Supplementary Files

Review

Carbon Biogeochemistry of the Estuaries Adjoining the Indian Sundarbans Mangrove Ecosystem: A Review

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This Supplementary file contains five tables (Tables S1 to S5)

Table S1. The list of studies on air-water CO_2 and CH_4 fluxes, along with other related carbon-biogeochemistry parameters carried out in the Indian Sundarbans estuaries.

Sl No.	Study Area	Time/Season of Sampling	Emphasis of the study	Reference
1	Sundarbans estuary (Saptamukhi, Thakuran, and Matla estuary)	April 2016 to January 2020	Air-water CO_2 and CH_4 fluxes	1
2	Hooghly and Matla estuary	August 2018, January 2019	Coupled Rn-222 and pCO_2 surveys	2
3	Dhanchi Island and Dimond Harbor	27 January to 06 February 2018	High temporal resolution direct measurement of $pCO_{2(water)}$	3
4	Matla estuary	May 2017, August 2017, December 2017, and March 2018	Seasonal $pCO_{2(water)}$ and air-water CO_2 fluxes	4
5	Hooghly-Sundarbans estuary	March to May 2016	Pre-monsoon C biogeochemistry emphasizing on $pCO_{2(water)}$ and CH_4 dynamics	5
6	Hooghly estuary	June 2015 to May 2016	Lateral flux of TAlk and DIC	6
7	Sadhupur, Pakhiralay, Dayapur, (Sundarban)	Winter, summer, pre-monsoon, monsoon (year not mentioned)	Seasonal fluctuation in greenhouse gas fluxes	7
8	Sundarbans estuary (Saptamukhi, Thakuran, and Matla estuary)	March 2017	Diurnal variability and role of tides in governing C biogeochemistry	8
9	Hooghly-Sundarbans estuary	November 2017	Post-monsoon C biogeochemistry	9
10	Hooghly-Sundarbans estuary	May and December 2014	Lateral flux of DIC, DOC, and POC	10
11	Lothian Island and adjacent Saptamukhi estuary	2010-2012	Mangrove methane biogeochemistry	11
12	Hooghly and Matla estuary	August 2013 to July 2014	Comparison of $pCO_{2(water)}$ and air-water CO_2 fluxes between river-dominated and mangrove-dominated marine estuary	12
13	Hooghly estuary and its adjacent coastal oceans	Winter and Summer of 2008 (January, February, May, September, November)	Estimation of $pCO_{2(water)}$ and air-water CO_2 fluxes using remote sensing techniques	13
14	Lothian Island and the adjacent Saptamukhi estuary	2011-2012	Exogenous CH_4 dynamics	14
15	Saptamukhi estuary	June (2010) to December (2011)	Photo-oxidation of CH_4	15
16	Hooghly estuary, Lothian Island, Saptamukhi estuary	Pre-monsoon, 2014	Biogeochemistry of organic matter	16

17	Indian Sundarbans [Edwards Creek, Thakuran River, and Herobhanga River]	April and May 2011	Spatial variability of $pCO_{2(water)}$ and air-water CO_2 fluxes in the pre-monsoon season	17
18	Saptamukhi estuary	June 2010 to December 2011	CH_4 flux from porewater	18
19	Jharkhali mangroves and Hooghly estuary	December (2006)	Air-water CH_4 flux	19
20	Muriganga, Saptamukhi, and Thakuran rivers, Lothian Island, and Hooghly estuary (Diamond Harbour, Kachuberia, Beguakhali)	2003	Air-water CH_4 flux	20
21	Hooghly estuary	Every 2 weeks between 1999 and 2001	Lateral fluxes of DIC and nutrients	21
22	Mooriganga, Saptamukhi, and Thakuran estuaries	January–December 2001	Biogenic controls on the air-water CO_2 flux	22
23	Hooghly Estuary	January–December 1999	Seasonal effects on Air-water CO_2 exchange	23
24	Mooriganga and Saptamukhi estuaries	August (1986)	Comparative analysis of CO_2 system in virgin and reclaimed mangrove waters	24

Table S2. List of observations on TAlk and DIC from several studies on the Indian Sundarbans estuaries. The results are displayed either as mean ± standard deviation from the mean or as the range (minimum to maximum). NA denotes not available.

