



HAL
open science

Sources and main controls of dissolved organic and inorganic carbon in river basins: A worldwide meta-analysis

Vincent Chaplot, Macdex Mutema

► **To cite this version:**

Vincent Chaplot, Macdex Mutema. Sources and main controls of dissolved organic and inorganic carbon in river basins: A worldwide meta-analysis. *Journal of Hydrology*, 2021, 603, pp.126941. 10.1016/j.jhydrol.2021.126941 . hal-03430564

HAL Id: hal-03430564

<https://hal.science/hal-03430564>

Submitted on 16 Oct 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

1 **Sources and main controls of dissolved organic and inorganic carbon in**
2 **river basins: a worldwide meta-analysis**

3 Vincent Chplot^{1, 2*} Macdex Mutema³

4 ¹Institut de Recherche pour le Développement (IRD), Laboratoire d'Océanographie et du Climat :
5 Expérimentations et approches numériques, UMR 7159, IRD-CNRS-UPMC-MNHN, 4 place Jussieu,
6 75252 Paris Cedex 05, France

7 ²School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal,
8 PB X01, Scottsville 3209, Pietermaritzburg, South Africa

9 ³Agricultural Research Council-Institute for Agricultural Engineering, PB X519, Silverton 0127,
10 Pretoria, South Africa

11 *Corresponding author: vincent.chaplot@ird.fr

12

13

14 **Abstract**

15 Despite dissolved carbon (C) exports from continents being crucial in the connection between
16 terrestrial, atmospheric and oceanic C pools, the relative contribution and process controls on
17 dissolved organic (DOC) and inorganic (DIC) fluxes within river basins are not fully
18 understood. This paper presents an analysis of data from 843 sites worldwide from 45 Web of
19 Science SCI-Expanded (ex ISI) indexed papers that report both the DOC and DIC contents
20 and fluxes in conjunction with chemical elements, such as Si, Na and ^{13}C abundance, to
21 investigate the likely origin, pathways and fate of the dissolved C. The reviewed papers also
22 report on selected environmental factors (e.g., MAP and MAT: mean annual precipitation and
23 temperature respectively; Climate, LU: land use, A: basin surface area). Regarding dissolved
24 C fluxes rivers transported on average, 8.4 GT C yr⁻¹ of dissolved C with 7.7 GT C yr⁻¹ (92%)
25 being DIC and remaining (8%) DOC. Asia has the highest within-river dissolved C transport
26 (5.8 GT C yr⁻¹) followed by Europe (2.0 GT C yr⁻¹), America (0.4 GT C yr⁻¹), and Africa (0.1
27 GT C yr⁻¹). The dissolved C fluxes tend to increase with river water fluxes and contribution
28 of interflow as seen in the tropical climate, which results in the export of relatively fresh
29 DOC with low aromaticity. In contrast, the lower river water fluxes in sub-tropical and
30 temperate climates corresponds to high concentration of comparatively more decomposed
31 DOC, which pointed to a high proportion of groundwater contribution to the water fluxes.
32 The results also imply that surface area and morphology of the river basins, as well as land
33 use, has insignificant impact on dissolved C dynamics. Such quantitative results, including on
34 the important role of climate on the dynamics of dissolved C in river basins, are helpful in
35 improving predictions on the impact of climate change on the global C cycle. New and
36 innovative multidisciplinary research on the subject is called for.

37

38 **Key words:** C erosion, dissolved C, global C cycle, river water fluxes

39

40

41 **1 Introduction**

42 Rivers transport enormous amounts of carbon (C) from the land to the ocean. They are thus a
43 key element in the connectivity between the terrestrial, atmospheric and oceanic C pools of
44 the global C cycle with important consequences on the regulation of climate, soil and water
45 quality and the overall ecological functioning. Despite that, the amount, quality and spatial
46 patterns of riverine C fluxes are not very well understood. Land C can be exported in
47 particulate, such as particulate organic C (POC) and inorganic C (PIC), and/or dissolved
48 forms, such as dissolved organic C (DOC) and inorganic C (DIC). POC and DOC originate
49 from organic matter (OM) eroded from soils or from aquatic plants. The DOC is a result of
50 the decomposition of OM, while DIC is derived from rock weathering.

