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1
2 **NUTRIENT DYNAMICS AND EUTROPHICATION ASSESSMENT IN THE**
3 **TROPICAL RIVER SYSTEM OF SAIGON – DONGNAI (SOUTHERN**
4 **VIETNAM)**

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15 **Abstract**

16 Saigon-Dongnai Rivers in Southern Vietnam is a complex lowland hydrological network
17 of tributaries that is strongly influenced by the tidal cycles. The increasing economic,
18 industrial and domestic developments in and around Ho Chi Minh City (HCMC) have led
19 to serious impacts on water quality due to lack of appropriate wastewaters treatment.
20 Drinking water production is impacted and the large aquaculture production areas may
21 also be affected. We analyzed spatial and seasonal variability of nutrient concentrations
22 (Phosphorus, Nitrogen and Silica) and eutrophication indicators (Organic Carbon,

23 Chlorophyll-*a* and Dissolved Oxygen) based on bi-monthly monitoring during two
24 hydrological cycles (July 2015 – December 2017). Four monitoring sites were selected to
25 assess the impact of HCMC: two upstream stations on the Saigon River and Dongnai
26 River branches to provide the reference water quality status before reaching the urbanized
27 area of HCMC; one monitoring station in the city center to highlight Saigon River water
28 quality within the heart of the megacity; the fourth station downstream of the confluence
29 to evaluate the impact of HCMC on the estuarine waters. This study points to excess
30 nutrients in HCMC's water body with concentrations of NH_4^+ and PO_4^{3-} averaging to 0.7
31 $\pm 0.6 \text{ mgN L}^{-1}$ and $0.07 \pm 0.06 \text{ mgP L}^{-1}$, respectively in mean over the monitored period
32 and rising up to 3 mgN L^{-1} and 0.2 mgP L^{-1} , in extreme conditions. During the dry
33 season, we evidenced that untreated domestic discharges leads to degradation of the
34 Saigon River's water quality with extreme values of algal biomass (up $150 \mu\text{Chl-a L}^{-1}$)
35 and hypoxic conditions occurring episodically ($\text{DO} < 2 \text{ mg L}^{-1}$) in the heart of the
36 megacity. Until now, eutrophication in the urban center has had no clear effect
37 downstream because eutrophic water mass from the Saigon River is efficiently mixed
38 with the Dongnai River and sea water masses during the successive semi-diurnal tidal
39 cycles.

40 *Keywords:* water quality, nutrients, megacity, eutrophication, tidal river.

41

42 **1. Introduction**

43 In the past few decades, eutrophication has become a significant issue for surface water
44 bodies' worldwide (Hilton et al., 2006; Romero et al., 2013; Smith and Schindler, 2009;
45 Smith et al., 1999). Eutrophication is an accelerated growth of algae caused by the
46 enrichment of nutrients in an aquatic system, especially nitrogen (N) and phosphorus (P);
47 which results in oxygen depletion in the water body through intense bacterial
48 mineralization (Billen and Garnier, 1997; Nixon (2009); Volterra et al., 2002). Five
49 decades ago, Redfield et al. (1963) proposed the Redfield stoichiometric ratio of carbon,
50 nitrogen and phosphorus (C:N:P) as a generic tool to assess which is the limiting factor
51 for primary production. The N:P ratio in an aquatic system is an important key which is
52 used to verify which element will become the limiting factor to be controlled to reduce
53 algal blooms. More recently, Billen and Garnier (2007) improved the concept to address
54 the question of coastal waters. They showed that eutrophication is the consequence of
55 unbalanced riverine nutrient inputs, with excess nitrogen and phosphorus with respect to
56 silica (Si), when compared to the requirements for algal growth; stated to be C:Si:N:P =
57 106:15:16:1 (Brzezinski, 1985). The enrichment of riverine waters in N and P, together
58 with decreasing suspended solids and Si, often result in eutrophication of coastal areas
59 (Billen and Garnier, 1997; Conley et al., 1989; Howarth et al., 2011), characterized by
60 non-diatom harmful algal blooms. The new production of non-siliceous algae can be
61 facilitated by the imbalance between nutrient inputs.

62 Nutrients (N, P) generally originate from over fertilized agricultural soils through
63 leaching and erosion processes (Cloern et al., 2014; Lau and Lane, 2002; Singkran, 2017;
64 Trinh et al., 2015) or from untreated domestic and industrial wastewaters (Billen et al.,
65 2007; Cloern et al., 2014; Trinh et al., 2007). In industrialized European and North
66 American industrialized countries, wastewater treatment started in the 1970s in order to
67 reduce the point sources of N and P towards the hydrosystem (Van Drecht et al., 2009).
68 While the reduction of point sources pollution was shown to be efficient, diffuse inputs
69 remained a worrying source of nutrients for watersheds in these countries (Grizzetti et al.,
70 2013). The situation described for industrialized countries described above is very
71 different to that of emerging countries, especially for those located in the tropical regions,
72 such as Vietnam (Le et al., 2015). With the onset of the 21st century, the Southeast Asian
73 countries faced significant environmental challenges, such as quantitative shortages and
74 qualitative deterioration of water resources due to rapid industrialization, urbanization,
75 and agricultural intensification (Le, 2007; Vo, 2007). Indeed, sanitation network
76 development in large cities does not provide sufficient support to cover population
77 growth (Trinh et al., 2012). As a result, domestic wastewaters are released without
78 appropriate treatment into the receiving aquatic environments, causing high levels of
79 organic and nutrient pollution. In parallel with urban growth, changes in agricultural
80 practices have involved an increasing supply of fertilizers (Garnier et al., 2015). The
81 change in land-use have led to an increase of nutrient inputs to surface water and of the
82 flows to the outlets of major watersheds (e.g., the Mekong River). Moreover, high rainfall
83 intensity in the tropics leads to significant erosion rates and associated nutrient flows into

84 the rivers (Syvitski et al., 2014). The seasonality of precipitation, with marked alternation
85 between the dry and wet seasons, influences the hydrological regime and promotes
86 eutrophication during the dry season (Boulton et al., 2008).

87 The Saigon River is the second largest river after the Dongnai River in supplying water to
88 Ho Chi Minh City (HCMC), the economic capital of Vietnam. Due to increasing urban
89 sprawl in HCMC and neighboring provinces situated near the Saigon River basin, the
90 water quality has significantly deteriorated (Nguyen et al., 2011; Strady et al., 2017; Tran
91 Ngoc et al., 2016; Vo, 2007). Water supply demand from the Saigon River was estimated
92 as 64 % (1.6 million m³ day⁻¹) for households in 2009 and will increase to 72 % (3.4
93 million m³ day⁻¹) according to future projections for 2025 (Nguyen et al., 2011). In
94 addition, water from the Saigon River water is also used for irrigation, aquaculture and
95 navigation.

96 The objectives of this study were to (i) characterize nutrients dynamics in the Saigon –
97 Dongnai River system to evaluate the eutrophic status of water bodies and (ii) determine
98 the controlling factors of eutrophication and the impact of HCMC on water quality
99 downstream. We implemented a bi-monthly monitoring sampling strategy from July
100 2015 to December 2017 to determine and analyze physico-chemical parameters and
101 nutrients (N, P and Si) in the dissolved and particulate phase.

102 **2. Materials and methods**

103 ***2.1. Study area***

104 The Saigon River is a part of the Saigon – Dongnai River basin and located in Southern
105 Vietnam. It is about 250 km long with a catchment area of 4,717 km² down to the

106 confluence with the Dongnai River (Figure 1a). Upstream of the Saigon River, the Dau
107 Tieng reservoir (surface area of 270 km² and storage capacity of 1,580×10⁶ m³) was
108 constructed in 1985 for irrigation, flood protection purposes and control of saline water
109 intrusion (Trieu et al., 2014). The Saigon River is connected to urban canals when
110 flowing through HCMC and then joins the Dongnai River to become the Nha Be River. It
111 then continues its flow through Can Gio Mangrove to the East Sea. The flow direction of
112 the Saigon River is strongly affected by the asymmetric semi-diurnal tides and the
113 discharge is mainly controlled during the dry season by the amount of water released
114 from the Dau Tieng reservoir.

115 The region falls in a tropical monsoon climate, with an average humidity of 78-82 % and
116 a mean air temperature of 28.5 ± 1.0 °C. The year is divided into two distinct seasons
117 (wet and dry). The wet season has an average rainfall of about 1,800 mm annually (about
118 150 rainy days year⁻¹), usually beginning in May and ending in November (Figure 1b).
119 The dry season lasts from December to April.

120 Ho Chi Minh City is intrinsically linked with the Saigon River. The megacity's economy
121 has developed considerably over the last ten years and HCMC is now considered the
122 second most dynamic city in the world (World Economic Forum News, January 2017).
123 HCMC resides on the banks of the Saigon River in a lowland floodplain area of the
124 Saigon-Dongnai River basin and belongs to a transitional area between the South-eastern
125 region of Vietnam and the Mekong Delta.

126 Land use in HCMC is dominated by agricultural activities in the north, urban settlement
127 in the center and Can Gio Mangrove forest to the south. Can Gio forest is located - 40 km

128 southeast of HCMC and is recognized as a biosphere reserve by UNESCO. Agricultural
129 land in HCMC was around 32 % in 2016, showing a decrease of 2 % in comparison to
130 2012 (data from HCMC Statistical Yearbook 2016).

131 The population of HCMC was 8.4 million inhabitants in 2016, which represents about 8.9
132 % of Vietnam's total population. This makes HCMC the largest and most densely
133 populated city in the country (Figure 1c). The population of HCMC is mainly
134 concentrated in the heart of the city (as presented in Figure 1) and 6.7 millions inhabitants
135 live in the nineteen urban districts. The rural population was 1.5 millions in the three
136 districts upstream of HCMC and only 230,000 in the two downstream districts. HCMC
137 reached an urban population proportion of 88% in 2004, since then the population of
138 HCMC and its boundary districts has increased rapidly (data from HCMC Statistical Year
139 Book 2016).

140 Less than 10 % of the domestic waste water is collected and treated before being
141 discharged directly into urban canals or rivers (Marcotullio, 2007). The main wastewater
142 treatment plant (Binh Hung WWTP) is located south of the high population density urban
143 area (Figure 1c). Its treatment capacity is 141,000 m³ day⁻¹ (426,000 inhabitants).
144 Construction began in 2017 to reach a total capacity of 469 000 m³ day⁻¹ (1,390,000
145 inhabitants) and authorities have scheduled the building of ten new WWTPs within the
146 next ten years (source: ATLAS Ho Chi Minh City).

147 *Figure 1.*

148 **2.2. Monitoring and sampling strategy**

149 A bi-monthly monitoring was undertaken at four sites from July 2015 to December 2017
150 in the Saigon – Dongnai River branches (Figure 1a). Two upstream stations on Saigon
151 River (SG-up) and Dongnai River (DN-up), respectively, characterize the reference water
152 status in the upstream of HCMC. One monitoring station in the city center (SG-city)
153 aimed at highlighting the impact of the city. The last station was placed downstream of
154 the confluence between the two rivers (Nha Be River – NBR) to assess the impact of
155 HCMC on estuarine waters. Water sampling was taken at low tide for each field survey to
156 consider the dominant fluvial flow from upstream to downstream and is illustrated in
157 Figure 2.

158 Two complementary longitudinal profiles were carried out during the wet and dry
159 seasons to understand the spatial fluctuation of water quality in the Saigon River. Total
160 profile length was 50 km with 18 sampling points (Figure 1a). The profiles were
161 conducted on-boat on 19th April 2017 from 8:00am to 4:30pm (dry season) and 20th
162 October 2017 from 9:30am to 6:00pm, starting at Saigon upstream (SG-up – SG01) and
163 ending at Saigon downstream (NBR – SG18) (Figure 1a). A GPS was used to mark
164 longitude and latitude values of each point and to calculate the corresponding kilometric
165 point (pK), in which pK = 0 was the confluence between the Saigon and Dongnai Rivers,
166 with negative values upward and positive downward.