Sampling Site/ Estuary	Time/ Season of Sampling (Year)	TAlk (μmol kg^{-1})	DIC (μmol kg^{-1})	Reference
Saptamukhi estuary	April 2016 to January 2020	1825 to 2506	1678 to 2203	1
Thakuran estuary	April 2016 to January 2020	1711 to 2543	1641 to 2205	1
Matla estuary	April 2016 to January 2020	1658 to 2380	1700 to 2108	1
Hooghly estuary (surface water)	August 2018, January 2019	1720 to 2996 (2256±489)	1671 to 3030 (2212±495)	2
Hooghly estuary (groundwater)	August 2018, January 2019	6136 to 18,178 (9087±5119)	5671 to 16400 (8333±4547)	2
Matla estuary (surface water)	August 2018, January 2019	1735 to 2438 (2015±213)	1938 to 2158 (1983±59)	2
Matla estuary (groundwater)	August 2018, January 2019	8099 to 9570 (8754±748)	7664 to 9224 (8272±578)	2
Dhanchi Island and Dimond Harbor	27th January to 6th February (2018)	2100 to 2750	1900 to 2700	4
Matla estuary	Pre-monsoon (2018)	2243 to 2353	1995 to 2084	3

Matla estuary	Post-monsoon (2017)	1757 to 1842	1730 to 1848	3
Matla estuary	Monsoon (2017)	1810 to 1915	1707 to 1783	3
Sundarbans estuary (Saptamukhi, Thakuran, and Matla estuary)	March (2017)	2190 to 2580	1920 to 2190	8
Hooghly estuary (surface water)	November (2017)	1797 to 2862	1678 to 2700 (2083±320)	9
Hooghly estuary (groundwater)	November (2017)		5655 to 11756	9
Sundarbans estuary (surface water)	November (2017)	2009 to 2289	1683 to 1920 (1756±73)	9
Sundarbans estuary (groundwater)	November (2017)	NA	7524 to 13599	9
Sundarbans estuary	March to May (2016)	2350 to 2580	1690 to 1890 (1770±60)	5
Hooghly estuary	March to May (2016)	2480 to 3110	1970 to 2680 (2270±220)	5
Hooghly estuary (Upper to lower estuary)	Monsoon (2015)	2162 to 1499	1463 to 2167	6
Hooghly estuary (Upper to lower estuary)	Pre-monsoon (2016)	3676 to 2494	2460 to 3608	6
Hooghly estuary (coastal area)	Annual (2015-16)	1925 to 2455	1754 to 2167	6
Lothian Island (mangrove)	Pre-monsoon (2014)	NA	2220±40	10
Hooghly estuary (upper estuary)	Pre-monsoon (2014)	NA	2880±70	10
Hooghly estuary (mid-estuary)	Pre-monsoon (2014)	NA	2700±20	10
Hooghly estuary (lower estuary)	Pre-monsoon (2014)	NA	2400±30	10
Lothian Island (mangrove)	Post-monsoon (2014)	NA	2130±100	10
Hooghly estuary (upper estuary)	Post-monsoon (2014)	NA	2790±100	10
Hooghly estuary (mid-estuary)	Post-monsoon (2014)	NA	2570±20	10
Hooghly estuary (lower estuary)	Post-monsoon (2014)	NA	2210±40	10
Hooghly estuary	Pre-monsoon (2014)	2790 to 2970	2400 to 2880	16
Saptamukhi estuary	Pre-monsoon (2014)	2700 to 2760	2170 to 2260	16
Hooghly estuary	August to July (2013-14)	1615 to 5390	1559 to 5426	12
Hooghly estuary and its adjacent coastal oceans	Winter (January, February, November) (2008)	NA	1310±107 1711±19 1130±29	13
Hooghly estuary and its adjacent coastal oceans	Summer (May and September) (2008)	NA	990±27 1697±77	13

Jharkhali mangroves	December (2006)	1820 to 2270 (2150±80)	1910 to 2170 (2070±60)	19
Hooghly estuary	December (2006)	2710 to 3210 (2910±180)	2620 to 2930 (2770±110)	19
Mooriganga, Saptamukhi, and Thakuran estuaries	Monsoon (2001)	1990±320	NA	22
Mooriganga, Saptamukhi, and Thakuran estuaries	Post-monsoon (2001)	1800±210	NA	22
Mooriganga, Saptamukhi, and Thakuran estuaries	Pre-monsoon (2001)	2700±350	NA	22
Hooghly estuary	Monsoon (1999)	1670±330	NA	23
Hooghly estuary	Post-monsoon (1999)	2200±430	NA	23
Hooghly estuary	Pre-monsoon (1999)	2590±270	NA	23

Table S3. List of observations on DOC and POC from several studies on the Indian Sundarbans estuaries. The results are displayed either as mean ± standard deviation from the mean or as the range (minimum to maximum). Single magnitudes, in some instances, represent the mean (without any reported standard deviation).

