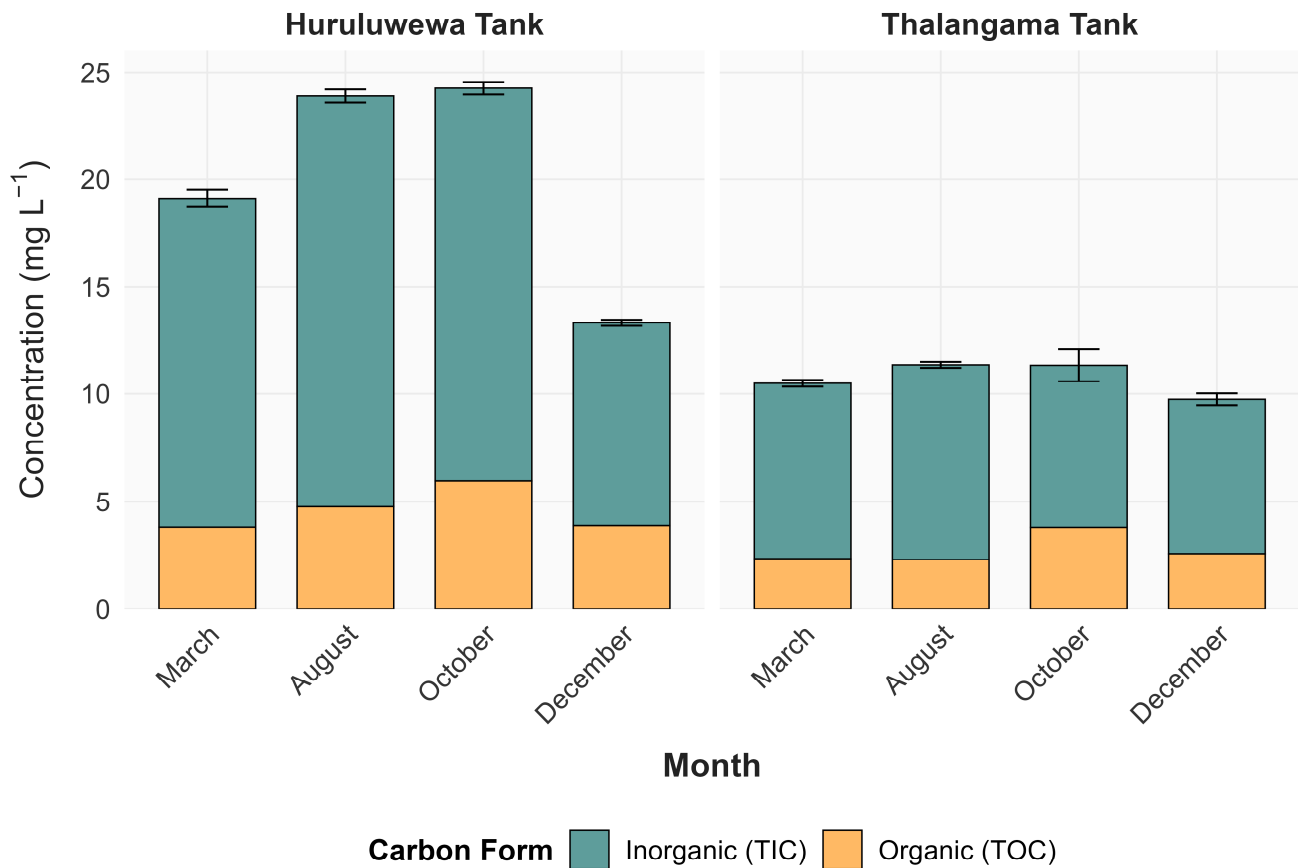


Figure 4. Carbon speciation in Huruluwewa Tank (HW, Dry Zone) and Thalangama Tank (TG, Wet Zone) across sampling campaigns (March, August, October, December 2025). Each stacked bar represents total carbon (TC) content, partitioned into its two constituent fractions: total inorganic carbon (TIC, teal) and total organic carbon (TOC, orange), stacked additively so that the full bar height equals the mean TC concentration for that month. Error bars denote mean $\pm$ 1 standard deviation (SD) of TC, calculated from measurements per campaign.

