

Contrasting Catchment Characteristics and Carbonate Buffering Capacity Shape Acidification Susceptibility and CO₂ Source-Sink Dynamics in Tropical Lagoons

Veran Weerathunga^{1,2}, Chin-Chang Hung^{2,3}, W. Sanjaya Weerakkody⁴, Fei-Ling Yuan², Kai-Jung Kao², Wen-Chen Chou^{5,6}, Hsueh-Han Hsieh², Kamal Ranatunga⁷, P. Nalaka Ranasinghe^{4,8}, Wathsala K. Suwandhahannadi⁹, Wei-Jen Huang^{2,10}

¹Institute of Earth Sciences, Academia Sinica, Nangang, Taipei, Taiwan

²Department of Oceanography, National Sun Yat-sen University, Kaohsiung, Taiwan

³Taiwan Research Center for Environmental Changes, Academia Sinica, Taipei, Taiwan

⁴Faculty of Fisheries and Marine Sciences & Technology, University of Ruhuna, Matara, Sri Lanka

⁵Institute of Marine Environment and Ecology, National Taiwan Ocean University, Keelung, Taiwan

⁶Center of Excellence for the Oceans, National Taiwan Ocean University, Keelung, Taiwan

⁷Centre for Marine Science and Technology, Department of Zoology, University of Sri Jayewardenepura, Nugegoda, Sri Lanka

⁸School of Chemistry, Environmental, and Geosciences, Lake Superior State University, Sault Ste Marie, MI, USA

⁹National Aquatic Resources Research and Development Agency, Crow Island, Colombo 15, Sri Lanka

¹⁰Marine Science Oriented Ocean Technology Implementation Center, National Sun Yat-sen University, Kaohsiung, Taiwan