Sampling Site/ Estuary	Time/ Season of Sampling (Year)	DOC (μmol l^{-1})	POC (μmol l^{-1})	Reference
Hooghly estuary (surface water)	Monsoon (2018)	95.3 to 248.2 (182.1±47.1)	NA	2
Hooghly estuary (surface water)	Post-monsoon (2019)	10.6 to 33.6 (22.8±7.9)	NA	2
Hooghly estuary (groundwater)	Monsoon (2018)	51.9 to 83.4 (69.9±16.2)	NA	2
Hooghly estuary (groundwater)	Post-monsoon (2019)	20.3 to 60.8 (40.5±28.6)	NA	2
Matla estuary (surface water)	Post-monsoon (2019)	95.1 to 178.1 (145.0±30.7)	NA	2
Matla estuary (groundwater)	Monsoon (2018)	124.4 to 190.6 (149.7±35.7)	NA	2
Matla estuary (groundwater)	Post-monsoon (2019)	113.9 to 131.7 (125.6±10.1)	NA	2
Matla estuary	Pre-monsoon (2018)	82.7 to 121.9	40.7 to 90.6	3
Matla estuary	Post-monsoon (2017)	105.7 to 170.1	24.2 to 83.9	3
Matla estuary	Monsoon (2017)	91.8 to 141.9	43.0 to 87.3	3
Matla estuary	Pre-monsoon (2017)	85.36 to 166.17	36.7 to 211.1	3
Sundarbans estuary (Saptamukhi, Thakuran, and Matla estuary)	March (2017)	109 to 287	130 to 508	8
Hooghly estuary	November (2017)	243 to 662	95 to 313	9
Sundarbans estuary	November (2017)	154 to 315	80 to 436	9

Hooghly estuary	March to May (2016)	383 to 1068	138.6 to 699.9	9
Sundarbans estuary	March to May (2016)	358 to 808	37.49 to 91.29	9
Lothian Island (mangrove)	Pre-monsoon (2014)	294.3±34	28.0±8.6	10
Hooghly River	Pre-monsoon (2014)	205	49	10
Hooghly estuary (upper estuary)	Pre-monsoon (2014)	245.5±26.5	11.0±2.4	10
Hooghly estuary (mid-estuary)	Pre-monsoon (2014)	249.0±25.9	43.2±1.7	10
Hooghly estuary (lower estuary)	Pre-monsoon (2014)	324±27	27.5±3.6	10
Lothian Island (mangrove)	Post-monsoon (2014)	262.5±48.2	45.4±7.5	10
Hooghly estuary (upper estuary)	Post-monsoon (2014)	232.8±15.3	40.3±1.1	10
Hooghly estuary (mid-estuary)	Post-monsoon (2014)	263.6±26.7	129.7±6.7	10
Hooghly estuary (lower estuary)	Post-monsoon (2014)	223.5±31	57.5±3.2	10
Hooghly estuary	Pre-monsoon (2014)	245.4±26 to 324±27	11.04±2.5 to 28.9±1.66	16
Saptamukhi estuary	Pre-monsoon (2014)	260.3 to 328.2	27 to 37	16
Jharkhali mangroves	December (2006)	NA	8.8 to 47.9 (26.7±9.3)	19
Hooghly estuary	December (2006)	NA	50 to 457 (183±109.0)	19

Table S4. List of observations on $pCO_{2(water)}$ and air-water CO_2 fluxes from several studies on the Indian Sundarbans estuaries. The results are displayed either as mean ± standard deviation from the mean or as the range (minimum to maximum). Single magnitudes, in some instances, represent the mean (without any reported standard deviation).