The mean campaign-level Carlson trophic state index based on chlorophyll-a, TSI(Chl) was 44.8 at Thalangama (TG), corresponding to a mesotrophic classification, and 57.9 at Huruluwewa (HW), corresponding to a eutrophic classification. Individual campaign values ranged from 30.1 to 56.7 at TG and from 47.1 to 63.4 at HW. TG campaigns spanned oligotrophic, mesotrophic, and eutrophic classifications, whereas HW was mesotrophic in January 2025 and eutrophic in all other sampled campaigns. Campaign-specific values and classifications are presented in Table S5.

Quantified environmental and water quality variables are summarized in Table 2. Correlation analysis revealed markedly different associations between environmental variables and CO₂ flux between the two lakes (Table 3). In HW, CO₂ flux was strongly negatively correlated with ionic content and pH, and strongly positively correlated with water level. Additional significant correlations were observed with air temperature, water temperature, relative humidity, atmospheric pressure, alkalinity, wind speed, solar radiation, and rainfall. Suggesting hydrometeorological forcing associated with the CO₂ flux. In contrast, TG showed substantially weaker correlations with ionic gradient and no significant relation-

ship with water level or pH. Instead, CO₂ flux in TG was most strongly associated with rainfall and DO, which were notably absent or much weaker in HW. Significant correlations in TG were also observed with water temperature, relative humidity, atmospheric pressure, and air temperature. Variables including turbidity, chlorophyll-a, total phosphate, and nitrate nitrogen showed no significant correlations with CO₂ flux in either lake.

Table 2. Summary of meteorological, physicochemical, and water-quality variables for *Thalangama* and *Huruluwewa* tanks. Values are mean $\pm$ standard deviation (SD) across all hourly monitoring campaigns (meteorological and physicochemical variables: $n = 84$ for *Thalangama*, $n = 77$ for *Huruluwewa*; water-quality variables: $n = 12$ per tank).

Parameter	Thalangama Tank		Huruluwewa Tank	
	<i>n</i>	Mean $\pm$ SD	<i>n</i>	Mean $\pm$ SD
Air Temperature (°C)	84	29.81 $\pm$ 1.55	77	30.09 $\pm$ 3.40
Wind Speed (m s ⁻¹)	84	1.58 $\pm$ 1.13	77	2.40 $\pm$ 1.82
Relative Humidity (%)	84	70.57 $\pm$ 12.98	77	69.68 $\pm$ 17.15
Atmospheric Pressure (kPa)	84	100.18 $\pm$ 0.35	77	98.77 $\pm$ 0.37
Solar Radiation (W m ⁻²)	84	474.09 $\pm$ 308.60	77	433.43 $\pm$ 303.39
Water Temperature (°C)	84	31.05 $\pm$ 1.64	77	29.42 $\pm$ 2.14
pH	84	7.36 $\pm$ 0.51	77	8.31 $\pm$ 0.69
Electrical Conductivity (μS cm ⁻¹)	84	189.08 $\pm$ 23.82	77	349.04 $\pm$ 85.64
Total Dissolved Solids (mg L ⁻¹)	84	94.58 $\pm$ 11.76	77	173.21 $\pm$ 40.31
Salinity (PSU)	84	0.09 $\pm$ 0.01	77	0.16 $\pm$ 0.04
Dissolved oxygen (mg L ⁻¹)	84	4.48 $\pm$ 1.10	77	4.65 $\pm$ 1.08
Total Phosphate (mg L ⁻¹)	12	0.15 $\pm$ 0.15	12	0.17 $\pm$ 0.16
Nitrate Nitrogen (mg L ⁻¹)	12	1.44 $\pm$ 0.90	12	2.48 $\pm$ 1.96
Total Alkalinity (mg L ⁻¹ of CaCO ₃)	12	44.06 $\pm$ 5.89	12	89.52 $\pm$ 40.15
Turbidity (NTU)	12	6.64 $\pm$ 2.35	12	14.06 $\pm$ 9.34
Chlorophyll a (μg L ⁻¹)	12	5.86 $\pm$ 3.90	12	18.47 $\pm$ 4.67

Table 3. Pearson's correlation coefficients (*r*) and associated *p*-values between CO₂ flux and meteorological, hydrological, and water-quality variables for *Thalangama* and *Huruluwewa* tanks.