167 *Figure 2.*

168 For each sample, surface water (0-30cm below the surface) was taken by using a 2.5 L
169 Niskin bottle in the middle of the river from either a bridge or a boat. Immediate
170 measurements of physico-chemical parameters were realized using a multi-parameter

171 probe (WTW 3420[®]), e.g., temperature, pH, conductivity, salinity, and dissolved oxygen
172 concentration and percentage of oxygen saturation. Each water sample was collected in a
173 5 L polypropylene recipient for Total Suspended Sediment (TSS), C, N, Si, and P
174 measurements and Chlorophyll-*a* analysis.

175 **2.3. Laboratory analyses**

176 Samples were immediately filtered through a Whatman GF/F filter (porosity 0.7 μ m) at
177 the Centre Asiatique de Recherche sur l'Eau (CARE) laboratory for analysis of dissolved
178 nutrients. Unfiltered samples were kept to measure total nutrients. TSS was measured
179 based on the different weight of a GF/F filter after 24 hours of drying at 50 °C.
180 Chlorophyll-*a* and Phaeopigments were measured after filtration through a second
181 Whatman GF/F filter using acetone (90 %) extraction method followed by a
182 spectrophotometry measurement at 665 and 750 nm absorbance (Aminot and K erouel,
183 2004).

184 Unfiltered water samples were used to measure Total N and Total P using persulfate
185 digestion procedure and standard colorimetric method (American Public Health
186 Association: APHA, 1995). Dissolved nutrients were analyzed on filtered water samples
187 using standard colorimetric methods (APHA, 1995). The NH₄⁺, NO₃⁻, PO₄³⁻ and
188 Dissolved Si (DSi) were analyzed by using respectively the Nessler reactive method, the
189 cadmium reduction method, the acid ascorbic method and the silicomolybdate method,
190 respectively. Reproducibility for replicate measurements was better than 5 % for all total
191 and dissolved nutrients.

192 A TOC (Total Organic Carbon) analyzer apparatus (TOC-V Shimadzu, CARE
193 laboratory, Vietnam) was used to determine Dissolved Organic Carbon (DOC) in filtered
194 water samples with accuracy higher than 5 % (Sugimura and Suzuki, 1988). Particulate
195 Organic Carbon (POC) was measured on suspended matter retained on a GF/F filter
196 (ignited at 550 °C). The POC content (in % of dry weight) was measured by using
197 combustion in a LECO CS-125 analyzer (Laboratory EPOC, Université de Bordeaux,
198 France) with precision better than 5 % (Etcheber et al., 2007). The POC concentration is
199 calculated as the product of POC % and TSS concentration and expressed in mgC L⁻¹.

200 ***2.4. Hydrological database***

201 Water discharges data was provided by the Center of Environmental Monitoring (CEM)
202 of the Department Of Natural Resources and Environment of HCMC (DONRE). This
203 national monitoring program allows the measuring of monthly discharges at different
204 locations within our study sites. Discharges are measured every hour during a 24-hour
205 cycle because the hydrodynamic effect of the tide is perceptible up to the dams (Figure
206 1a). The residual discharge is then calculated as the difference between positive and
207 negative discharges over the tide cycle. The residual discharge corresponds to the net
208 positive water flow of the river from land to the sea. Data was collected for the 2012-
209 2016 period in order to characterize the mean monthly distribution of the discharge at two
210 locations in the Saigon River (SG-city) and in the Dongnai River (DN-up) (Figure 1a).

211 **3. Results**

212 ***3.1. Seasonal hydrological variability***

213 Water discharge distribution is mainly controlled by precipitation seasonality (Figure 1b).
214 The wet season shows a water discharge increase from June to October followed by a
215 decrease at the end of November in both Saigon and Dongnai Rivers (Figure 3). The
216 mean inter-annual discharge calculated over the 2012-2016 period for the Saigon River
217 ($50 \pm 20 \text{ m}^3 \text{ s}^{-1}$) is twelve times lower than for the Dongnai River ($613 \pm 220 \text{ m}^3 \text{ s}^{-1}$). The
218 Saigon River discharge can be artificially controlled during the dry season by releasing
219 water from Dau Tieng reservoir to flush out salt intrusion. Trieu et al. (2014) suggest that
220 water release regulation from the reservoir can be up to $30 \text{ m}^3 \text{ s}^{-1}$ during the dry season.
221 This is in good agreement with the field data provided by DONRE.

222 *Figure 3.*

223 **3.2. Interannual variations of the water quality in the Saigon River**

224 *3.2.1. Physico-chemical parameters*

225 Water temperature in the Saigon and the Dongnai Rivers ranged between 27 to 33 °C,
226 with low fluctuations. Mean value was $30.0 \pm 1.2 \text{ °C}$ at four stations. As shown in Figure
227 4a, pH increased from upstream to downstream in the Saigon River (6.3 ± 0.2 and $6.8 \pm$
228 0.3 at SG-up and NBR, respectively), while mean pH in DN-up was 7.0 ± 0.3 . For
229 salinity, values were almost zero in SG-up and DN-up, whereas higher values and wider
230 ranges of seasonal fluctuations were observed in SG-city and NBR (the highest value
231 observed was 5.0 in SG-city and 8.7 in NBR during the 2016 dry season – Figure 4b).
232 Dissolved oxygen (DO) fluctuated at the four stations without specific variability and
233 reached its highest value at DN-up (7.96 mg L^{-1}) and the lowest value at SG-city (0.57
234 mg L^{-1}) (Figure 4c). Average DO concentrations were $6.1 \pm 0.6 \text{ mg L}^{-1}$, $2.5 \pm 0.9 \text{ mg L}^{-1}$,

235 $1.7 \pm 0.8 \text{ mg L}^{-1}$ and $3.6 \pm 1.0 \text{ mg L}^{-1}$ at DN-up, SG-up, SG-city and NBR, respectively.
236 The TSS concentrations evidenced seasonal variations at SG-up and DN-up, (Figure 4d)
237 and reached their highest values during the wet season at SG-up and DN-up (140 mg L^{-1}
238 in DN-up and 184 mg L^{-1} in SG-up during the wet season). However, the mean TSS
239 value at SG-city ($98.5 \pm 56.7 \text{ mg L}^{-1}$) was higher than at the other stations (36.8 ± 26.4
240 mg L^{-1} , $67.3 \pm 36.7 \text{ mg L}^{-1}$ and $33.1 \pm 25.6 \text{ mg L}^{-1}$ at SG-up, NBR and DN-up,
241 respectively).

242 *Figure 4.*

243 3.2.2. Dissolved and total nutrients

244 Total N reached its highest value at SG-city ($3.4 \pm 0.9 \text{ mgN L}^{-1}$) and lowest at DN-up
245 ($1.5 \pm 0.4 \text{ mgN L}^{-1}$; Figure 5a). Total N tends to significantly increase from upstream
246 (SG-up) to Saigon City Center (SG-city) before slightly decreasing downstream of
247 Saigon (NBR). NO_3^- was lower than 2 mgN L^{-1} in all samples (except one point in SG-
248 city in July 2015), averaging $0.6 \pm 0.3 \text{ mgN L}^{-1}$, $0.7 \pm 0.5 \text{ mgN L}^{-1}$, $0.6 \pm 0.3 \text{ mgN L}^{-1}$
249 and $0.5 \pm 0.2 \text{ mgN L}^{-1}$ for SG-up, SG-city, NBR, and DN-up, respectively. NO_3^-
250 concentrations at DN-up fluctuated slightly with no evident seasonality. At SG-city, NO_3^-
251 presented much more fluctuation from 0.0 to 2.4 mgN L^{-1} (Figure 5b). NH_4^+ was low at
252 DN-up ($< 0.5 \text{ mgN L}^{-1}$), but reached peak value up to over 3 mgN L^{-1} (Figure 5c) at SG-
253 city. Average NH_4^+ was $0.3 \pm 0.2 \text{ mgN L}^{-1}$, $0.8 \pm 0.6 \text{ mgN L}^{-1}$, $0.1 \pm 0.1 \text{ mgN L}^{-1}$ and 0.1
254 $\pm 0.1 \text{ mgN L}^{-1}$ at SG-up, SG-city, NBR and DN-up, respectively.

255 *Figure 5.*

256 Total P and PO_4^{3-} did not present specific seasonal variations. Total P was dramatically
257 high in SG-city, $0.3 \pm 0.2 \text{ mgP L}^{-1}$ on average and up to 0.8 mgP L^{-1} for peak values
258 (Figure 5d). Average Total P was $0.2 \pm 0.1 \text{ mgP L}^{-1}$, $0.1 \pm 0.1 \text{ mgP L}^{-1}$ and $0.1 \pm 0.1 \text{ mgP}$
259 L^{-1} in SG-up, NBR and DN-up, respectively. The PO_4^{3-} concentration (Figure 5e) was
260 low in DN-up (experienced at $0.04 \pm 0.02 \text{ mgP L}^{-1}$ on average). Mean PO_4^{3-} value was
261 $0.04 \pm 0.03 \text{ mgP L}^{-1}$, $0.07 \pm 0.06 \text{ mgP L}^{-1}$ and $0.03 \pm 0.02 \text{ mgP L}^{-1}$ in SG-up and NBR,
262 respectively.

263 A seasonal DSi concentration fluctuation was observed at the four sites from 6 to 8 mgSi
264 L^{-1} during the wet season down to values below 1 mgSi L^{-1} during the dry season.
265 Average DSi concentrations were $2.6 \pm 2.1 \text{ mgSi L}^{-1}$, $1.7 \pm 1.8 \text{ mgSi L}^{-1}$, $1.8 \pm 1.8 \text{ mgSi}$
266 L^{-1} and $2.0 \pm 1.8 \text{ mgSi L}^{-1}$ at DN-up, SG-up, SG-city and NBR, respectively (Figure 5f).

267 *3.2.3. Organic carbon, chlorophyll-a, and phaeopigments*

268 The DOC concentrations were $2.4 \pm 0.7 \text{ mg L}^{-1}$, $2.5 \pm 1.9 \text{ mg L}^{-1}$, $3.6 \pm 1.1 \text{ mg L}^{-1}$ and
269 $3.8 \pm 0.7 \text{ mg L}^{-1}$ on average at DN-up, SG-up, SG-city and NBR, respectively (Figure
270 6a). As compared with other parameters measured during this study, DOC concentrations
271 were remarkably stable at the four sites during the observation period, except in March
272 2017 with a peak of DOC observed in SG-up and DN-up. POC reached its highest value
273 at SG-city, with an average of $4.3 \pm 1.6 \text{ mg L}^{-1}$ and lowest value at the other sites,
274 making up $1.3 \pm 0.5 \text{ mg L}^{-1}$, 1.7 ± 0.8 and 1.6 ± 1.0 on average at DN-up, SG-up and
275 NBR, respectively (Figure 6b).

276 *Figure 6.*

277 Chl-*a* concentrations varied from 0.01 $\mu\text{g L}^{-1}$ to 147 $\mu\text{g L}^{-1}$ at SG-city (Figure 6c). Chl-*a*
278 and phaeopigments exhibited contrasted variability both spatially and seasonally for the
279 whole survey period. The mean value of pigments at SG-city ($29.6 \pm 32.4 \mu\text{g Chl-}a \text{ L}^{-1}$
280 and $19.5 \pm 16.7 \mu\text{g phaeopigments L}^{-1}$, respectively) was higher than at DN-up (4.7 ± 3.8
281 $\mu\text{g Chl-}a \text{ L}^{-1}$ and $5.7 \pm 5.3 \mu\text{g phaeopigments L}^{-1}$), SG-up ($3.2 \pm 5.5 \mu\text{g Chl-}a \text{ L}^{-1}$ and 4.9
282 $\pm 4.8 \mu\text{g phaeopigments L}^{-1}$) and NBR ($1.6 \pm 1.1 \mu\text{g Chl-}a \text{ L}^{-1}$ and $2.6 \pm 1.7 \mu\text{g}$
283 phaeopigments L^{-1}).