51 The exported C varies chemically from easily decomposable to more stable compounds,
52 depending on sources and pathways (Lloret et al., 2016). Virtually all natural water contains
53 some form of DOC, ranging from highly reactive freshly produced DOC to low reactive
54 recalcitrant DOC that escaped remineralization for upwards of 6000 years (Druffel and
55 Williams, 1992). Therefore, a thorough understanding of the riverine C fluxes and their
56 controls is needed, particularly to assess their responses to current and future climatic change
57 and influence of anthropogenic activities. Previous studies have shown that approximately 1
58 Pg C is exported each year from the land to the ocean with 65% of it being dissolved and
59 35% particulate. Sixty percent (60%) of the dissolved C export is inorganic, while 40% is
60 organic (Probst et al., 1994). These data correspond to 0.22 Pg C yr⁻¹ DOC and 0.18 Pg C yr⁻¹
61 POC export; while 0.43 and 0.17 Pg C yr⁻¹ are DIC and PIC export, respectively.

62 Nevertheless, existing literature indicated the existence of large flux variations of these forms
63 of riverine C (Meybeck, 1982; Ludwig et al., 1996; Huang et al., 2012; Regnier et al., 2013),
64 resulting in different impacts on climate, aquatic and terrestrial ecosystems.

65 Humid tropical and subtropical regions of the world are characterized by large C exports
66 (Galy et al., 2015; Hilton, 2017) with their rivers lying between 30°N and S latitudes
67 transporting 62% of the global DOC export to the ocean (Dai et al., 2012). Their estimated
68 export rates of 2.1 and 3.3 t C km⁻² yr⁻¹ for DOC and DIC, respectively, are far above the
69 respective global export averages of 1.4 and 2.6 t C km⁻² yr⁻¹ (Huang et al., 2012). Yet the
70 controls of their exports and ratios between them are scarcely investigated worldwide.

71 Results from the project named ‘Transport of Carbon and Minerals in Major World Rivers’
72 (SCOPE/UNEP) revealed that POC fluxes are a function of total suspended sediments, while
73 DOC fluxes are linked to drainage intensity, basin slope, amount of soil C and C:N ratio
74 (Ludwig et al., 1996). Li et al (2017) indicated that while DOC fluxes were primarily related
75 to discharge ($r^2=0.93$) and soil organic C content ($r^2=0.60$), DIC fluxes correlated to CO₂
76 consumption by rock weathering ($r^2 =0.66$) and river discharge ($r^2=0.63$). While several
77 studies estimated the types of C exported by rivers, little is known about the global variations
78 of the sources of the C, specifically dissolved C.

79 The major sources of riverine organic C are either autochthonous DOC produced by riverine
80 biological activities or allochthonous C from detrital input (Aitkenhead-Peterson et al., 2003).
81 In the case of allochthonous sources, the main driver of the organic C input into river systems
82 is soil erosion. During erosive rainfall events, soil organic C is either intensively leached or
83 eroded and transferred to aquatic ecosystems in dissolved and particulate forms. During low
84 water stages, the DOC input can also be completed by soil water infiltration. The soil organic
85 C (SOC) pool, which contains 1400–1500 Gt of C, is one of the major reservoirs of C
86 (Schlesinger, 1977) storing twice the quantity of C in vegetation. Therefore, any change in

87 SOC abundance and composition has important effect on the global C cycle as well as soil
88 ecosystems.

89 SOC is essentially regulated by biological production and decay rate of organic compounds
90 (Tian et al., 2016). Plant litter falling onto the soil surface is gradually decomposed through
91 physical fragmentation, faunal interactions, mineralization, and humus formation (Baudin et
92 al., 2007). Overall, these processes induce variations in concentration and isotopic
93 composition of total SOC in the soil profile. The decomposition of litter and SOM induces a
94 differential decrease of SOC and nitrogen content in the soils. Carbon and nitrogen are not
95 recycled at the same rate, hence the C/N ratios also vary throughout the soil profile. The C/N
96 ratios are typically higher in the litter fall and lower in SOM due to humification (Yang et al.,
97 2010). Selective degradation changes the stable C isotope ratios. Surface litter is more
98 depleted in ^{13}C than SOM (Lichtfouse et al., 1995), which is progressively enriched with soil
99 depth (Balesdent and Mariotti, 1996; Amiotte-Suchet et al., 1999, 2007). Therefore,
100 highlighting the variations of concentrations and isotopic compositions of soil C (in solid and
101 solute fractions) could help to track the origin of organic C in rivers with respect to their
102 hydrological stages.