Variable	TG		HW	
	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
DO	−0.356	$p < 0.001$	−0.030	0.793
Rainfall	0.656	0.014	0.595	0.041
Water Temperature	−0.331	0.002	−0.451	$p < 0.001$
RH	0.321	0.003	0.419	$p < 0.001$
Atmospheric Pressure	0.282	0.009	0.378	$p < 0.001$
Air Temperature	−0.276	0.011	−0.479	$p < 0.001$
Turbidity	0.345	0.248	0.462	0.130
TDS	−0.246	0.024	−0.768	$p < 0.001$
Chlorophyll a	0.339	0.256	−0.414	0.184
EC	−0.233	0.033	−0.755	$p < 0.001$
Water Level	0.437	0.135	0.778	0.002
Alkalinity	−0.532	0.061	−0.613	0.034
pH	−0.207	0.059	−0.716	$p < 0.001$
Salinity	−0.164	0.135	−0.760	$p < 0.001$
Total Phosphate	−0.383	0.196	0.27	0.395
Nitrate Nitrogen	−0.223	0.465	−0.069	0.832
Windspeed	−0.019	0.867	−0.33	0.003
Solar Radiation	−0.016	0.885	−0.312	0.006

HW had higher mean chlorophyll-a, salinity, and total alkalinity than TG. HW also had higher mean pH, electrical conductivity, total dissolved solids, and turbidity, whereas TG had a higher mean water temperature.

These contrasting patterns indicate that CO₂ flux in HW is associated with ionic concentration reflecting meteorologically driven evaporative concentration and rainfall-driven dilution. Whereas CO₂ flux in TG is more strongly linked to dissolved oxygen and rainfall, suggesting that metabolic balance moderated by rainfall dominates rather than ionic content as in HW.

3.3. Principal Component Analysis

For Huruluwewa Tank, an initial set of ten candidate environmental variables was evaluated for multicollinearity before PCA. Electrical conductivity (EC), salinity, and total dissolved solids (TDS) exhibited very high pairwise correlations ($r > 0.93$) and inflated variance inflation factors ($VIF > 15$), indicating severe multicollinearity. EC was retained as the primary indicator of ionic content, and salinity and TDS were excluded to avoid distortion of the component structure [29]. Following this reduction, iterative Kaiser–Meyer–Olkin (KMO) assessment was performed to ensure sampling adequacy. Variables with low measure of sampling adequacy ($MSA < 0.50$) were sequentially removed: atmospheric pressure ($MSA = 0.34$), dissolved oxygen ($MSA = 0.35$) and wind speed ($MSA = 0.35$). The final variable set ($n = 77$ hourly observations; $n/p = 7.7$) satisfied sampling adequacy criteria (overall KMO = 0.82; Bartlett’s test of sphericity: $\chi^2 = 315.6$, $df = 15$, $p < 0.001$). A single principal component with eigenvalue > 1 was retained, explaining 64.6% of the total variance. This component (PC1) represented a meteorological, thermal, and chemical coupling axis, characterized by strong positive loadings of air temperature (0.91), water temperature (0.79), pH (0.75), EC (0.76), and solar radiation (0.69), and a strong negative loading of relative humidity (−0.90). PC1 scores were significantly negatively correlated with CO₂ flux (Spearman $r = -0.57$, $p < 0.001$), indicating that CO₂ flux was lowest during warm, dry, high-radiation conditions that promote elevated ionic concentration and highest during cool, humid, low-radiation periods with low ionic concentration.

Similar to HW, EC, salinity, and TDS exhibited very high pairwise correlations ($|r| > 0.93$) and inflated variance inflation factors ($VIF > 15$), indicating severe multicollinearity in TG. EC was retained as the primary indicator of ionic content. According to the iterative Kaiser–Meyer–Olkin (KMO) assessment, relative humidity ($MSA = 0.50$) was removed from PCA analysis. The final variable set ($n = 84$ hourly observations; $n/p = 8.4$) satisfied sampling adequacy criteria (overall KMO = 0.65; Bartlett’s test of sphericity: $\chi^2 = 132.9$, $df = 28$, $p < 0.001$). Three principal components with eigenvalues > 1 were retained, collectively explaining 65.0% of the total variance. The first component (PC1; 22.3% of variance) represented a meteorological forcing axis, characterized by strong positive loadings of air temperature (0.83), wind speed (0.65), and solar radiation (0.65); however, PC1 was not significantly correlated with CO₂ flux (Spearman $r = -0.16$, $p = 0.145$). The second component (PC2; 22.2% of variance) represented an oxygenation carbonate chemistry axis, with strong positive loadings of pH (0.83) and dissolved oxygen (0.79). PC2 was significantly negatively correlated with CO₂ flux (Spearman $\rho = -0.40$, $p < 0.001$), indicating that CO₂ efflux was lowest during high pH, well-oxygenated conditions and highest during low pH, low DO. The third component (PC3; 20.5% of variance) was characterized by loadings from water temperature (0.62), EC (0.70), and atmospheric pressure (0.67), but was not significantly correlated with CO₂ flux ($\rho = 0.02$, $p = 0.884$). These results suggest that metabolic balance, rather than meteorological forcing or ionic content, is associated with temporal dynamics of CO₂ flux in TG.