284 ***3.3. Longitudinal profile in the Saigon River***

285 The longitudinal profile was divided into three sections (i.e., was defined according to
286 population density distribution) to assess the impact of urbanization on the Saigon River
287 water quality: (i) the upstream section was from Phu Cuong Bridge (SG01) to Thanh Da
288 canal (SG06), (ii) the middle section was representative of the high urban system
289 extending from Thanh Da canal (SG07) to Bach Dang Harbor (SG11) and (iii) the
290 downstream section was from Bach Dang Harbor (SG12) to Binh Khanh Ferry (SG18).
291 The Saigon River water quality changed considerably between the profiles realized
292 during the dry and wet seasons (Figure 7). The pH increased gradually from land to the
293 ocean (with more acid water during the wet season from 5.8 to 6.2) than during the dry
294 season (6.3 to 7.2) (Figure 7). DO values varied between moderate to severe hypoxic
295 conditions (as low as 0.5 mg L^{-1} in the upstream section and rose up to 4.7 mg L^{-1} in the
296 downstream section). During the wet season, DO increased rapidly from extremely low
297 concentrations at upstream of HCMC (SG01 to SG06 during the wet season with DO
298 values below 2 mg L^{-1}) to high values after City Center (point SG13, with DO values

299 above 4 mg L⁻¹). Saline water intrusion during the dry season was observed up to about
300 40 km from the confluence between the two rivers. Salinity was nearly 0 during the wet
301 season in the three sections. The magnitude of TSS fluctuations was higher during the
302 wet season with a peak of 71.5 mg L⁻¹ at SG03, a minimum of 17.6 mg L⁻¹ at SG09 and a
303 new maximum downstream with a value of 78.6 mg L⁻¹ at SG17.

304 While Total N and NO₃⁻ concentrations were stable from the upstream to downstream
305 sections, NH₄⁺ tended to increase in the middle section during the wet season. Total P
306 concentrations were high in the upstream and middle section before decreasing in the
307 downstream section, especially during the dry season. The PO₄³⁻ concentrations fluctuated
308 from the upstream to downstream sections during both seasons. The DOC, POC, Chl-*a*
309 and phaeopigments varied in the same range. Chl-*a* content was stable and lower than 2
310 µg L⁻¹ for Chl-*a* and 5 µg L⁻¹ for phaeopigments during the wet season, while Chl-*a* and
311 phaeopigments concentrations reached their highest values at the transition between
312 upstream and middle sections during the dry season (110.3 µg Chl-*a* L⁻¹ at SG06 and 72.2
313 µg phaeopigments L⁻¹ at SG07). DSi values were rather low in the upstream section (1mg
314 DSi L⁻¹) but increased locally to 2 mg DSi L⁻¹ in the middle (dry season) or downstream
315 sections (wet season).

316 *Figure 7.*

317 **3.4. Nutrients ratios**

318 We have assembled a data set of dissolved nutrients (N, P and Si) concentrations at the
319 four sampling sites in the Saigon and Dongnai Rivers. These dissolved nutrient
320 concentrations were used to calculate the Redfield ratio (N:P:Si ratios). When the graph

321 was plotted according to the Si:N and Si:P ratios, the theoretical lines represented a
322 theoretical nutrients ratio and the graph was separated into four areas (Figure 8). Each
323 area represented, respectively, from the lower right quadrant counter-clockwise: an area
324 with N in limiting amounts and Si in excess; an area with N in limiting amounts and Si
325 deficiency; an area with P in limiting amounts and Si deficiency; and an area with P in
326 limiting amounts and Si in excess (Billen and Garnier, 2007). Figure 8 showed that the
327 four sampling sites in the Saigon – Dongnai River system were distributed in overlapping
328 clusters. From bi-monthly monitoring, we can observed that the Saigon – Dongnai River
329 system was characterized by a N:P ratio above the Redfield value and by a substantial
330 excess of Si over both P and N. Additionally, the molar Si:P ratio was higher than 15 and
331 reached the maximum value of 200 (Figure 8), indicating that Si still exceeded diatom
332 growth requirement, and could therefore limit the development of non-diatoms algae in
333 this environment.

334 *Figure 8.*

335 **4. Discussion**

336 ***4.1. Level of nutrients contamination***

337 The level of nutrients measured in the Saigon and Dongnai Rivers was compared to the
338 European standard of water quality (Water Framework Directive, 2000). The European
339 standard of water quality has five surface water quality assessment categories (high,
340 good, moderate, bad and very bad status). Vietnamese water quality regulation
341 (QCVN08, 2015) is not complete enough for nutrient assessment and only provide water

342 quality legislation for industrial and domestic usage, but this standard does not include
343 the general health of the ecosystem.

344 *Nitrogen.* In the whole Saigon and Dongnai basin, NO_3^- concentration was lower than 2.5
345 mgN L^{-1} , which is equivalent to good (0.5-2.5 mg. L^{-1}) and high status ($< 0.5 \text{ mgN L}^{-1}$)
346 (WFD, 2000). The NH_4^+ concentration was around 0.1 mgN L^{-1} (good status $<0.4 \text{ mgN}$
347 L^{-1} , WFD 2000) at upstream Dongnai River (DN-up) and downstream Saigon River
348 (NBR). This was not the case for Saigon City Center (SG-City), as it is affected by urban
349 wastewater discharge, NH_4^+ concentration being on average 0.7 mgN L^{-1} and rising up to
350 3 mgN L^{-1} (moderate, 0.4-1.6 mgN L^{-1} to bad status, 1.6-3.9 mg L^{-1} , WFD 2000). The
351 Saigon River was then highly polluted by ammonium in the dense urban area but less by
352 nitrates, which indicates low emissions from agricultural practices (Grizzetti et al., 2012).

353 Concentrations of NO_3^- and NH_4^+ in the Saigon River were not only higher than in the
354 very polluted urban Nhue River in Hanoi, Northern Vietnam: 0.0-0.1 $\text{mgN-NO}_3^- \text{ L}^{-1}$ and
355 0.02-0.15 $\text{mgN-NH}_4^+ \text{ L}^{-1}$ (Trinh et al., 2015) but also than in other major tropical rivers,
356 such as the Lower Mekong River (Vietnam): $0.15 \pm 0.05 \text{ mgN-NO}_3^- \text{ L}^{-1}$ and 0.03 ± 0.03
357 $\text{mgN-NH}_4^+ \text{ L}^{-1}$ (Li and Bush, 2015), the Senegal River (Senegal): 0.042-0.17 mgN-NO_3^-
358 L^{-1} and 0.005-0.03 $\text{mgN-NH}_4^+ \text{ L}^{-1}$ (Mamadou et al., 2016), Chap Phraya River
359 (Thailand): 1.3 mgN L^{-1} and 0.08 mgP L^{-1} (Jens et al., 2001) and the Yangtze River
360 (China): 0.019-0.027 $\text{mgN-NO}_3^- \text{ L}^{-1}$ and 0.003-0.005 $\text{mgN-NH}_4^+ \text{ L}^{-1}$ (Liu et al., 2016).
361 Land use in boundary areas of HCMC is dominated by agriculture, while the upstream
362 parts of both the Saigon and Dongnai Rivers are more populated compared to

363 downstream of HCMC; the heart of HCMC being the most densely populated (Figure
364 1c). NO_3^- originates principally from the leaching of agricultural soils (Billen et al.,
365 2010). However, in rivers influenced by urban wastewater discharges, it can originate
366 from the ammonium nitrification process (Garnier et al., 2007; Herbert, 1999; Xia et al.,
367 2009). In HCMC, due to the lack of wastewater treatment plants, most of the untreated
368 domestic waste water is discharged directly into the three main urban canals connected to
369 the Saigon River (Figure 1c). Therefore, the untreated domestic waste water becomes the
370 principal source of NH_4^+ .

371 Indeed, NH_4^+ is a good indicator of domestic pollution among all nitrogen forms. NH_4^+
372 concentrations increased considerably in Saigon City Center evidencing pollution by
373 effluents from HCMC and its suburbs (Figure 7). At the Saigon – Dongnai River
374 confluence, NH_4^+ concentrations returned close to the values observed in upstream
375 Dongnai River showing the spatially limited NH_4^+ pollution of HCMC on its river further
376 downstream. NO_3^- concentrations also decreased at the confluence and we hypothesized
377 that they (NH_4^+ and NO_3^-) played a major role in the stimulation of primary production
378 by phytoplankton in the Saigon River aquatic system (Dugdale and Goering, 1967).

379 *Phosphorus and silica.* PO_4^{3-} concentrations ranged from 0.05 up to 0.2 mgP L⁻¹ in
380 Saigon City Center (SG-city) corresponding to good-to-moderate status (WFD, 2000) but
381 Total P concentrations were much critical up to 0.96 mgP L⁻¹ (bad status, WFD, 2000). In
382 the other upstream locations (SG-up) and downstream (NBR) of the Saigon River and
383 upstream of the Dongnai River (DN-up), PO_4^{3-} concentrations were lower than 0.1 mgP
384 L⁻¹ (good status, WFD, 2000) and Total P concentrations were lower than 0.4 mgP L⁻¹

385 (good to moderate status, WFD, 2000). These results indicated a high level of phosphorus
386 within the city center, especially Total P. The proportion of particulate P in Total P was
387 high (mean of 78 ± 6 % in mean) indicating a strong interaction with suspended
388 sediments. PO_4^{3-} concentrations in the Saigon River were higher than in other rivers, e.g.,
389 the Lower Mekong River (Vietnam): 0.02 ± 0.04 mgP L⁻¹ (Li and Bush, 2015) and the
390 Senegal River (Senegal): 0.003-0.013 mgP L⁻¹ (Mamadou et al., 2016). Moreover, we
391 observed that DSi fluctuated between four sampling sites during the 2015-2017 period.
392 The sources of DSi were mainly from diffuse origins (e.g., weathering and erosion of
393 natural rocks) or from point sources (e.g., urban runoff, domestic and industrial waste
394 waters) (Sferratore et al., 2006). Particulate silica can then be dissolved to become a
395 source of DSi, which could explain the fluctuation of DSi observed at the four sampling
396 sites.

397 Due to the very poor sanitation in HCMC, Total P inputs are mainly from industrial and
398 domestic sources, so that the Total P load in the Saigon – Dongnai River is rather
399 constant over the year. Less than 10% of domestic effluents and less than 50 % of
400 industrial effluents are treated before being discharged directly into the river
401 (Marcotullio, 2007). The theoretical domestic P concentration can be estimated at 30 mgP
402 L⁻¹ from the equivalent per capita (4 gP inhab.⁻¹ day⁻¹ and 150 L inhab.⁻¹ day⁻¹; Lam et al.,
403 2008 and Ministry of Construction, 1998) and total wastewater flux at about 10 m³ s⁻¹
404 (considering the total unconnected urban population at 6 million inhabitants, i.e., 90% of
405 the 6.7 million inhabitants living in urban districts). Untreated wastewaters would
406 contribute to about 20 % of mean annual discharge of the Saigon River (50 m³ s⁻¹) and

407 untreated wastewaters P concentrations would be 100 times higher than P concentrations
408 measured in the Saigon River (mean of 0.3 mgP L⁻¹ in mean). Domestic inputs are then
409 constant over the time regardless of the season and could maintain P concentrations at a
410 high level within the Saigon River.