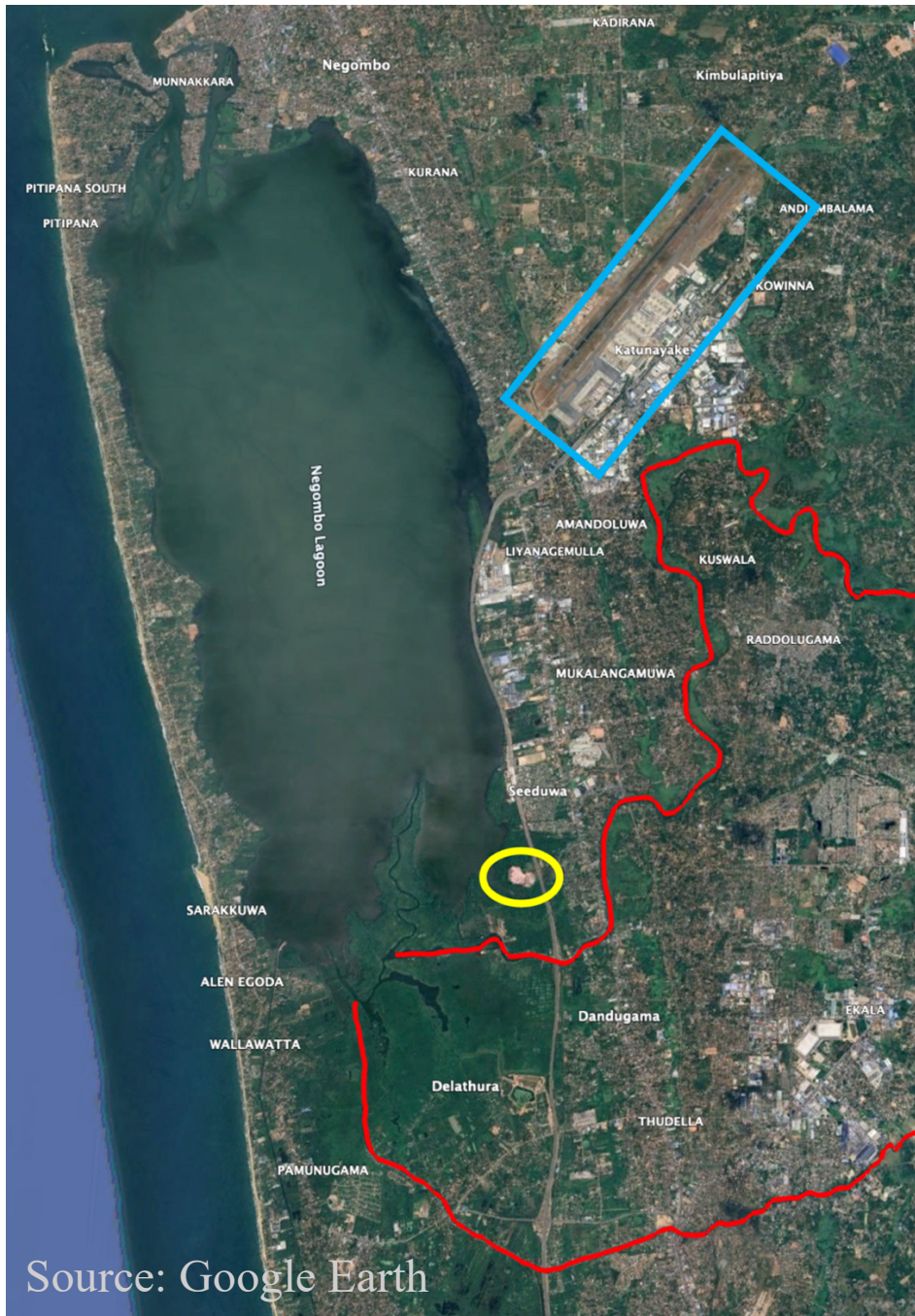


Figure S1. Surrounding land use of Negombo Lagoon. Settlements occupy the largest fraction of the lagoon’s surroundings. Main rivers flowing into the lagoon are shown in red, the large garbage dumping site is marked with a yellow circle, and the international airport is highlighted with a blue rectangle (Map data © 2025 Google).



Figure S2. Surrounding land use of Rekawa Lagoon. Settlements occupy a smaller fraction of the lagoon's surroundings. The main river flowing into the lagoon is shown in red (Map data © 2025 Google).