3.4. Daytime Variation in Carbonate Speciation

Daytime carbonate speciation exhibited clear diurnal dynamics in both tanks, with the relative proportions of CO_2^* , HCO_3^- , and CO_3^{2-} shifting systematically as pH and temperature evolved through the daylight hours (Table 4; The complete seasonal dataset is available in Supplementary Tables S3 and S4). In Huruluwewa, October showed strong bicarbonate dominance throughout the day, with the CO_2^* fraction highest in the early morning and declining steadily as pH rose toward midday and afternoon. In contrast, December displayed comparatively higher CO_2^* fractions across the daytime period under cooler, lower-pH conditions. In Thalangama, October was marked by elevated CO_2^* fractions during the morning at low pH, decreasing progressively through the afternoon as pH increased, while December maintained intermediate CO_2^* levels across the daytime sequence. Across both tanks, the carbonate ion remained a minor component throughout daylight hours.

Table 4. Daytime carbonate speciation fractions ($\alpha_0 \text{CO}_2^*$, $\alpha_1 \text{HCO}_3^-$, $\alpha_2 \text{CO}_3^{2-}$, expressed as percentage of total dissolved inorganic carbon) for Huruluwewa and Thalangama tanks during October and December campaigns. Speciation was calculated from measured pH and water temperature using temperature-dependent first and second dissociation constants (pK_1 and pK_2) corrected to each hourly water temperature. Temp ($^\circ\text{C}$) = water temperature; DO = dissolved oxygen. Results for all other months are provided in the Supplementary Material (Tables S3 and S4).

Month	Hour	Temp ($^\circ\text{C}$)	pH	DO (mg/L)	$\alpha_0 \text{CO}_2^*$ (%)	$\alpha_1 \text{HCO}_3^-$ (%)	$\alpha_2 \text{CO}_3^{2-}$ (%)
<i>Huruluwewa Tank</i>							
October	9:00	29.97	7.41	3.66	7.62	92.26	0.12
	10:00	30.94	8.28	4.32	1.08	97.94	0.98
	11:00	32.08	8.75	4.16	0.36	96.74	2.91
	12:00	33.05	8.80	4.22	0.32	96.38	3.30
	13:00	33.55	8.93	4.59	0.23	95.33	4.44
	14:00	33.48	8.99	4.53	0.20	94.74	5.06
	15:00	32.49	9.01	4.35	0.19	94.60	5.21
	16:00	31.90	8.97	5.14	0.21	95.06	4.73
December	10:00	26.43	7.18	3.75	12.71	87.23	0.06
	11:00	26.14	7.79	4.73	3.45	96.26	0.28
	12:00	26.38	7.67	3.47	4.50	95.29	0.21
	13:00	26.60	7.73	3.73	3.93	95.82	0.25
	14:00	26.71	7.85	3.82	3.00	96.67	0.33
	15:00	26.35	7.85	4.47	3.01	96.66	0.33
	16:00	26.10	7.84	4.52	3.09	96.59	0.32
	17:00	25.92	7.82	3.96	3.24	96.46	0.30
<i>Thalangama Tank</i>							
October	10:00	31.17	6.58	2.46	35.56	64.43	0.01
	11:00	32.05	6.64	4.46	32.29	67.70	0.02
	12:00	31.91	6.89	4.90	21.16	78.81	0.03
	13:00	33.11	7.41	5.72	7.42	92.45	0.13
	14:00	33.52	7.59	5.98	5.01	94.79	0.20
	15:00	32.76	7.74	5.37	3.62	96.10	0.29
	16:00	31.89	7.62	5.81	4.75	95.04	0.21
December	10:00	28.14	7.13	2.38	13.81	86.13	0.06
	11:00	28.42	7.07	2.83	15.50	84.45	0.05
	12:00	28.90	7.25	3.52	10.76	89.16	0.08
	13:00	29.52	7.31	4.11	9.45	90.46	0.09
	14:00	29.25	7.38	4.71	8.17	91.72	0.11
	15:00	29.49	7.30	5.17	9.65	90.26	0.09

Table 4. Cont.