411 During the wet season, the river flow was higher than during the dry season (Figure 3); P
412 input was diluted by rainfall and there was a P depletion with regards to Si. During the
413 dry season, most of the Saigon River water discharge comes from the Dau Tieng
414 reservoir, modifying the nutrients balance. Despite inputs being less diluted during the
415 dry season, the decrease of PO₄³⁻ concentrations, especially effective at this time can be
416 due to algal growth (Causse et al., 2015). In addition, the canal system in HCMC is the
417 main drain for untreated effluents from the urban catchment area so that P can be stored
418 within the sediments. Urban areas include houses, roads, and other public areas, are
419 regularly flooded with a mix of storm water and wastewater leading to the sediments
420 being flushed out by the overflow under rainy conditions (Tran Ngoc et al, 2016). Indeed,
421 high levels of PO₄³⁻ in water and Particulate P in sediment were observed in urban canals
422 in HCMC (Strady et al., 2017) indicating an intense adsorption process of dissolved P
423 onto sediment. This accumulation in the sediment was evidenced in the urban canals of
424 Bangkok (Thailand), which presents similar geography, demography and wastewaters
425 management to HCMC (Færge et al, 2001).

426 *Nutrients proportions.* We observed from bi-monthly monitoring data that the dissolved
427 inorganic nitrogen proportion (%DIN) at four sampling sites fluctuated slightly from 38 ±
428 24 % at NBR to 49 ± 22 % at SG-up during the 2015-2017 period. Whilst PO₄³⁻

429 proportion was lowest at SG-city (32 ± 27 %), Dongnai River experienced the highest
430 proportion (49 ± 31 % at DN-up). The change in proportion of primary nutrients (N, P
431 and Si) can lead to a change in the Redfield ratio N:P:Si, affecting the risk of
432 eutrophication in aquatic systems. In turn, phytoplankton uptake affects nutrient
433 concentrations (Redfield, 1958 and many others since then); furthermore, the increased
434 anthropogenic nutrient inputs necessarily change the proportion of nutrients for
435 phytoplankton growth (Turner and Rabalais, 1991). It means that the feedback effect
436 between nutrients and phytoplankton uptake, can control phytoplankton dynamics (e.g.,
437 dominant species, successions from diatoms to non-diatoms).

438 The seasonal variability of water quality in the Saigon River was explored from the bi-
439 monthly monitoring. Seasonality is of most important in terms of the eutrophication
440 problem because phytoplankton development is naturally controlled by factors that
441 follow seasonal cycles (Le et al., 2015). Surprisingly, there was no clear seasonality of all
442 observed parameters. The relation between water discharge and nutrient variation is not
443 relevant in this system as the discharge is controlled by the tide and water release from
444 Dau Tieng reservoir (Trieu et al 2014). The parameters monitored and presented in
445 Figures 4 to 6 showed that the salinity was by far the one that exhibits the strongest
446 seasonality. We can actually clearly distinguish the two peaks during the 2016 and 2017
447 dry seasons, but we can also clearly see that their magnitudes are very different. Based on
448 statistical analyses, we observed that some nutrients fluctuated seasonally (p-value <
449 0.05), e.g., NO_3^- (p-value = 0.015) and NH_4^+ (p-value = 0.04) in SG-up; Total P (p-value
450 = 0.026) in DN-up or NO_3^- (p-value = 0.049) in SG-city. Other nutrients such PO_4^{3-} did

451 not vary seasonally with p -value > 0.05 , especially in SG-city. Therefore there is no
452 evidence of hydrological seasonality to explain the variability of most of the nutrient
453 concentrations.

454 Concerning the spatial fluctuation of nutrients in the Saigon River, our results clearly
455 showed the impact of HCMC on nutrient concentrations, which is presented by an
456 increase of Total N, NH_4^+ , Total P and PO_4^{3-} (Figure 7).

457 ***4.2. Eutrophication status and limiting factors***

458 According to the eutrophication classes proposed by Dodds et al. (1998) and Dodds and
459 Welch (2000), we classified the water quality of the Saigon and Dongnai River branches
460 upstream and downstream of the City Center as mesotrophic, and being clearly eutrophic
461 in the SG-city site (Table 1). To identify the principal limiting factor of algal blooms in
462 the system, we used the N:P molar ratio presented in Figure 8. A molar ratio of N:P lower
463 than 16 indicates that P is the limiting factor for algal growth, while a ratio higher than 16
464 shows that N is the key element. When observation that the molar N:P ratio is higher than
465 16:1 in the Saigon – Dongnai River system, P is indicated as the limiting factor. More
466 precisely, the molar N:P ratio in the Saigon River ($\text{N:P} = 69.7 \pm 44.8$ on average) was
467 higher than that of the Dongnai River ($\text{N:P} = 45.5 \pm 22.9$ on average). In May 2017, the
468 N:P ratio peaked at 258, showing that N was largely in excess in comparison to P. It
469 would seem that in order to reduce eutrophication in the Saigon River, the control of the
470 key element P is necessary.

471 *Table 1.*

472 The relationship between POC and Chl-*a* was analyzed at the four sampling sites to
473 verify the origin of organic carbon. This relationship observed with $R^2 < 20\%$ indicates
474 that the main composition of organic carbon in the Saigon River is not phytoplankton.
475 Furthermore, POC/Chl-*a* weight-to-weight ratio values were calculated for each site and
476 were all higher than 200 (e.g., 1573 ± 1600 , 517 ± 770 , 1564 ± 1620 and 524 ± 620 at
477 SG-up, SG-city, NBR and DN-up, respectively), characterizing a detrital or degraded
478 material (Cifuentes et al., 1988). This means that the origin of the organic matter within
479 the river was principally allochthonous and likely from untreated wastewaters. Moreover,
480 the average C:N ratios calculated at the four sampling sites were all lower than 12 ($3.0 \pm$
481 2.5 , 4.5 ± 4.7 , 2.6 ± 3.2 and 2.8 ± 4.5 at SG-up, SG-city, NBR and DN-up, respectively).
482 These findings supported the assumption of allochthonous organic matter inputs from
483 wastewaters (Hedges et al., 1986; Hedges and Oades, 1997; Balakrishna and Probst,
484 2005; Zafirah et al., 2017). Nevertheless, values of POC/Chl-*a* ratio decreased in SG-city
485 where algal development is maximum. It indicated that in this part of the river, the
486 proportion of autochthonous organic matter is increasing due to eutrophication.

487 ***4.3. Impact of HCMC on the water quality of the Saigon River***

488 Since the early 1990's, HCMC has been experiencing an economic boom (Du and
489 Fukushima, 2010; Vo, 2007). This growth has been accompanied with a rapid
490 urbanization, the urban surface area has indeed quintupled between 1990 and 2012; with
491 about 660 km² of surface becoming urbanized during that period (Kongtis et al., 2014).
492 Since the study of Gurby et al. (2002), urbanization has continued to expand along the
493 Saigon River (North and South), with a population density that can exceed 30,000

494 inhabitants per km² (see Figure 1c). This economic and demographic evolution has
495 created new challenges for the city in terms of water quality management (Vo, 2007).
496 Policy makers are now being forced to find new solutions to reduce pollution and restore
497 the aquatic ecosystem of the Saigon River.

498 The monitoring conducted at our four stations for more than two hydrological years
499 underlines a critical eutrophication observed each year at SG-city. The three episodes of
500 eutrophication observed during our survey lasted several weeks, but were not easily
501 correlated with dry or wet hydrological seasons; even if the highest peak of
502 eutrophication was observed in the middle of the dry season in January 2017 (Chl-*a* >
503 150 µg L⁻¹, Figure 6c).

504 Figure 9 proposes a synthetic view of population distribution along the Saigon River and
505 the level of the trophic status in order to highlight the connections between urbanization
506 and eutrophication. The snapshot presented in Figure 9a shows a rapid deterioration of
507 water quality, from oligotrophic waters in the upper 5-10 km of monitoring (pK-55 to pK
508 -48) to mesotrophic (pK-48 to pK-40) and eutrophic waters downstream (pK -40 to pK -
509 12). The water quality is then restored quite rapidly and recovers an oligotrophic status
510 around pK-10, i.e., ten kilometers before the confluence of Saigon and Dongnai Rivers.

511 *Figure 9.*

512 For the upper stretch of the river (from pK-55 to pK-10), Figure 9 shows a good match
513 between the increase in eutrophication and the density of inhabitants, which demonstrates
514 the direct effect of untreated urban wastewater release on river quality. The restoration of
515 water quality beyond pK-10 can appear surprising, but it is supported by two

516 assumptions: first, the restoration of water quality can be attributed (at least partially) to
517 the positive effect of the Binh Hung wastewater treatment plant, which collects and treats
518 a part of the wastewaters from the south of the City Center (district 5, district 7); second,
519 water quality improvement is more likely due to the dilution of polluted water from the
520 Saigon River as it mixes with seawater and the Dongnai River waters. The water quality
521 monitored at station NBR indeed presented a good water quality status ($\text{Chl-}a < 10 \mu\text{g L}^{-1}$)
522 throughout the 30 months of monitoring. During the dry season, this water body mixes
523 daily with the Saigon River and progressively diffuses upstream. This is demonstrated by
524 the saline intrusion observed at SG-city station in Figure 4b.

525 Furthermore, during the dry season survey (19th April 2017), the DO level was high due
526 to photosynthesis processes by a high level of phytoplankton, reaching its highest value at
527 $110 \mu\text{g Chl-}a \text{ L}^{-1}$. During the wet season, the upstream and middle sections of the Saigon
528 River were deoxygenated ($\text{DO} < 2 \text{ mg L}^{-1}$, see Figure 7) because of oxygen consumption
529 by biological activities (not only degradation of organic matter but also nitrification). At
530 these locations, the water body contains large amounts of organic matter which is
531 quantified by high DOC and POC concentrations (making up above 3 mgC L^{-1}) and NH_4^+
532 concentrations higher than 0.2 mgN L^{-1} (cf. Figure 7).

533 In addition to the high level of NH_4^+ in the middle section, NO_3^- was also low in this area
534 (Figure 7). There was a slight decrease in NH_4^+ concentrations during the dry season
535 from upstream to downstream of HCMC, while there was a drastic increase in NH_4^+
536 levels at the City Center during the wet season due to the discharge of untreated domestic
537 waste water from urban zones. By contrast, NO_3^- concentration increased at the City

538 Center during the wet season, whereas their values decreased during the dry season
539 (Figure 7). During the dry season, NH_4^+ slightly decreased at the same time as NO_3^-
540 indicating a dilution by the Dongnai River or seawaters. On the contrary, during the wet
541 season, there was a strong nitrification process with a rapid decrease of NH_4^+ at City
542 Center occurring at the same time as an increase in NO_3^- (Figure 7). The nitrification
543 process was likely initiated with the input of oxic waters up to pK -10 (Figure 7). The
544 result highlights the potential capacity of the estuary to metabolize the pollution emitted
545 by HCMC (Flemer, 2006).

546 In general, anthropogenic activities (e.g., agricultural and industrial activities, poor
547 domestic wastewater treatment) have led to eutrophication of water bodies with an
548 expected impact on water quality and drinking water production. To deal with these
549 problems, wastewater planning and management is needed. It is critical that wastewater
550 management becomes a fundamental part of urban planning and watershed management.
551 HCMC authorities have already planned to build ten new WWTPs able to treat most of
552 the domestic waters in the next ten years (Tran Ngoc et al., 2016). HCMC must also
553 urgently incorporate principles of ecosystem management from the watershed into the
554 coastal ocean. The natural ecosystem can be used to provide water more sustainably; with
555 this in mind, wetland management is an essential option to sustain the water cycle and
556 hence, to decrease nutrient and organic pollution (Gupta et al., 2016).