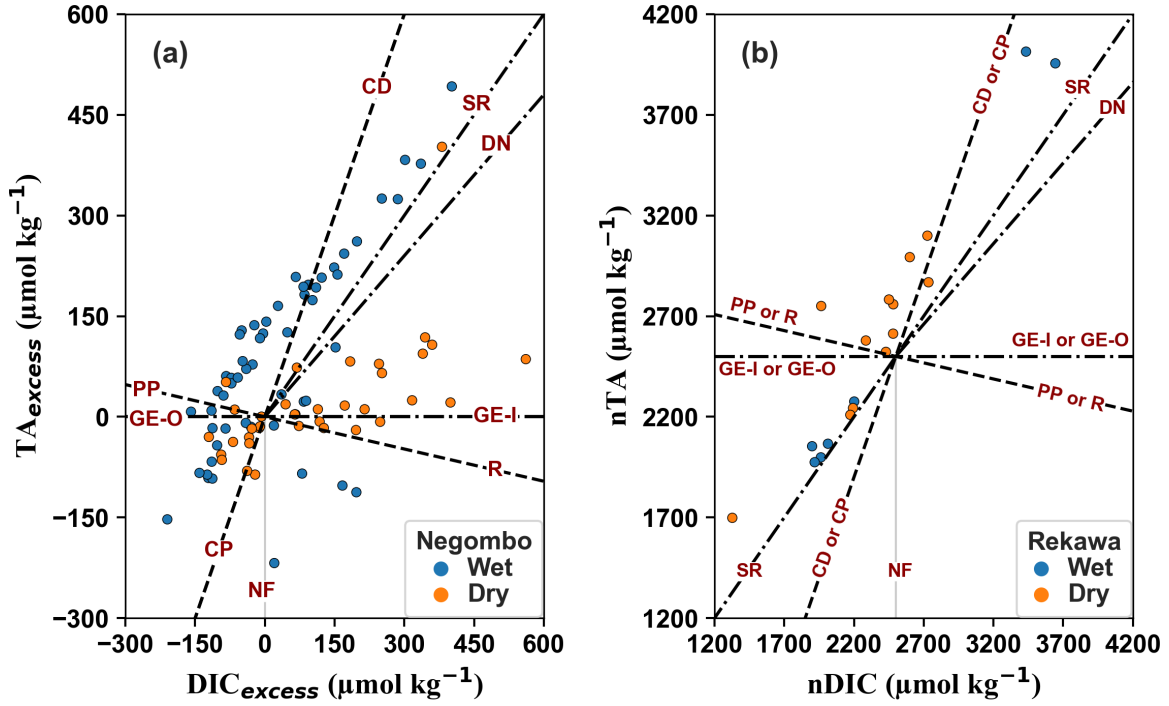


Figure S3. Biogeochemical influence on carbonate system dynamics. (a) Relationships between TA_{excess} and DIC_{excess} during the wet and dry seasons in Negombo Lagoon. (b) Relationships between normalized TA (nTA) and normalized DIC (nDIC) during the wet and dry seasons in Rekawa Lagoon. Lines indicate reference slopes for biogeochemical processes (GE-O: CO₂ outgassing, GE-I: CO₂ uptake, PP: primary production, R: respiration, CD: carbonate dissolution, CP: carbonate precipitation, SR: sulfate reduction, DN: denitrification, NF: nitrification).

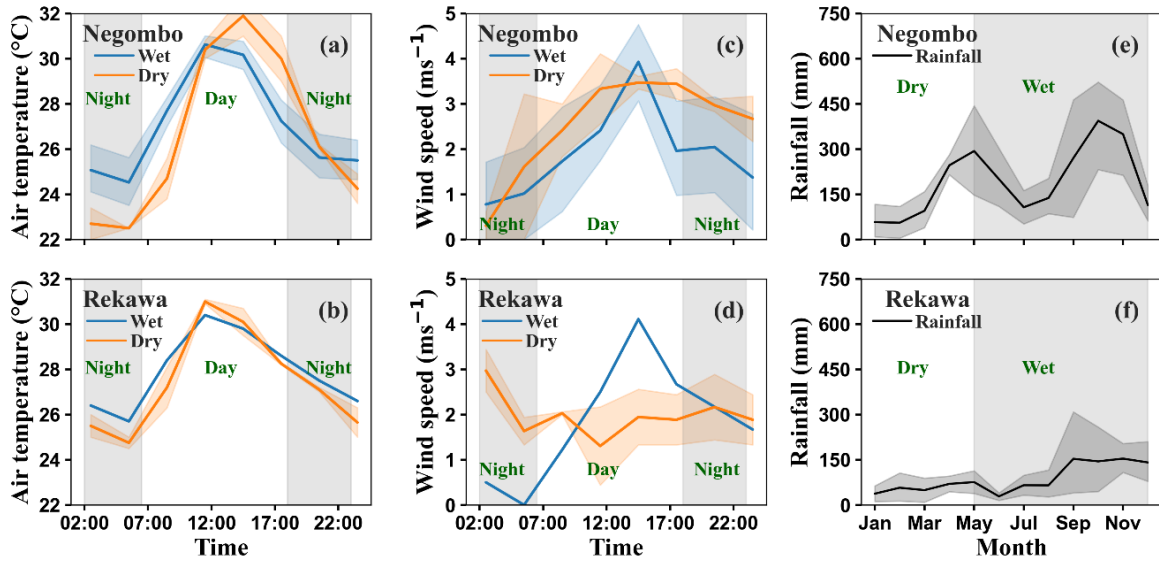


Figure S4. Temporal variations of key environmental parameters in Negombo and Rekawa Lagoons. (a) and (b) diurnal air temperature variations, (c) and (d) diurnal wind speed variations, and (e) and (f) monthly rainfall patterns. Blue and orange lines represent the wet and dry season trends, respectively. Shaded areas denote standard deviation around the mean diurnal air temperature and wind speed observed during sampling campaigns. Rainfall values represent monthly means with standard deviations (shaded area) calculated from data collected between August 2018 and July 2023.