Sampling Site/ Estuary	Time/ Season of Sampling (Year)	pCO_2 (µatm)	Air-Water CO_2 Flux (µmol m^{-2} h^{-1})	Reference
Saptamukhi estuary	Annual (2016-20)	180 to 2015	-290 to 7230	1
Thakuran estuary	Annual (2016-20)	211 to 1867	-860 to 4630	1
Matla estuary	Annual (2016-20)	439 to 2569	-550 to 15110	1
Hooghly estuary	Monsoon 2018	705 to 3679 (1873±9640)	944 to 19024	2
Hooghly estuary	Post-monsoon 2019	559 to 1711 (1090±481)	265 to 4647	2
Matla estuary	Monsoon 2018	464 to 1813 (1007±360)	178 to 7584	2
Matla estuary	Post-monsoon 2019	429 to 571 (508±33)	35 to 513	2
Creek (Dhanchi Island)	27th January to 6th February (2018)	315 to 1204 (470±162)	13±34 to 107±284	4
Estuary	27th January to 6th February (2018)	311 to 636 (387±58)	-4±12 to -37±95	4
Matla estuary	Annual (2017-18)	78 to 773 (327±195)	-100 to 2286 (983±644)	3

Matla estuary	Pre-monsoon (2018)	173 to 438 (297±79)	702 to 1777 (1202±319)	3
Matla estuary	Post-monsoon (2017)	78 to 386 (160±158)	-100 to 501 (208±205)	3
Matla estuary	Monsoon (2017)	335 to 773 (523±126)	981 to 2286 (1540±378)	3
Sundarbans estuary (Saptamukhi, Thakuran and Matla estuary)	March (2017)	533 to 918 (690±129)	398 to 3364	8
Hooghly estuary	November (2017)	267 to 4678	-19.3 to 717	9
Sundarbans estuary	November (2017)	376 to 561	-2.6 to 30.3	9
Hooghly estuary	Pre-monsoon (2016)	556 to 5002	2290	5
Sundarbans estuary	Pre-monsoon (2016)	268 to 418	-162	5
Hooghly estuary	2015-16	1193±657 (475 – 3330)	116 to 18759	6
Lothian Island (mangrove)	Pre-monsoon (2014)	634±112	NA	10
Hooghly estuary (upper estuary)	Pre-monsoon (2014)	992±60	NA	10
Hooghly estuary (mid-estuary)	Pre-monsoon (2014)	750±146	NA	10
Hooghly estuary (lower estuary)	Pre-monsoon (2014)	593±81	NA	10
Lothian Island (mangrove)	Post-monsoon (2014)	641±39	NA	10
Hooghly estuary (upper estuary)	Post-monsoon (2014)	441±13	NA	10
Hooghly estuary (lower estuary)	Post-monsoon (2014)	372±46	NA	10
Hooghly estuary	Pre-monsoon (2014)	592±81 to 1013±60	NA	16
Saptamukhi estuary	Pre-monsoon (2014)	506 to 712	NA	16
Hooghly estuary	August to July (2013-14)	2200	121 to 16944	12
Matla estuary	August to July (2013-14)	530	-668 to 3033	12
Herobhanga River	April and May (2011)	507.98±73.69	28.1±13.24	17
Thakuran River	April and May (2011)	518.84±71.94	22.36±12.36	17
Edwards Creek	April and May (2011)	234.34±64.08	-31.6±13.52	17
Hooghly estuary (coastal waters)	Winter (January, February, November) (2008)	320 to 500	57	13
Hooghly estuary and its adjacent coastal oceans	Summer (May and September) (2008)	450	10274	13
Jharkhali mangroves	December (2006)	353 to 476 (411±39.7)	80 to 120	19
Hooghly estuary	December (2006)	930 to 1068 (996±40.5)	670 to 1440	19

Mooriganga, Saptamukhi, and Thakuran estuaries	January–December (2001)	416 to 1062	-16.2 to 49.9	22
Tip and base of Sagar Island and Diamond Harbour	January–December (1999)	300 to 1200 (±200)	-2780 to 8440	23
Mooriganga estuary	August (1986)	830±363	967±421	24
Saptamukhi estuary	August (1986)	2210±1460	2363±1558	24

Table S5. List of observations on CH_4 concentration in water and air-water CH_4 fluxes from several studies on the Indian Sundarbans estuaries. The results are displayed either as mean ± standard deviation from the mean or as the range (minimum to maximum). Single magnitudes, in some instances, represent the mean (without any reported standard deviation).