557 **5. Conclusions**

558 Our two-and-a-half year survey of water quality was the first time to evaluate global
559 nutrient levels in the Saigon – Dongnai Rivers. As outlined above, the values observed in

560 the upstream of HCMC were close to those observed in the downstream of HCMC,
561 which showed the low anthropogenic impact in the more rural areas. We did not take into
562 account nutrient input from diffuse sources (e.g., agricultural activities) due to lack of
563 data. However, we assumed that nutrient input from diffuse sources is of second order in
564 comparison to high nutrient input from point sources in the urban areas of HCMC. Indeed
565 water in the heart of HCMC was polluted and exhibited high nutrient concentrations
566 (especially phosphorus) due to untreated effluents from residential and industrial areas.
567 The Saigon River experienced extreme eutrophication episodes. We can therefore
568 conclude that there are numerous problems and challenges with regards to water quality
569 management in HCMC. The question we need to ask is how to revise, improve and
570 implement the current legal system regarding the water sector in general, and wastewater
571 management in particular. Appropriate quantification of the eutrophication status is a first
572 step in which scientists and policy makers need to work together using operational
573 modelling tools to move from observation to mitigation. We need to understand how
574 water quality in downstream of HCMC is recovered. This should be further investigated
575 when looking at dilution between the Saigon River, the Dongnai River and seawater
576 within the whole salinity gradient down to the coastal area. A modelling approach of the
577 hydrodynamics and biogeochemistry of the estuary is currently conducted to identify the
578 predominance of each of the internal biogeochemical processes.

579

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795 **Figure 1.** (a) Map of Saigon – Dongnai Rivers and location of sampling sites, (b)
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800 **Figure 2.** Water level during (a) the dry season (April 2017) and (b) the wet season
801 (October 2017) at HCMC (source: tide4fishing.com; black points indicate bi-
802 monthly monitoring and black lines correspond to the time period during which
803 longitudinal profiles were carried out).

804

805 **Figure 3.** Distribution of mean monthly discharges (period 2012-2016) in the Saigon and
806 Dongnai Rivers (data source: DONRE; see Figure 1a for the location).

807

808 **Figure 4.** Seasonal variations of (a) pH, (b) salinity, (c) DO and (d) TSS at the four
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811 the wet season from May to November.