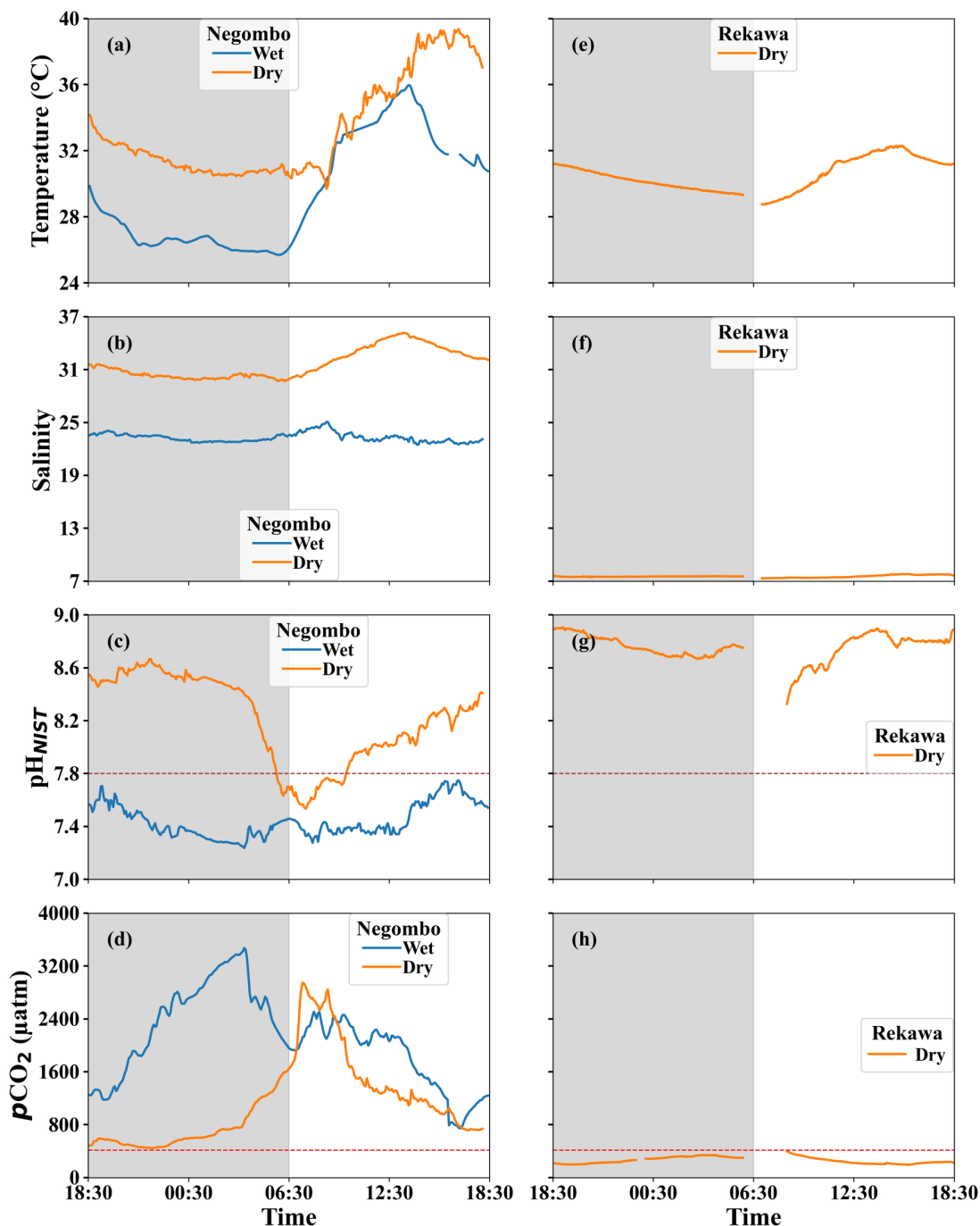


Figure S5. Diurnal variations of hydrological parameters, pH, and $p\text{CO}_2$ in two lagoons. Shaded areas refer to the nighttime (18:30 to 6:30) and the non-shaded regions refer to daytime (6:30 am to 18:30). Brown and red dashed lines show the predicted open ocean pH at the end of the 21st century (pH = 7.8; IPCC, 2014) and the average atmospheric $p\text{CO}_2$ in 2023 (415.5 μatm), respectively.

Table S1. Comparison of characteristics of Negombo and Rekawa lagoons.