Month	Hour	Temp (°C)	pH	DO (mg/L)	α_0 CO ₂ * (%)	α_1 HCO ₃ [−] (%)	α_2 CO ₃ ^{2−} (%)
December	16:00	29.11	7.39	5.08	8.01	91.87	0.11
	17:00	28.92	7.39	5.58	8.03	91.86	0.11

4. Discussion

Several studies of tropical freshwater systems have shown that these ecosystems can function as either net CO₂ sources or sinks, consistent with the contrasting patterns observed in the present study [9,13,18,30]. Despite serving the same purpose (irrigation), HW and TG tanks exhibited markedly different temporal flux dynamics. Daytime flux quantification showed overall positive flux in TG, while HW showed flux reversal within a one-year observation period. TG exhibited CO₂ uptake during only 5.9% of hourly observations, whereas HW showed uptake in 51.8% of hourly observations. These differences reflect fundamentally distinct biogeochemical controls driven by contrasting hydroclimatic zones.

Seasonal CO₂ flux dynamics in HW appear to be primarily regulated by hydrological variability driven by meteorological forcing and water management, consistent with previously reported patterns in tropical freshwater systems. In deep tropical lakes, reversals in CO₂ flux from positive to negative values have been associated with rising water levels. For example, Lake Malawi exhibited a mean daily CO₂ flux of $-2050 \pm 270 \mu\text{mol m}^{-2} \text{d}^{-1}$ alongside observed flux reversals [9]. Whereas in shallow floodplain lakes, CO₂ uptake has been observed during low water periods [31]. HW more closely resembles the shallow lake pattern. During the SWM and SIM seasons, when CO₂ uptake was observed, water levels declined substantially due to irrigation drawdown and reduced rainfall (Figure 5). Under these low water conditions, longer hydraulic residence times combined with elevated evapotranspiration concentrated the water column, creating a moderate ionic gradient [32]. Phytoplankton communities in dry zone irrigation tanks in Sri Lanka are known to be diverse and quantitatively abundant, with phytoplankton species composition [33] and abundance are modulated by hydrological regime and water quality [34]. This ionic enrichment, together with altered solar radiation, air temperature, and water temperature, may have modulated the phytoplankton abundance and likely facilitated autotrophic CO₂ assimilation [35]. While tropical manmade aquatic systems are generally reported as net CO₂ sources when compared to natural systems [10,36], HW represents a case of a man-made tropical system that exhibits flux reversal, including periods of daytime CO₂ uptake.

The relatively low TOC: TIC ratios observed in HW in August (SWM) and October (SIM) months suggest that inorganic carbon represented a larger proportion of the measured total carbon pool than in the December (NEM) and March (FIM) months, which receive comparatively higher rainfall. This seasonal difference coincided with lower daytime CO₂ fluxes, including periods of net CO₂ uptake, and with changes in hydrological conditions. This pattern is consistent with the possibility that inorganic carbon processes contributed to the observed flux variation depending on system chemistry, as reported by other studies [37,38]. In contrast, many subtropical systems have CO₂ flux closely coupled to biological variables such as chlorophyll-a and dissolved oxygen [39]. The available productivity indicators did not show comparable support as independent explanatory variables. But, together with the positive association of rainfall and water level, the ionic gradient implies that physicochemical and hydrometeorological conditions were associated with seasonal CO₂ flux variation in HW.