Sampling Site/ Estuary	Time/ Season of Sampling (Year)	CH_4 conc. in water (nmol l^{-1})	Air-Water CH_4 Flux (μmol m^{-2} h^{-1})	Reference
Hooghly estuary	Pre-monsoon (2016)	15.4 to 445.7	5.4	5
Sadhupur mangrove	Winter	83.8±1.2 to 652.7±8.8	-8.3±0.4 to 2.9±0.2	7
Sadhupur mangrove	Summer	153.4±1.9 to 772.0±3.5	-1.2±0.3 to 8.7±0.4	7
Sadhupur mangrove	Pre-monsoon	78.5±3.3 to 228.3±4.8	2.1±0.1 to 8.3±0.1	7
Sadhupur mangrove	Monsoon	85.7±5.6 to 1341.2±13.4	10.41±0.5 to 15.9±1.6	7
Pakhiralaya mangrove	Winter	104.8±3.2 to 159.0±3.5	-4.6±0.6 to 5.8±0.1	7
Pakhiralaya mangrove	Summer	92.8±5.6 to 152.7±3.4	-3.3±0.4 to 6.6±0.3	7
Pakhiralaya mangrove	Pre-monsoon	94.4±4.3 to 215.7±5.3	2.1±0.1 to 11.2±0.8	7
Pakhiralaya mangrove	Monsoon	71.7±3.6 to 1125.4±10.6	7.5±0.8 to 23.8±1.3	7
Dayapur mangrove	Winter	82.2±3.3 to 117.2±3.2	-10.0±1.0 to 6.7±0.7	7
Dayapur mangrove	Summer	79.8±1.2 to 771.1±9.1	-2.5±0.1 to 10.8±0.5	7
Dayapur mangrove	Pre-monsoon	94.4±4.4 to 149.3±3.9	5.9±0.4 to 9.2±0.2	7
Dayapur mangrove	Monsoon	83.8±4.3 to 327.2±7.8	14.2±1.4 to 16.7±0.9	7
Lothian Island and adjacent Saptamukhi estuary	Pre-monsoon (2010-2012)	47.28±12.85 to 54.20±5.06	0.3±0.1	11
Lothian Island and adjacent Saptamukhi estuary	Monsoon (2010-2012)	53.27±19.47 to 64.58±10.56	0.4±0.3	11
Lothian Island and adjacent Saptamukhi estuary	Post-monsoon (2010-2012)	67.97±33.12 to 90.91±21.20	0.4±0.1	11
Saptamukhi estuary	June (2010) to December (2011)	54.20±5.06 to 90.91±21.20	0.3	15

Saptamukhi estuary	Pre-monsoon (2010-2011)	46.92±15.26	265.02±95.43	18
Saptamukhi estuary	Monsoon (2010-2011)	72.29±11.13	515.06±65.04	18
Saptamukhi estuary	Post-monsoon (2010-2011)	90.06±29.28	444.29±170.76	18
Jharkhali mangroves	December (2006)	5.8 to 30.9 (13.3±6.5)	0.4 to 1.4	19
Hooghly estuary	December (2006)	3.6 to 29.8 (10.3±6.8)	0.2 to 0.9	19
Muriganga, Saptamukhi and Thakuran	Pre-monsoon (2003)	42.31±20.96	0.30±0.16	20
Muriganga, Saptamukhi and Thakuran	Monsoon (2003)	35.75±15.48	0.45±0.38	20
Muriganga, Saptamukhi and Thakuran (porewater)	Pre-monsoon (2003)	814±572	12.97±55.84	20
Muriganga, Saptamukhi and Thakuran (porewater)	Monsoon (2003)	817±828	52.53±31.62	20
Muriganga, Saptamukhi and Thakuran (porewater)	Post-monsoon (2003)	1546±1562	48.00±67.53	20
Hooghly estuary (Diamond Harbour)	Pre-monsoon (2003)	54.39 to 59.25	371.1 to 2801.2	20
Hooghly estuary (Kachuberia)	Pre-monsoon (2003)	29.3 to 53.5	309.2 to 3658.4	20
Hooghly estuary (Beguakhali)	Pre-monsoon (2003)	42.45 to 46.88	5333.7 to 6193.5	20
Hooghly estuary (Diamond Harbour)	Monsoon (2003)	19.67 to 22.10	53.7 to 57.65	20
Hooghly estuary (Kachuberia)	Monsoon (2003)	17.25 to 23.62	61.6 to 107.9	20
Hooghly estuary (Beguakhali)	Monsoon (2003)	13.65 to 15.45	65.45 to 69.3	20
Hooghly estuary (Diamond Harbour)	Post-monsoon (2003)	23.25 to 45.33	39.93 to 1230.5	20
Hooghly estuary (Kachuberia)	Post-monsoon (2003)	18.44 to 49.23	99.1 to 375.52	20
Hooghly estuary (Beguakhali)	Post-monsoon (2003)	10.3 to 52.4	36.7 to 968.1	20

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