103 In their study of a tropical river using C isotopes, Lloret et al. (2016) indicated that DOC
104 derived essentially from both the lixiviation of the soil surface layers during floods and
105 groundwater flow during low water levels. Furthermore, DOC is extensively reworked within
106 rivers through biotic processes such as bacterial degradation as well as abiotic processes such
107 as photo-oxidation, and co-precipitate alongside inorganic minerals and salts. Albéric et al.
108 (2018) further indicated that DOC transported in the Amazon basin exhibited higher $d^{13}\text{C}$ -
109 DOC values, with a lower range in the upper than downstream reaches (-28.0 to -34.6%),
110 which they attributed to increased proportion of fresh DOC from floodplains and open lakes.

111 These authors also reported higher $\delta^{13}\text{C}$ -DOC values during low flows, which they could not
112 fully understood.

113 Despite numerous studies on the C fluxes and the different forms from continents to the
114 ocean, little is known globally about the sources of this C, its pathways and fate, and the main
115 associated controls. Several questions including the following largely remain unanswered.
116 Does riverine DOC originate from top-soils, deep soil horizons or from within stream
117 production? What are the likely dominant pathways from overland flow to the river systems;
118 is it groundwater flow or interflow? How do sources and pathways vary from one climate to
119 the other, from one continent to the other?

120 Several studies reported disparities in DOC and DIC exports under different climates,
121 topographic conditions, land uses and water regimes; hence, there is no consensus yet on the
122 impact of these factors. Although C transformations and interactions between different
123 chemical and size fractions are important in influencing the chemistry and cycling of C in
124 aquatic environments, most studies focused on single C species, preventing a comprehensive
125 understanding of the C dynamics and export fluxes. Determining how the C dynamics vary as
126 flowing water increases in volume from first-order springs until they seep into the great rivers
127 of the world is a central problem in riverine ecology. Moreover, an improved understanding
128 of the pathways of the exported C may allow a better understanding of the origin and overall
129 dynamics of the exported C.

130 The existence of many studies across the world that reported data on DOC and DIC, and on
131 several water chemicals provides opportunities for comprehensive analyses of DOC and DIC
132 fluxes, and their pathways to draw a general understanding of the main controls of these
133 dissolved C dynamics. Therefore, the objective of the current study is to compile and analyze
134 available studies on river DOC and DIC and associated chemicals to assess and quantify their
135 dynamics at river basin level. The information on $\delta^{13}\text{C}$, together with water chemistry, might

136 allow to decipher the C dynamics. In pursuit of these objectives, the study compiled data
137 from 843 sampling locations around the world.

138

139 **2 Materials and Methods**

140 **2.1 Study setup**

141 The study is based on data collected from available literature that reported on dissolved C
142 exports to the ocean through major rivers around the world. The literature search targeted to
143 identify and collect C exports, with specific focus on the dissolved forms (and associated data
144 on isotope ^{13}C and water chemistry to inform on the sources, pathways and quality of
145 dissolved C), from peer reviewed scientific articles published in Web of Science SCI-
146 Expanded (ex ISI) indexed journals. Besides, a number of topic related key words and terms
147 (such as “soil carbon exports from river basins”, “exports of carbon by river systems” and
148 “dissolved carbon losses from landscapes”) were used to search for journal papers in Google,
149 Google Scholar, Science Direct, Springer Link, Scopus and SciFinder.

150 In order to be accepted for inclusion in the analysis, the key criterion was that a paper had to
151 report on the C content and the fluxes of the water exported by a river tied to a time scale.
152 The river name and location had to be stated as well. The search yielded 48 research papers
153 with 843 data points worldwide (Figure 1). Most of the observations (n=223) were in North
154 America as reported by 14 papers. This was followed by 169 observation points (10 papers)
155 in South America, 148 (14 papers) in Europe, 136 (4 papers) in Oceania, 84 (9 papers) in
156 Africa and lastly 81 (7) in Asia. Nevertheless, data from Oceania were not considered in the
157 analysis because 81 of the 84 observations came from Papua New Guinea.

158 Data from the 48 papers were captured and used to build a database with information such as
159 paper author/s and year when paper was published, title of paper, locational details of river
160 studied (i.e., country, continent, latitude, longitude and altitude), characteristics of the river

161 (i.e., length, river basin size, average slope, water temperature, discharge and content in
162 selected chemicals, namely Si: Silicate, Na: Sodium, and ^{13}C isotope), environmental
163 characteristics (climatic data: MAP and MAT, and major land uses) and C discharge
164 (discharge rates of the different forms of C such as DOC, DIC, POC and PIC).