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820 and wet season (20th October 2017); from top to bottom and from left to right: pH,
821 DO, salinity, Total N, NO₃⁻, NH₄⁺, Total P, PO₄³⁻, DSi, TSS, DOC, POC, Chl-a
822 and Phaeopigments. Last panel represents the longitudinal profile divided into
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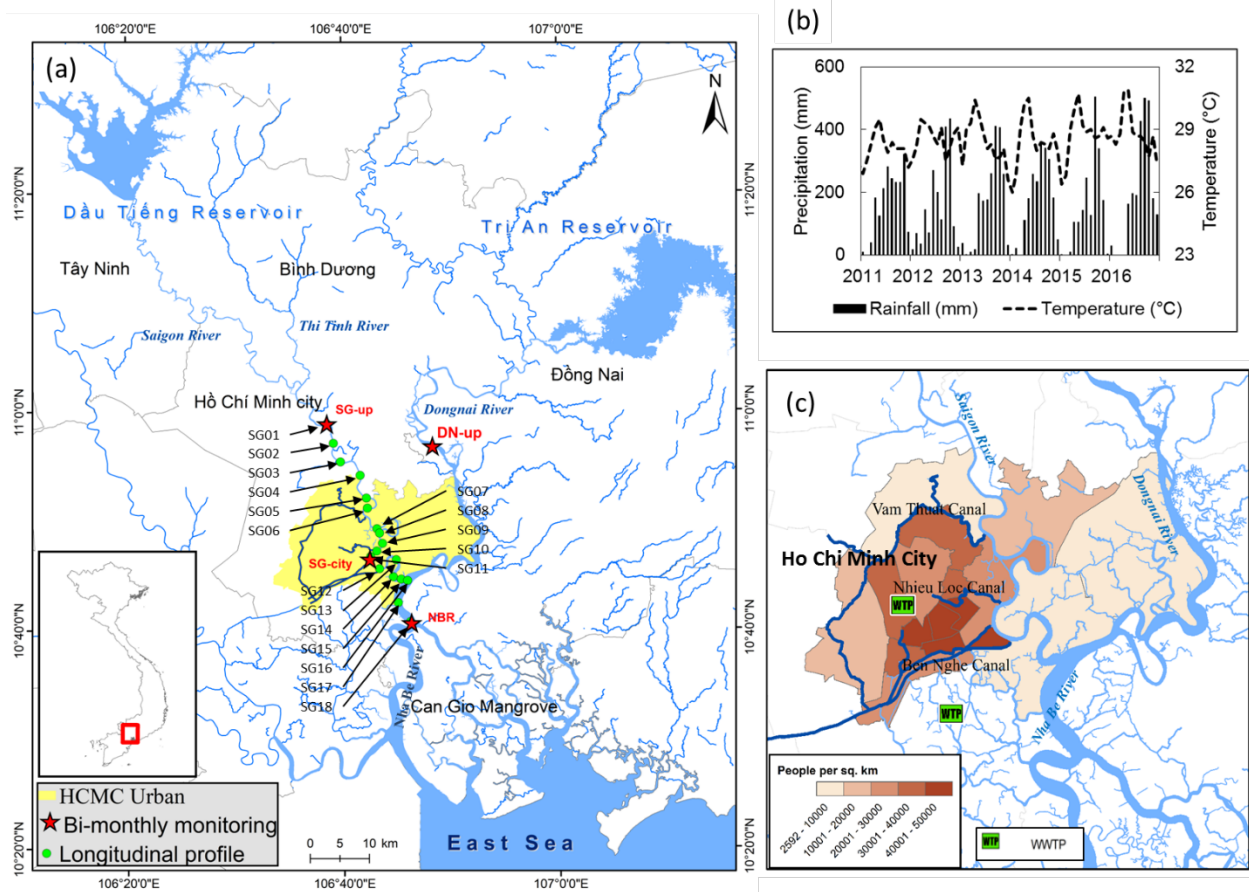
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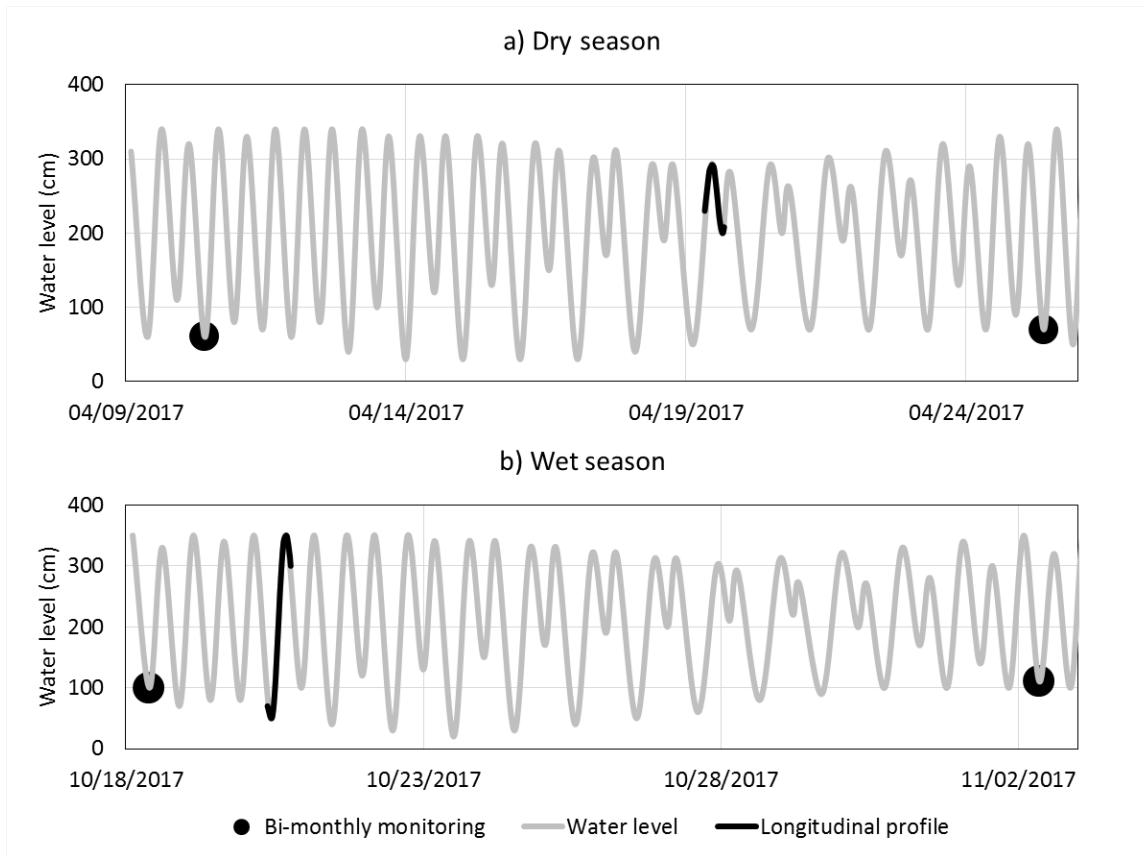
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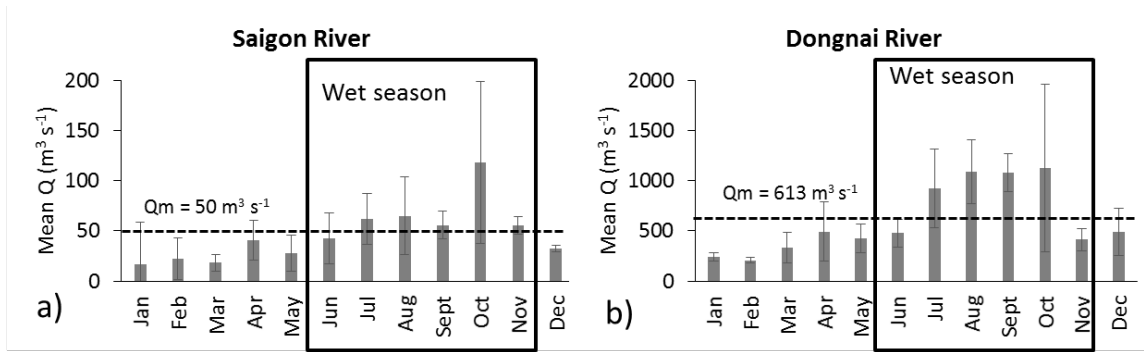
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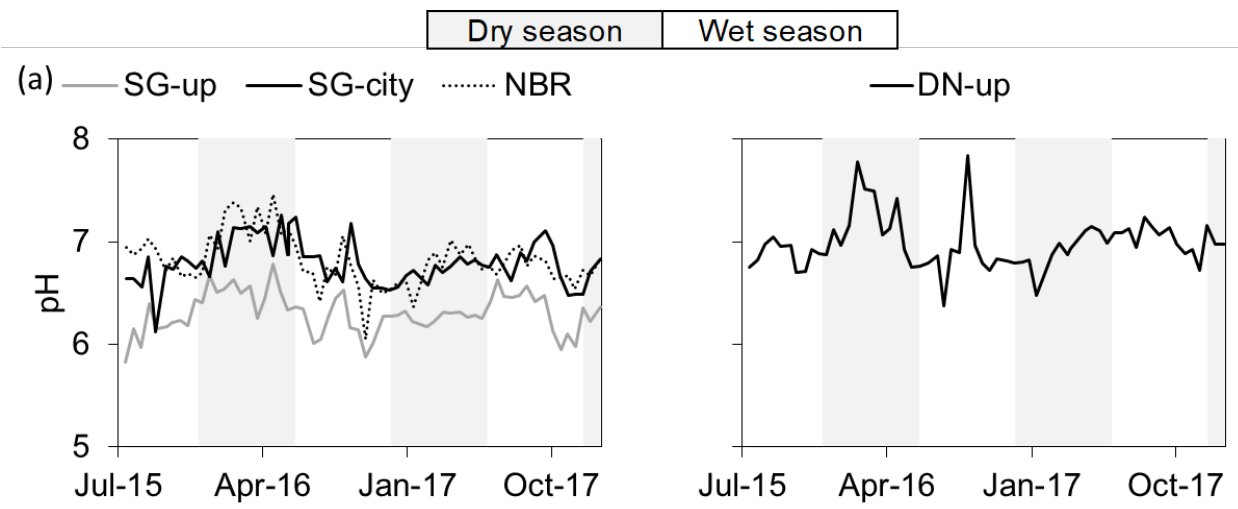
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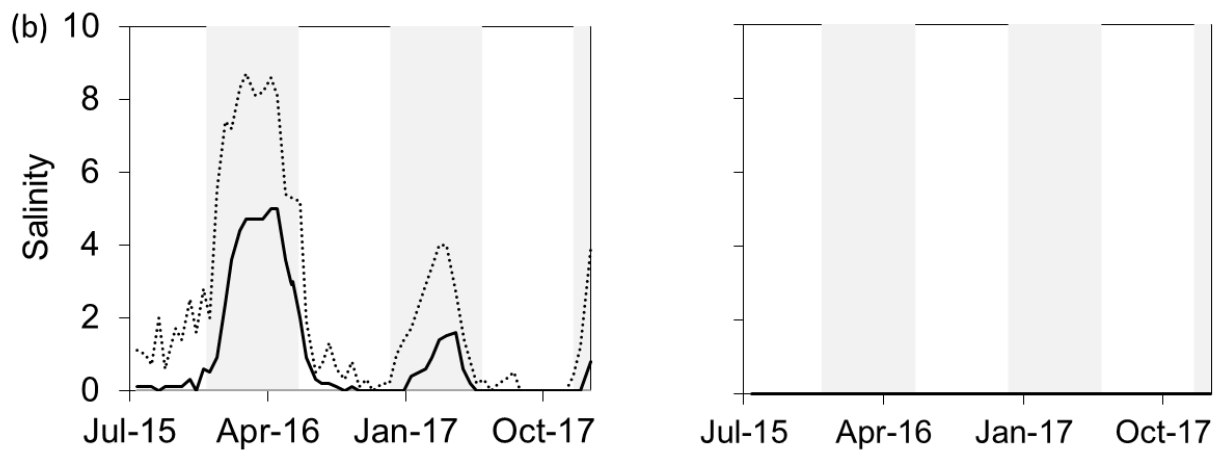
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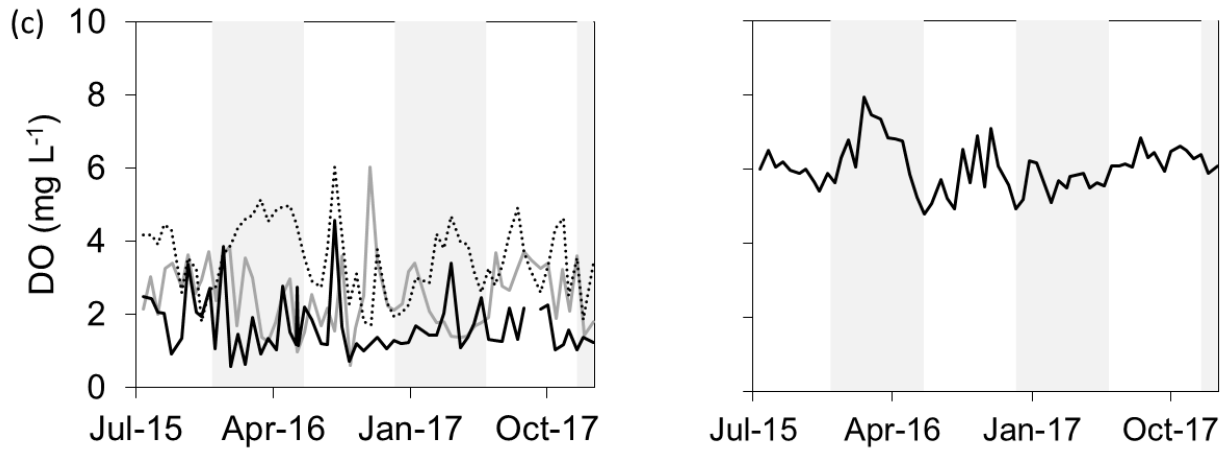
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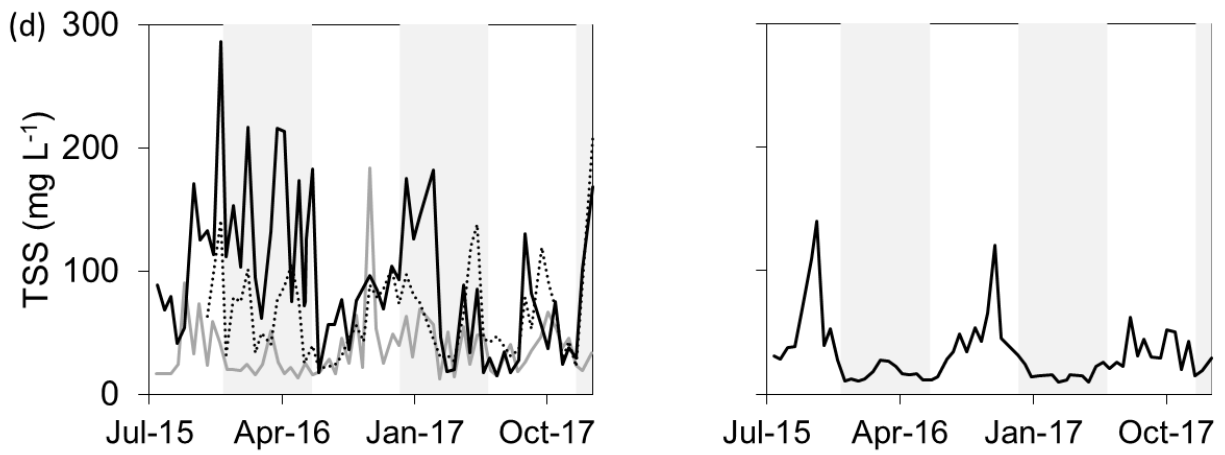
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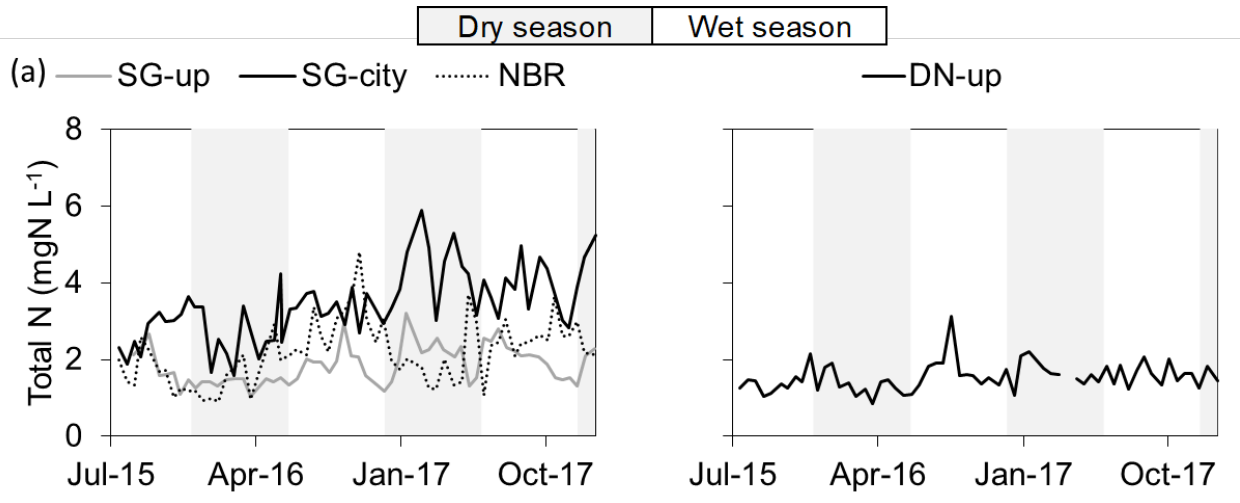
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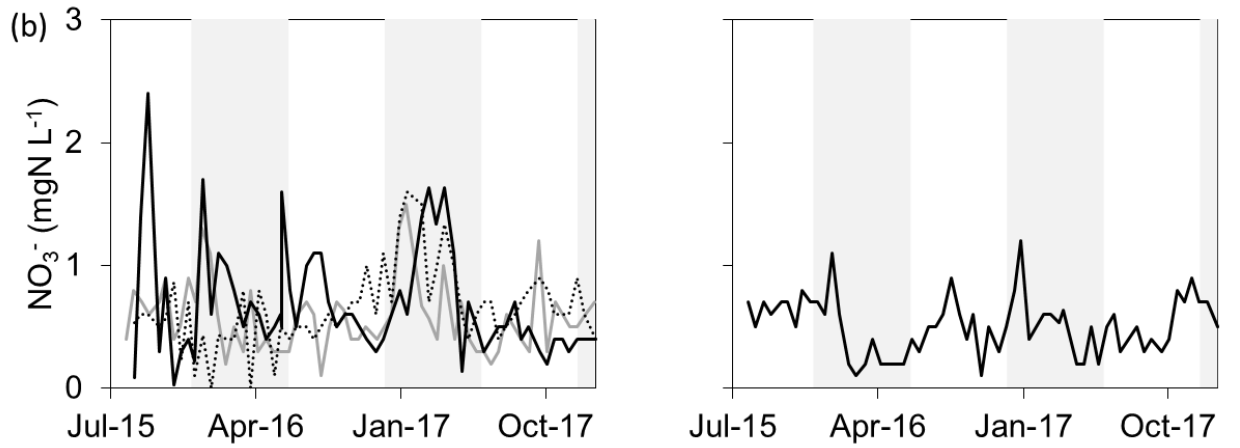
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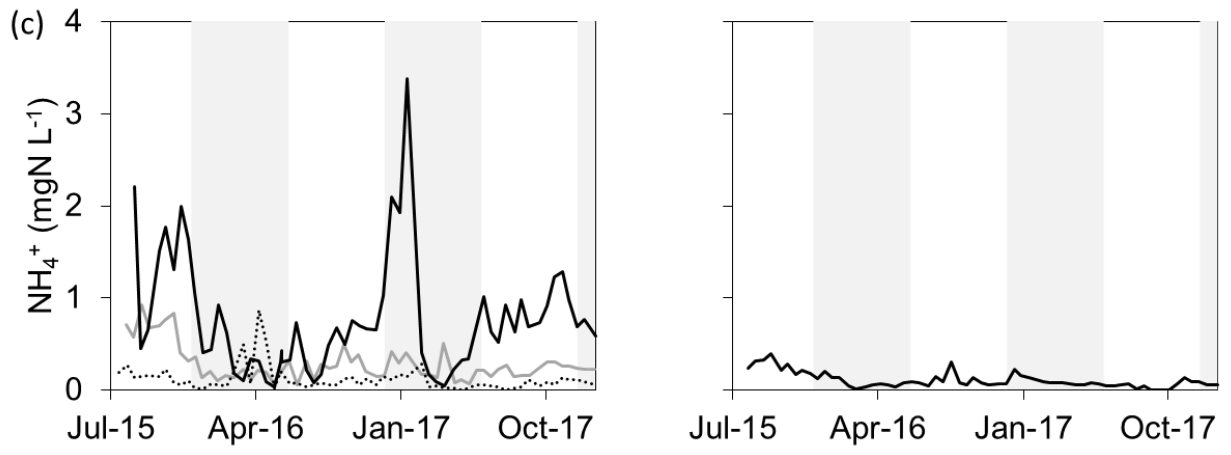
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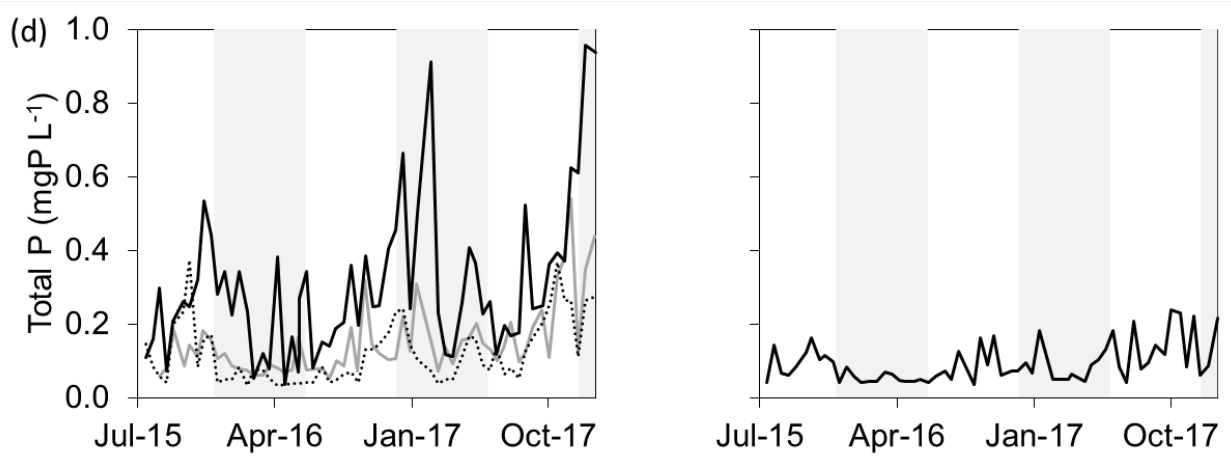
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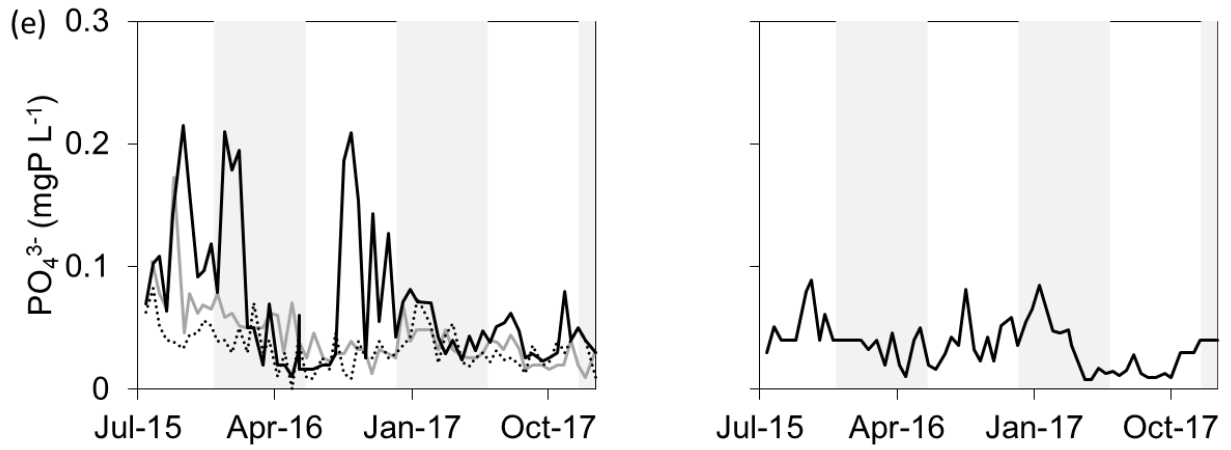
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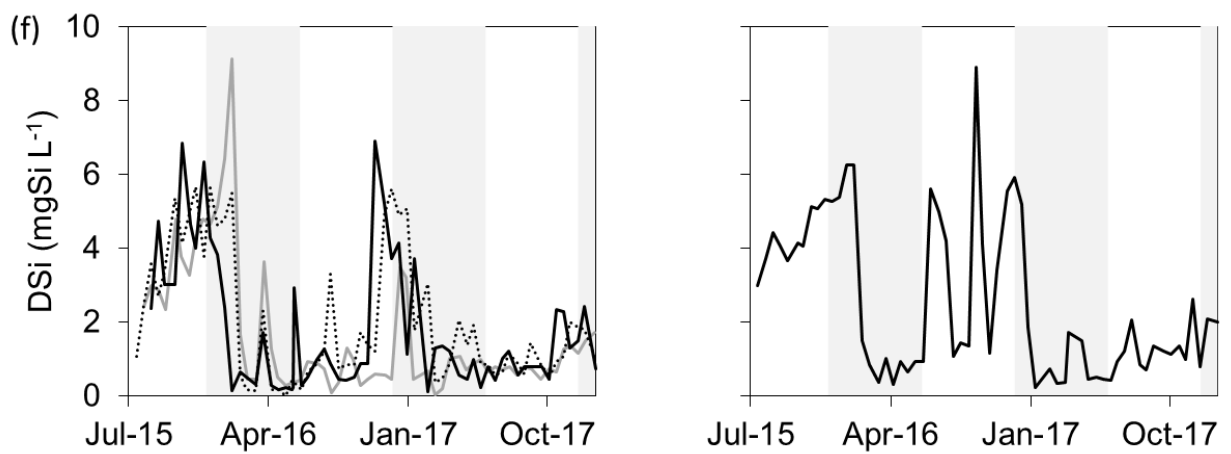
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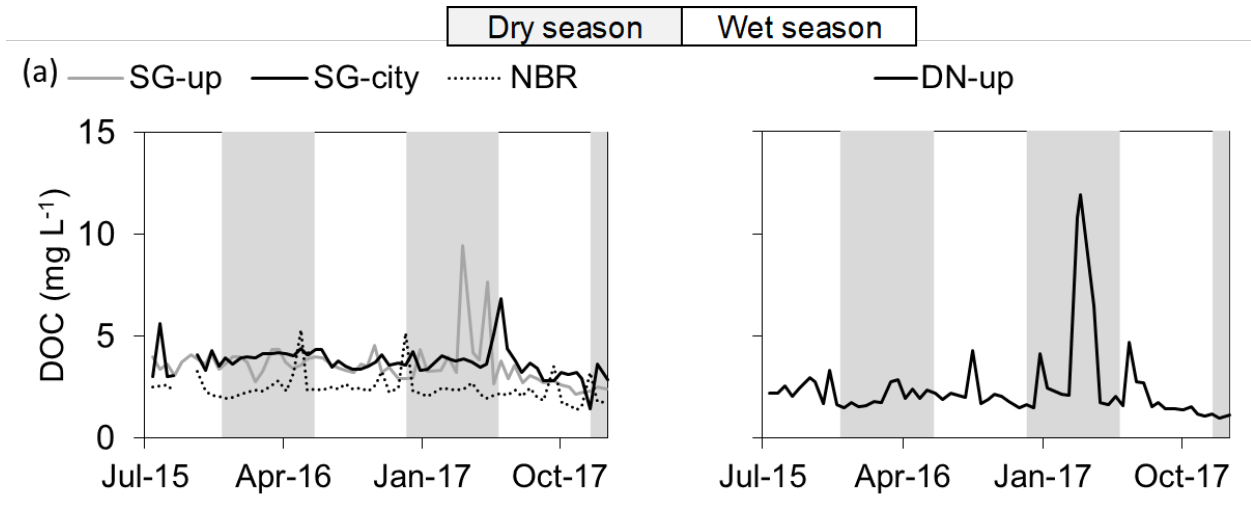