Charateristic	Negombo	Rekawa	References
Depth (m)	~1	~0.5	Rydberg and Wickbom, 1996
Area (km ²)	31.5	2.3	Rajapaksha and Jayasiri, 2000
Residence time (days)	2 -14	30	Thushara and Wijeratne, 2007; Rajapaksha and Jayasiri, 2000; Rydberg and Wickbom, 1996
^W Freshwater discharge (m ³ s ⁻¹)	88	4.76	Rajapaksha and Jayasiri, 2000; Silva et
^D Freshwater discharge (m ³ s ⁻¹)	47	4.76	al., 2013
^W Ocean exchange (m ³ s ⁻¹)	35	-	Rajapaksha and Jayasiri, 2000
^D Ocean exchange (m ³ s ⁻¹)	37		Rajapaksha and Jayasiri, 2000
^W Monthly Rainfall (mm)	222	89	This study, data obtained from Department of Meteorology, Sri Lanka
^D Monthly Rainfall (mm)	114	71	
Population density (Count per km ²)	3146	230	Joseph, 2011; Wijesooriya et al., 2005
Land use: agriculture (%)	9.7		^a CCD, 2005; Joseph, 2011
Land use: settlements (%)	35.6		^a CCD, 2005; Joseph, 2011
Hotel & resuarants (Count per km)	3.2	1.5	^b Googlpe Maps
Count of fisherman	3310	162	^c DFAR, 2012; Atapattu and Nissanka, 2005
Count of fishing boats	1172	60	^c DFAR, 2012;; Suwandhahannadi et al., 2024

(^WWet season, ^DDry season, ^aCCD: coastal conervation department of Sri Lanka, ^bCalculated by manually counting establishments visible on Google Maps within 100 m of the lagoon coastline, ^cDepartment of Fisheries and Aquatic Resources)

Table S2. Durations of sampling visits for two lagoons.

Lagoon	Sampling dates	Season
Negombo	26 th to 28 th February 2019	Dry
	13 th to 17 th October 2019	Wet
	5 th to 7 th February 2020	Dry
	21 st to 22 nd August 2022	Wet
	14 th to 15 th February 2023	Dry
Rekawa	17 th August 2022	Wet
	21 st to 22 nd February 2023	Dry

Table S3. Average temperature, salinity, TA ($\mu\text{mol kg}^{-1}$), DIC ($\mu\text{mol kg}^{-1}$), TA/DIC ratio, pH_{NIST} , and calculated $p\text{CO}_2$ (μatm) in river and ocean end members during dry and wet seasons in Negombo lagoon. Calculated $p\text{CO}_2$ values represent the average of $\text{CO}_2\text{SYS v3.0_Err}$ computations using the following parameter pairs: 1) TA and DIC, 2) TA and pH, and 3) DIC and pH. Calculations employed dissociation constants from Cai and Wang (1998), the hydrogen sulfate ion dissociation constant from Dickson (1990), and total boron concentration from Lee et al. (2010).

Lagoon	Site	Season	Temp ($^{\circ}\text{C}$)	Salinity	TA	DIC	TA/DIC	pH_{NIST}	Calc. $p\text{CO}_2$
Negombo	River	Dry	30.9 ± 0.4	0.5 ± 0.4	580 ± 31.8	782.9 ± 13.9	0.74 ± 0.04	6.82 ± 0.1	6276 ± 1133
	River	Wet	29.2 ± 0.2	0	448.7 ± 51	645.9 ± 21.3	0.7 ± 0.09	6.49 ± 0.03	8777 ± 338
Rekawa	River	Dry	30.7	1.2	2647.9	2619.2	1.01	7.79	1948
	River	Wet	32.2	1	2722.9	2695.6	1.01	7.72	2383
Negombo	Ocean	Dry	28.3 ± 0.2	33.5 ± 0.1	2217.7 ± 5.4	2015.3 ± 25.1	1.08 ± 0.01	8.2 ± 0.01	639 ± 43
	Ocean	Wet	29.5 ± 0.4	32.3 ± 0.7	2047.3 ± 28.1	1895.1 ± 126.5	1.1 ± 0.08	8.27 ± 0.01	337 ± 15

Table S4. Averages of hydrological and carbonate system parameters in two lagoons ($\pm$ standard error). The t -statistic and p -value are from two-sample t -tests comparing the wet and dry seasons.