165

166 **2.2 Definitions of environmental factors and variables**

167 Mean annual temperature (MAT, $^{\circ}\text{C}$) and precipitation (MAP, mm yr^{-1}) are the long term (\geq
168 30 year) average values for the basins of the studied rivers, and they are captured MAT and
169 MAP as presented in the source papers. The longitude (LONG), latitude (LAT) and altitude
170 (Z) are for the observation points. In the event MAT and MAP are missing from source
171 papers, data are retrieved either using other research papers in the area or global databases
172 (see Mutema et al, 2015). Length (L, km) refers to the estimated length of the river from its
173 source to the observation point (i.e., outlet to the ocean or to another major river) and Q (m^3
174 s^{-1}) its annual average discharge at the observation point; both are as reported in the source
175 papers. The other factors, such as river water temperature (T_w , $^{\circ}\text{C}$) and pH, are also specific
176 to the observation points used and as reported in the source papers.

177 The variables of interest are dissolved organic (DOCc, mg C l^{-1}) and inorganic C (DICc, mg
178 C l^{-1}) and particulate organic C (POCc, mg C l^{-1}) content within rivers. DOCc and DICc are
179 dissolved organic and inorganic carbon concentrations (mg C l^{-1}), respectively, of water
180 samples from specific observation points as reported in the source papers. POCc is the
181 corresponding concentration of particulate organic carbon (mg C l^{-1}) in the water samples.
182 Therefore, total organic C (TOCc, mg C l^{-1}) is computed as a sum of DOCc and POCc, while
183 total C (TCc, mg C l^{-1}) includes DICc. Si/Na is ratio of silicon to sodium concentration as
184 reported for the water samples analysed.

185 Within-river fluxes were computed as follow:

186
$$DOC_F = \frac{DOC_c \times Q}{A} \quad (\text{Eqn. 1})$$

187
$$DIC_F = \frac{DIC_c \times Q}{A} \quad (\text{Eqn. 2})$$

188 where DOC_F and DIC_F ($\text{g C s}^{-1} \text{ km}^{-2}$) are dissolved organic and inorganic carbon fluxes
189 respectively, DOC_c and DIC_c (g L^{-1}) are the corresponding average dissolved organic and
190 inorganic carbon concentrations, Q (L s^{-1}) is the average discharge of the river at the
191 observation point, and A (km^2) is the area discharge of the catchment draining at the
192 observation point. DOC_F and DIC_F were finally expressed for main world regions in Giga
193 Tons (GT C yr^{-1}) by extrapolating the data to the surface area of each region.

194 Several land use types were considered and the major ones were forests (natural and/or tree
195 plantations), grasslands (include natural veld and planted grasses, and open Savannahs),
196 wetlands (mostly natural, but also included cultivated wetlands such as paddy fields), urban
197 and croplands. The most dominant land use, in terms of fractional area covered, was assigned
198 to a river basin. The climatic regions used in the current study (polar, temperate, sub-tropical
199 and tropical) were inspired by Mutema et al. (2015) and do not necessarily adhere to the
200 Köppen (1936) classification system. These climatic regions are defined in Table 2, where
201 the polar to tropical region transition represents a general increase in air temperature and
202 precipitation.

203

204 **2.3 Data analysis**

205 **2.3.1 Estimation of the sources and pathways of dissolved C**

206 Stable water and C isotopes have been used to determine the origin, pathways and fate of
207 organic substances in river systems (Mayorga et al., 2007; Trumbore, 2009, Zao et al., 2018).
208 Isotopic tracers of hydrogen and oxygen are the most frequently used for estimating the
209 sources of river waters (Lambs, 2004; Xu et al., 2017). However, the limited information on

210 them in conjunction with river water C content calls for alternatives. Easy to access
211 hydrochemical parameters such as anions and cations make it possible to compare the
212 contributions of groundwater versus surface water in river basins (Cook et al., 2003).

213 Si and Na can reasonably be considered as conservative elements and show large
214 concentration differences between water compartments (Mutema and Chaplot, 2018; Chaplot
215 and Ribolzi, 2014; Gomi et al., 2010; Ladouche et al., 2001). For example, water derived
216 from melted snow and ice, and/or overland flow, which had low contact with soils and rocks,
217 exhibits low Si and Na concentrations. As the duration of contact with rocks increases, the
218 chemical content of the water increases. This explains groundwater enrichment, in most
219 cases, in Ca and Na, as a result of the alteration of plagioclase, and interflow being Si
220 enriched. The present study analysed the Si and Na content of the river waters as proxy for
221 identifying the origin of the water transporting dissolved C.