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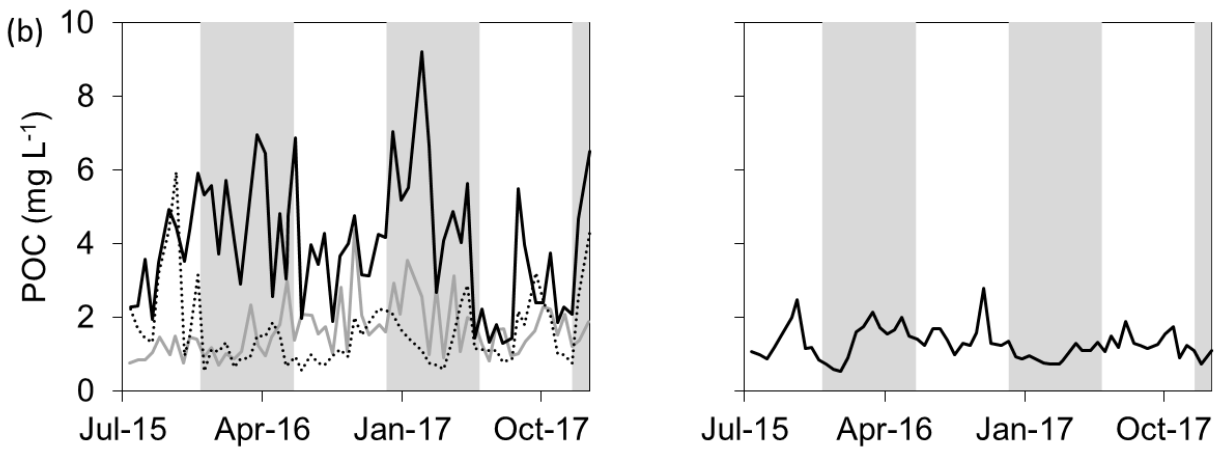
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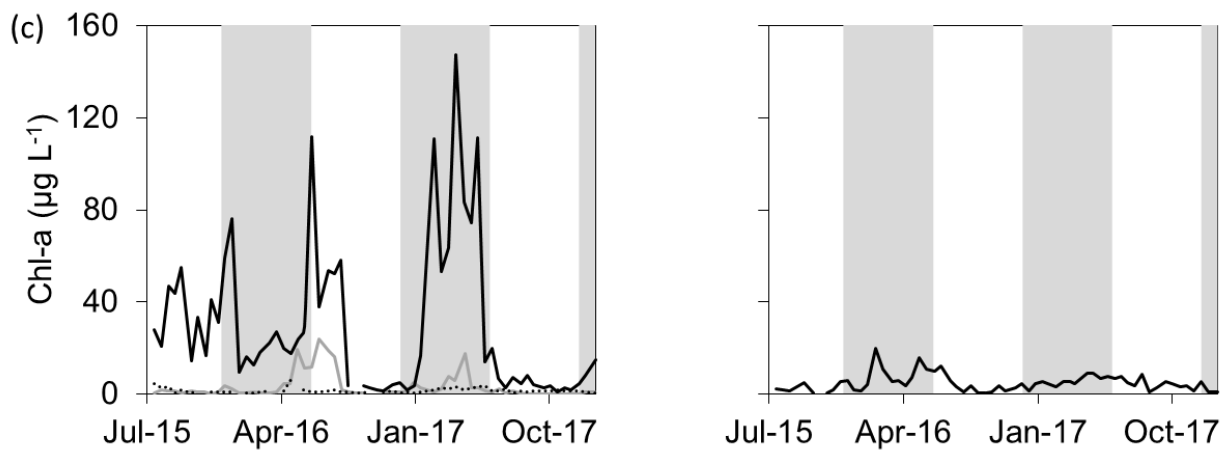
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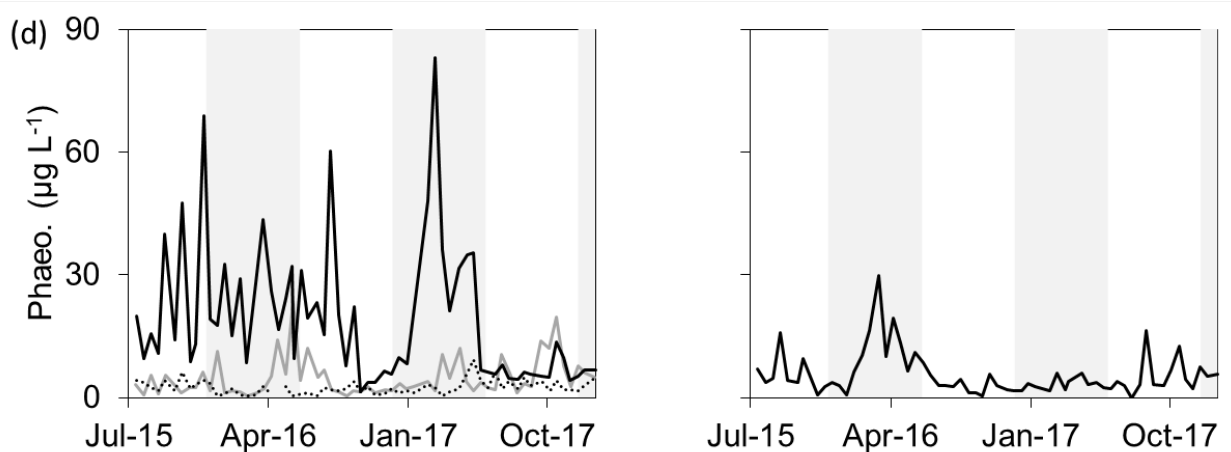
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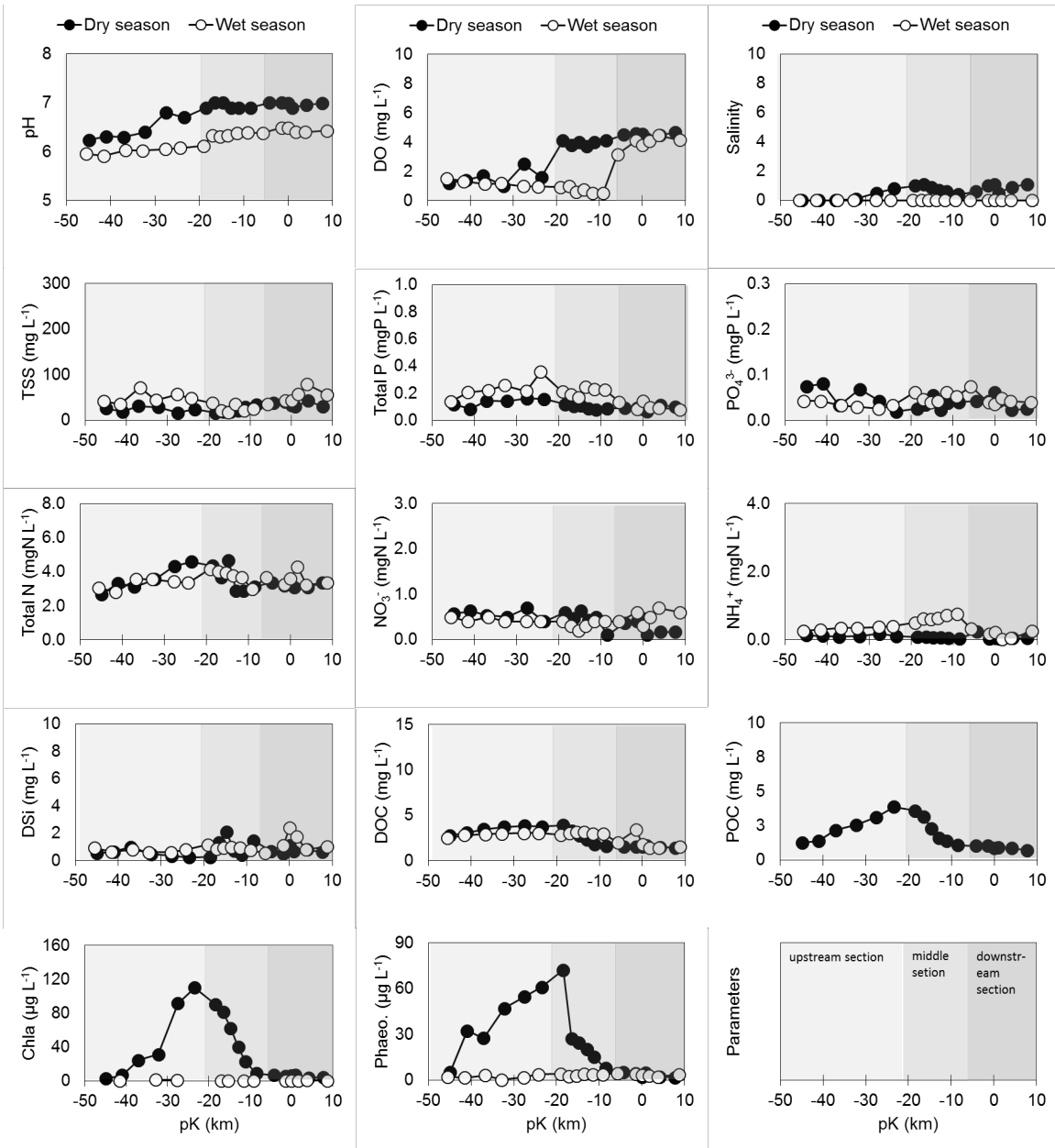