Lagoon	Parameter	Dry season	Wet season	t -statistic	p -value
Negombo	Temp	30.4 ± 0.3 (n = 39)	30.5 ± 0.2 (n = 56)	0.18	0.859
	Salinity	23.8 ± 1 (n = 39)	9.2 ± 1.3 (n = 56)	-9.02	< 0.001
	TA ($\mu\text{mol kg}^{-1}$)	1755.1 ± 52.2 (n = 39)	973.1 ± 60.8 (n = 56)	-9.75	< 0.001
	DIC ($\mu\text{mol kg}^{-1}$)	1733.2 ± 56.8 (n = 38)	1016.2 ± 52.8 (n = 56)	-9.76	< 0.001
	pH _{NIST}	7.83 ± 0.07 (n = 39)	7.38 ± 0.07 (n = 56)	-4.69	< 0.001
Rekawa	Temp	29 ± 0.2 (n = 12)	31 ± 0.4 (n = 7)	2.8	0.006
	Salinity	5.4 ± 0.1 (n = 12)	13.7 ± 1.7 (n = 7)	4.56	0.004
	TA ($\mu\text{mol kg}^{-1}$)	2407.8 ± 16 (n = 12)	2362.9 ± 86.1 (n = 7)	-1.72	0.112
	DIC ($\mu\text{mol kg}^{-1}$)	2072 ± 27.1 (n = 12)	2233.3 ± 113.3 (n = 7)	-0.38	0.709
	pH _{NIST}	8.72 ± 0.03 (n = 12)	8.03 ± 0.13 (n = 7)	-2.47	0.026

Table S5. Results of regression analyses and two end-member mixing models during dry and wet seasons.

	In-situ data				Mixing model	
	Slope	Intercept	R ²	<i>p</i> -value	Slope	Intercept
TA vs Salinity						
Negombo-Dry	49.8	564.3	0.96	< 0.001	49.6	555.2
Negombo-Wet	45.1	546.2	0.88	< 0.001	49.5	448.7
Rekawa-Dry	35.2	2342.7	0.03	0.573	--	--
Rekawa-Wet	34.7	1940.5	0.36	0.118	--	--
DIC vs Salinity						
Negombo-Dry	39.0	800.3	0.81	< 0.001	37.3	764.2
Negombo-Wet	37.3	670.4	0.86	< 0.001	38.7	645.9
Rekawa-Dry	135.5	1499.5	0.15	0.184	--	--
Rekawa-Wet	50.1	1614.7	0.44	0.074	--	--
TA/DIC vs Salinity						
Negombo-Dry	0.01	0.8	0.52	< 0.001	--	--
Negombo-Wet	0.01	0.81	0.45	< 0.001	--	--
Rekawa-Dry	-0.05	1.41	0.14	0.23	--	--
Rekawa-Wet	-0.01	1.14	0.65	0.052	--	--

Table S6. Comparison of air-water CO₂ fluxes (mmol m⁻² d⁻¹) in regional lagoons and estuaries across South Asia, Southeast Asia, and East Africa. When multiple studies reported CO₂ fluxes for a particular lagoon, the average flux across all studies is presented.

Lagoon/Estuary	Country	CO ₂ flux	Reference
Saptamukhi	India	39.4	Borges et al. 2003; Acharya et al. 2022
Thakuran	India	34.8	Acharya et al. 2022
Matla	India	48.8	Acharya et al. 2022; Akhand et al. 2022
Hooghly	India	56.7	Mukhopadhyay et al. 2002; Akhand et al. 2022
Devi	India	109.9	Akhtar et al. 2021
Godavari	India	79.4	Bouillon et al. 2003; Sarma et al. 2011; Sarma et al. 2012
Kalighat	India	60.1	Linto et al. 2014
Wright Myo	India	74.2	Linto et al. 2014
Mahanadi	India	1.0	Sarma et al. 2012; Pattanaik et al. 2020a; Pattanaik et al. 2020b
Gaderu	India	56.0	Borges et al. 2003
Mooringanga	India	23.2	Borges et al. 2003
Cochin	India	267.0	Gupta et al. 2009
Chilika	India	85.5	Muduli et al. 2012
Mandovi-Zuari	India	39.0	Sarma et al. 2001
Dhamra	India	-0.7	Pattanaik et al. 2020b; Swain et al. 2023
Mekong	Vietnam	121.0	Borges et al. 2018
Kiên Vãng	Vietnam	93.5	Kone and Borges 2008
Lupar	Malaysia	171.8	Müller et al. 2016
Saribas	Malaysia	145.2	Müller et al. 2016
Ras Dege	Tanzania	18.2	Bouillon et al. 2007b; Kristensen et al. 2008
Mtoni	Tanzania	4.9	Kristensen et al. 2008
Tana	Kenya	116.0	Bouillon et al. 2007c
Kinondo	Kenya	32.0	Bouillon et al. 2007a
Betsiboka	Madagascar	9.1	Ralison et al. 2008
Negombo	Sri Lanka	9.1	This Study
Rekawa	Sri Lanka	-1.8	This Study

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