222 In addition, available data on ^{13}C content of the dissolved C were considered to account the
223 level of organic matter (OM) aromaticity, and thus its potential source and fate. In general,
224 fresh OM is depleted in ^{13}C , while the older and decomposed OM is enriched due to selective
225 preservation of plant lignin and lipids (Lichtfouse et al., 1995). Another important variation
226 of ^{13}C abundance in dissolved C depends on the type of plant where it originated from (C3 vs.
227 C4 photosynthetic pathway), which informs on the source of DOC.

228 Data for each sampling data point were confronted to types of climate such as for figure 7
229 and to ^{13}C data (Figure 8).

230

231 **2.3.2 Correlations between dissolved C content, fluxes and main controls**

232 Units for similar factors of control and variables of interest differed from paper to paper.
233 Sometimes the units depicted the spatio-temporal scales at which studies reported in the
234 papers were carried out. Therefore, the first step in the data analysis process was to normalize

235 the data for each factor and/or variable to the same unit. The second step was an analysis for
236 descriptive statistics, such as mean, median, minimum, maximum, standard deviation and
237 standard error of mean, coefficient of variation, kurtosis and skewness. Skewness and
238 kurtosis were used to test normality of dataset distribution. The mean values were tested for
239 significance of differences using the *T-test*. The third step was an exploratory analysis of the
240 main factors controlling the exports of dissolved C using correlation and Principal
241 Component Analysis (PCA). Correlation analyses tested strengths of one-on-one
242 relationships between factors and variables. The correlations were tested for statistical
243 significance at $p < 0.05$. The PCA was used to evaluate multiple relationships between DOCc,
244 DICc, Q and Si/Na on one hand, and factors of control (MAP, MAT, Z: altitude and A: river
245 basin area) on the other. In general, a PCA converts factors and variables into their linear
246 combinations (Jambu, 1991). The last step was a more in-depth analysis of the impacts of
247 selected control factors on the variables using box-plots. Each box plot shows the quartiles
248 for the non-outlier range. Data for each sampling data point were considered for computed
249 the continental mean values displayed in (Table 3) or the worldwide mean values (Table 4).

250

251

252 **3 Results**

253 **3.1 Environmental setting**

254 Table 1 introduces summary statistics for the selected studies worldwide. The mean annual
255 temperatures (MAT) of the river basins under the current study was 16.7°C, with a variation
256 from -3.1°C (USA: Cai et al., 2008) to 27.0°C (Venezuela: Saunders and Lewis, 1988; Paolini
257 et al., 1987, and Nigeria: Martins, 1983). The corresponding mean annual precipitation
258 (MAP) varied from 224 (Pakistan: Arain, 1987) to 4341 mm yr⁻¹ (Costa Rica: Genereux et al.,
259 2013), with a mean of 1456 mm yr⁻¹ (CV=71%).

260 Information on the river characteristics, such as river length, discharge, water temperature
261 and pH, was generally scanty. Nevertheless, the available data showed large variations in the
262 case of river length (CV=139%), with smallest length being 4 for Horonai River in Japan
263 (Shibata et al., 2001) and longest 6290 km for the Amazon (Peru, Colombia and Brazil in
264 South America). River discharge varied even more (CV=355%), but water temperature (37%)
265 had low variation.

266 The DOC content (DOC_c) averaged 5.30 mg C l⁻¹, with values from average 0.7 for some
267 observations in Puerto Rico (Bhatt and McDowell, 2007) to 19.7 mg C l⁻¹ in Venezuela
268 (Paolini et al., 1987). The DIC content (DIC_c) average was 14.85 mg C l⁻¹, which was three
269 times greater than DOC_c. POC content (POC_c) varied from 0.5 mg C L⁻¹ in Japan (Shibata et
270 al., 2001) to 24.2 mg C l⁻¹ in France (Némery et al., 2013), with an average of 5.0 mg C L⁻¹.
271 The corresponding total organic C content (TOC_c) averaged 11.0 mg C l⁻¹. The DIC_c varied
272 between 0.6 for observations in the UK (Neal and Hill, 1994) and 64.4 mg C l⁻¹ for Belgium
273 (Abril et al., 2000). The overall total C (TC_c) , the sum of all organic C forms and DIC,
274 averaged 27.6 mg C l⁻¹, with a variation from 6.5 to 82.1 mg C l⁻¹ (CV=73%).