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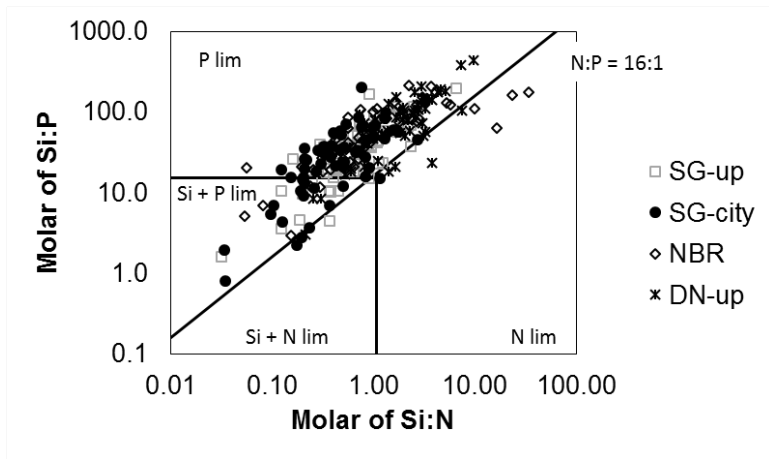
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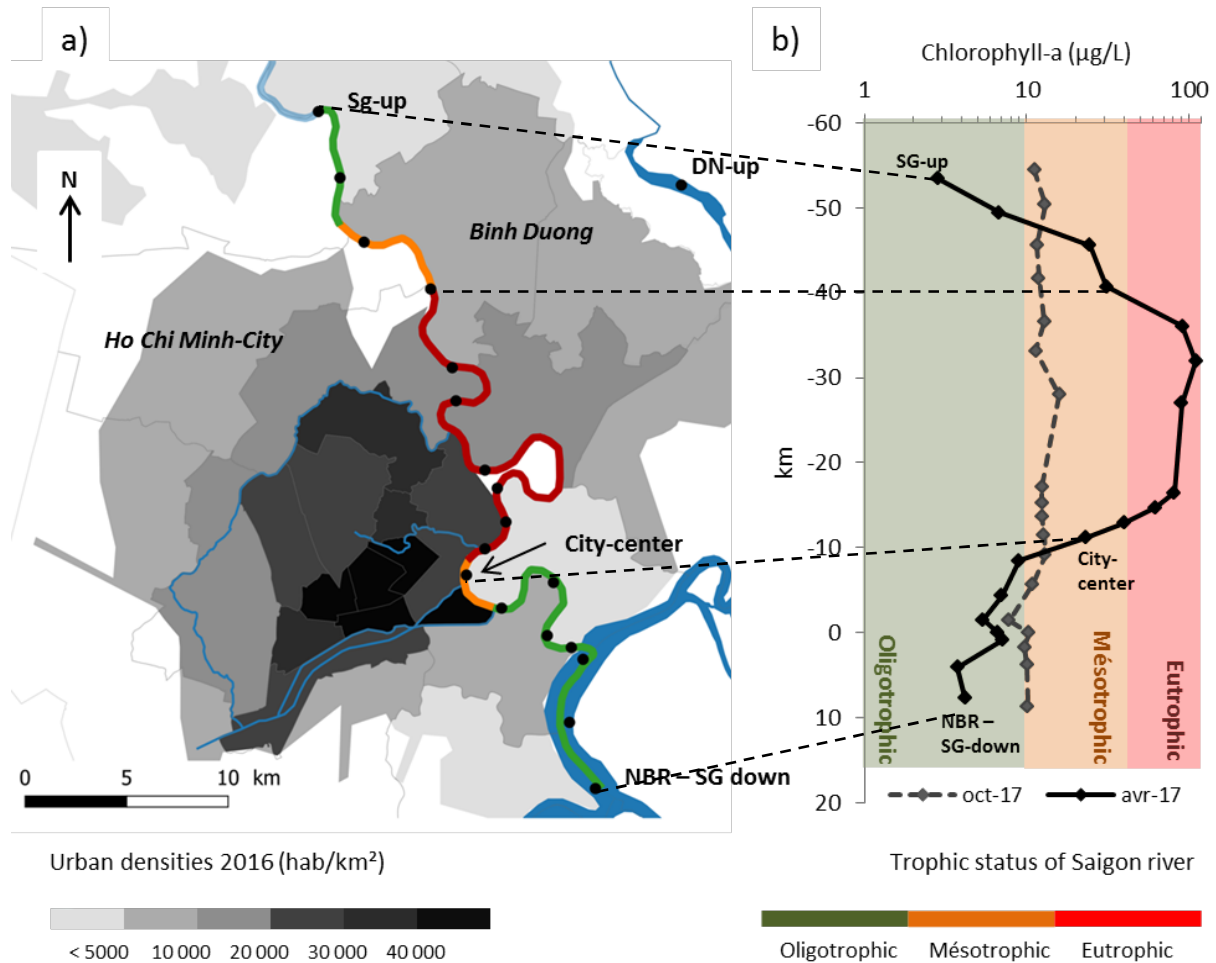


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899 **Table 1.** Classification of trophic levels of rivers and assessment of levels for the four
900 sampling sites in the Saigon – Dongnai Rivers.

901

902 Table 1. Classification of trophic levels of rivers and assessment of levels for the four
 903 sampling sites in the Saigon – Dongnai Rivers.

| Site | DO (mg L⁻¹) | Total N (mg L⁻¹) | Total P (mg L⁻¹) | Chl-a (µg L⁻¹) | Trophic status classification |
|--|---|--|--|--|--|
| According to Dodds et al., 1998 and Dodds and Welch, 2000 | | | | | |
| | >5 | <0.7 | <0.025 | <10 | Oligotrophic |
| | 1-5 | 0.7-1.5 | 0.025-0.075 | 10-30 | Mesotrophic |
| | 0-1 | >1.5 | >0.075 | >30 | Eutrophic |
| Classification of trophic levels of four sampling sites in Saigon – Dongnai Rivers | | | | | |
| SG-up | 2.5 | 1.8 | 0.15 | 3.2 | Mesotrophic |
| SG-city | 1.7 | 3.4 | 0.30 | 29.6 | Eutrophic |
| NBR | 3.6 | 2.2 | 0.12 | 1.6 | Mesotrophic |
| DN-up | 6.1 | 1.5 | 0.09 | 4.7 | Oligotrophic |

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