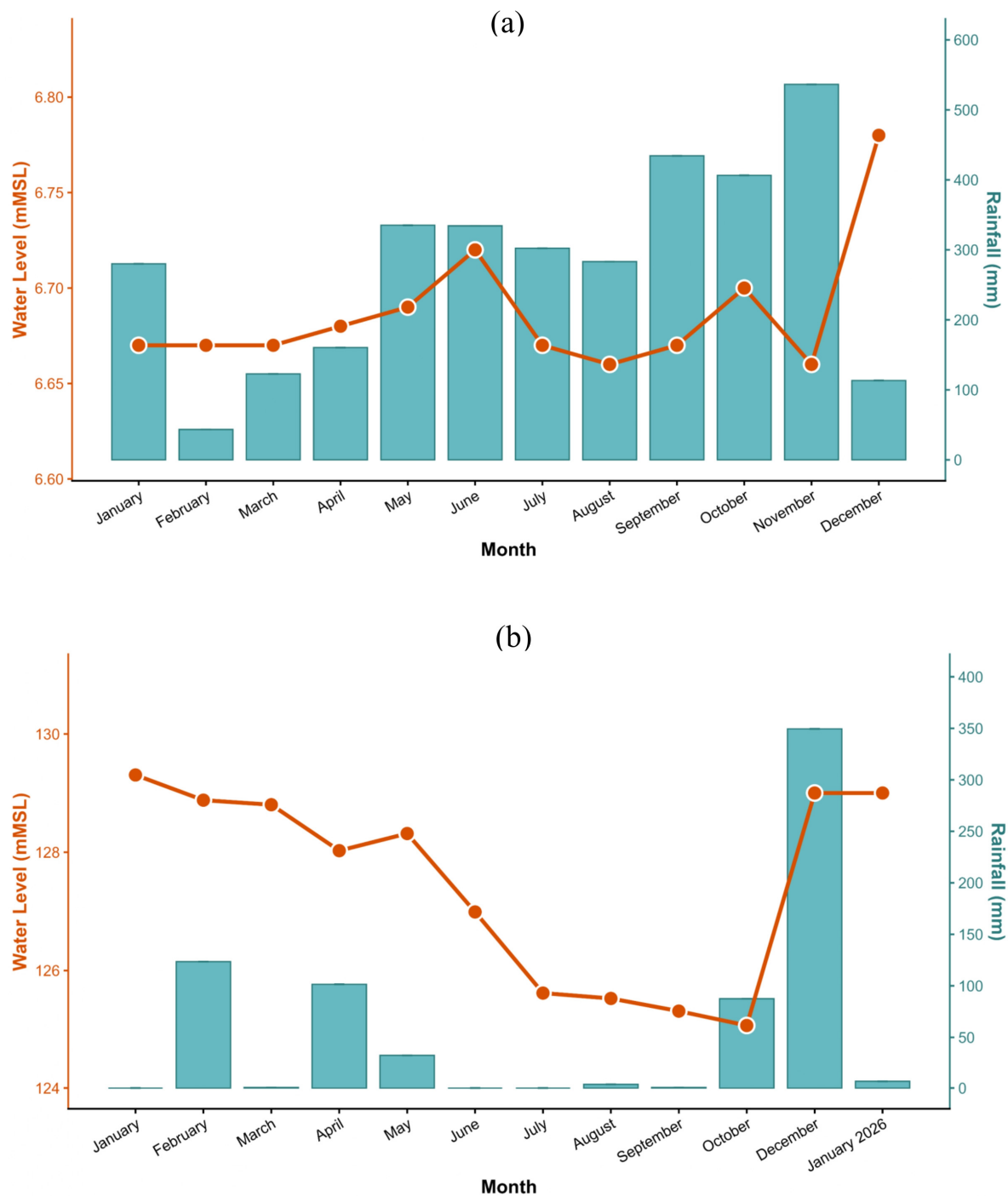


Figure 5. Monthly water level and rainfall dynamics at *Thalangama* tank (a) and *Huruluwewa* Tank (b) during the study period from January 2025 to January 2026. The orange line (left axis) shows mean monthly water level (m above Mean Sea Level, mMSL), and teal bars (right axis) represent total monthly rainfall (mm).

The positive CO_2 flux observed in TG is consistent with the tendency of many tropical freshwater systems to be supersaturated with CO_2 [11]. However, flux magnitude increased during the SWM and SIM seasons relative to the NEM and FIM, suggesting that seasonal hydrology and watershed inputs still modulate the strength of emission even when the system does not switch to net uptake. The higher TOC: TIC ratio observed during SIM indicates a relatively larger organic carbon pool available to support microbial respiration, and external organic matter inputs likely stimulated CO_2 production through heterotrophic

decomposition, as reported in other freshwater systems [40]. The positive relationship between rainfall and CO₂ flux further suggests that catchment runoff may enhance the delivery of labile organic matter and nutrients to the water column, increasing respiratory CO₂ generation [41]. The negative association with DO is also consistent with tight coupling between photosynthesis, respiration, and gas exchange in productive tropical waters, where higher DO often coincides with stronger daytime CO₂ assimilation [42]. Taken together, although TG showed no significant seasonal variation in CO₂ flux, hydrological forcing appeared to modulate flux magnitude through its influence on the metabolic balance.

Daytime CO₂ flux variability at HW can be explained by changes in hourly physico-chemical conditions. PCA identified an ionic gradient coupled with strong hydrometeorological forcing associated with the CO₂ flux dynamics. During the October campaign, carbonate species fractions calculated from hourly pH and water temperature showed pronounced daytime redistribution of the inorganic carbon species. The calculated CO₂* fraction declined from 7.62% at 09:00 h to 0.19–0.36% between 11:00 and 15:00 h, while the calculated bicarbonate fraction increased from 92.26% to 94.60–97.94% (Table 4). This pattern coincided with increasing pH and generally higher dissolved oxygen during the daytime observation period [43]. The strongest hourly uptake was noted at the end of the day at 16:00 h with the highest recorded DO. This observation may be due to the lag effect in CO₂ equilibrium in high-alkalinity systems and weakening of the metabolic linkage between CO₂ and O₂ [44]. These co-occurring patterns are consistent with diel biological activity influencing pH and relative carbonate-species distribution; however, the calculations represent fractions only and do not quantify absolute dissolved CO₂, atmospheric equilibrium, or an air-water concentration gradient. Therefore, the relative contributions of biological activity, hydrodynamic gas transfer, and inorganic carbon processes to the observed flux pattern cannot be separated using the present data.

During the December campaign, daytime CO₂ fluxes at HW were predominantly positive (Figure 6). Fluxes were lower between 12:00 and 14:00 h, coinciding with higher solar radiation and an increase in pH from 7.67 to 7.85. Over the same interval, the calculated relative CO₂* fraction declined from 4.50% at 12:00 h to 3.00% at 14:00 h, while the calculated bicarbonate fraction remained dominant (95.29–96.67%). The highest observed positive flux occurred at 16:00 h, when solar radiation had declined. These co-occurring diel patterns are consistent with short-term variation in biological activity, pH, and relative inorganic carbon speciation. This photosynthesis-driven diurnal flux pattern has been observed in many lotic ecosystems [39,45,46].

TG 15. h, coinciding with the highest recorded pH of the day (7.74) and the lowest calculated relative CO₂* fraction (3.62%). Across the daytime observation period, the calculated CO₂* fraction decreased from 35.56% at 10:00 h to 3.62% at 15:00 h, while the calculated bicarbonate fraction increased from 64.43% to 96.10%. Flux returned to a positive value during the subsequent hourly observation, when solar radiation declined. These co-occurring changes are consistent with short-term diel variation in pH, irradiance, biological activity, and the relative distribution of inorganic carbon species as a result of metabolic balance.

Monitoring and estimation of CO₂ flux remain challenging in aquatic ecosystems due to high spatiotemporal variability and data limitations [47]. The contrasting temporal patterns between the two tanks also highlight the potential limitations of estimating freshwater daytime CO₂ fluxes using broad water body categories alone. Differences in hydrological setting, water chemistry, and meteorological conditions may contribute to significant variation in temporal dynamics even among freshwater systems with comparable management purposes.

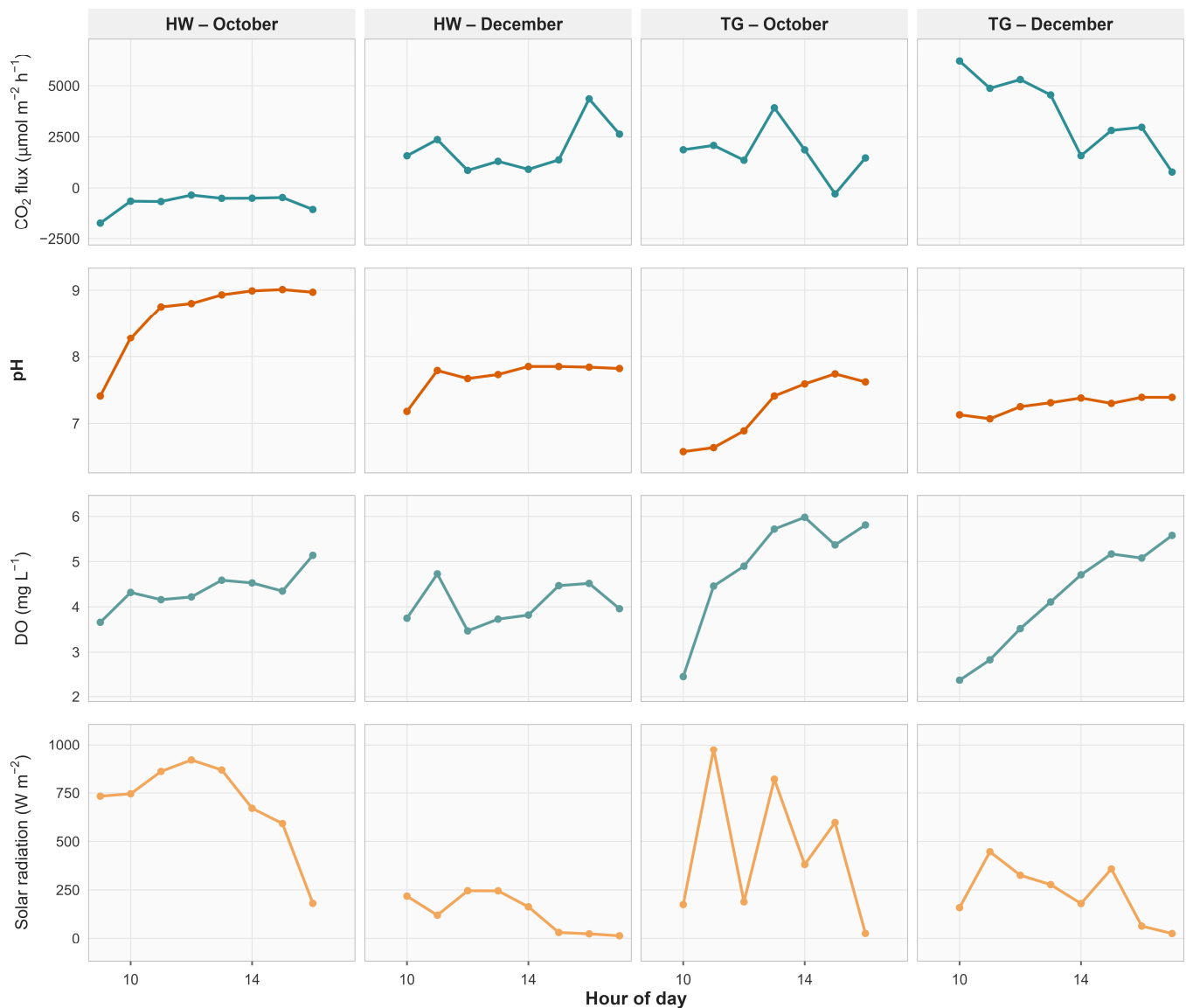


Figure 6. Diurnal dynamics of CO₂ flux, pH, dissolved oxygen (DO), and solar radiation in HW and TG during October and December monitoring campaigns. Each row shows one variable plotted against hour of day, with an identical *y*-axis scale applied across all four campaigns to enable direct visual comparison. Columns represent HW-October, HW-December, TG-October, and TG-December, respectively, with hour of day shared on the *x*-axis.

5. Conclusions

The two tropical irrigation tanks exhibited contrasting seasonal dynamics in daytime CO₂ Flux despite their broadly similar function as human-managed freshwater systems. HW showed significant seasonal variation in daytime CO₂ flux, including observations of both CO₂ uptake and emission, whereas TG showed predominantly positive daytime fluxes across the sampled campaigns and did not show statistically supported seasonal variation. These contrasting patterns indicate that CO₂ exchange in tropical irrigation tanks can vary among individual systems.

At HW, changes in daytime CO₂ flux occurred alongside shifts in ionic gradient moderated by meteorological and hydrological conditions. At TG, daytime flux remained predominantly positive despite comparable short-term variation in environmental conditions. Interestingly, Flux variation in TG was associated with rainfall and indicators of metabolic balance.

These conclusions are limited to daytime observations from one chamber location in each of two tanks and therefore cannot represent spatial flux variability, nighttime exchange and annual CO₂ budgets. Future studies should include continuous day and night monitoring with more spatial coverage for better upscaling.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/limnolrev26040063/s1>, Tables S1 and S2 provide hourly daytime CO₂ flux measurements for HW and TG tanks; Tables S3 and S4 present measured pH, water temperature and dissolved oxygen alongside calculated hourly carbonate-speciation fractions; and Table S5 reports campaign-level chlorophyll-a-based Carlson trophic state indices and classifications for both tanks.

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Abbreviations

The following abbreviations are used in this manuscript:

HW	Huruluwewa Tank
TG	Thalangama Tank
NEM	North East Monsoon
SIM	Second Inter Monsoon
SWM	Southwest Monsoon
FIM	First Inter Monsoon

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