275

276 **3.2 Within-river DOC and DIC fluxes**

277 **3.2.1 Differences between global regions**

278 Figure 2 shows the variability of DOC_c, DIC_c and the respective DOC_c/DIC_c ratios across
279 global regions. Asian rivers show the highest within-river DOC_c (Figure 2A), with an
280 average of 8.7±1.4 mg C l⁻¹ (Table 3). The other regions do not appear to differ that much
281 among themselves. The European rivers are the second highest with a significantly lower
282 average value of 4.63±1.10 mg C l⁻¹, which is not significantly different from Africa (4.2±1.1
283 mg C l⁻¹), North (4.0±1.1 mg C l⁻¹) and South America (3.9±1.3 mg C l⁻¹). DIC_c shows a

284 different trend (Figure 2B) with European rivers showing the highest average value of
285 $24.1 \pm 0.8 \text{ mg C l}^{-1}$ (Table 3), which is not significantly different from the Asian rivers
286 ($23.9 \pm 1.1 \text{ mg C l}^{-1}$). The North American rivers have significantly lower DICc ($14.0 \pm 1.1 \text{ mg}$
287 C l^{-1}) than the Asian rivers, but significantly higher than the South American rivers (12.0 ± 0.9
288 mg C l^{-1}). The African rivers have the least significant DIC ($8.8 \pm 1.0 \text{ mg C l}^{-1}$). The
289 corresponding DOCc/DICc ratios are depicted in Figure 2C.

290 Table 3 also show that DOC fluxes (DOC_F) descended in the following order: Europe (0.5 g
291 $\text{C s}^{-1} \text{ km}^{-2}$) > Asia ($0.3 \text{ g C s}^{-1} \text{ km}^{-2}$) > South America ($0.1 \text{ g C s}^{-1} \text{ km}^{-2}$) > North America (0.1
292 $\text{g C s}^{-1} \text{ km}^{-2}$) > Africa ($0.04 \text{ g C s}^{-1} \text{ km}^{-2}$). DIC fluxes (DIC_F) show a similar trend, but with
293 higher values than DOC_F at 5.7, 3.9, 0.4, 0.1 and $0.08 \text{ g C s}^{-1} \text{ km}^{-2}$ for Europe, Asia, South
294 and North America, respectively. In terms of DOC (DOC_E) and DIC exports (DIC_E), Asia has
295 the highest values at 0.4 and 5.4 GT C yr^{-1} , respectively, followed by Europe at much lower
296 values (0.2 and 1.8 GT C yr^{-1} , respectively). The other continents have similar DOC_E (0.04 ,
297 0.05 and $0.06 \text{ GT C yr}^{-1}$ for Africa, North and South America, respectively); however, South
298 America show much higher DIC_E (0.2 GT C yr^{-1}) than both North America (0.1 GT C yr^{-1})
299 and Africa ($0.08 \text{ GT C yr}^{-1}$).

300

301 **3.2.2 Differences due to climate**

302 A comparison of DOCc and DICc in different climatic regions shows that DOCc tends to
303 decrease from the cold polar region to the hot and wet tropical area (Figure 3). However,
304 DOCc does not differ significantly among the climatic regions at 5.3 ± 1.1 , 4.3 ± 1.4 , 4.8 ± 1.1
305 and $3.6 \pm 1.5 \text{ mg C l}^{-1}$ for polar, temperate, subtropical and tropical region, respectively
306 (Figure 3A). DICc behaves differently with a general increase from the polar to temperate
307 region, followed by a decrease to the tropical through the subtropical region (Figure 3B). The
308 temperate region rivers show the most significant DICc ($26.3 \pm 0.8 \text{ mg C l}^{-1}$), followed by the

309 subtropical (17.4 ± 0.7 mg C l⁻¹), polar (14.0 ± 0.9 mg C l⁻¹) and tropical region (10.7 ± 1.2 mg C
310 l⁻¹). All the DICc regional average values are significantly different from each other. The
311 corresponding DOCc/DICc ratios show a tendency to be higher in the polar region than the
312 other regions. The average ratios decrease in the order polar (1.5) > subtropical (1.0) >
313 tropical (0.9) > temperate region (0.3).

314

315 **3.2.3 Land use/land cover**

316 Urban rivers appear to have the highest DOCc; however, wetlands show the highest variation
317 of DOCc (Figure 4A). The two land uses are not significantly different with average values of
318 6.6 ± 0.7 and 5.7 ± 1.4 mg C l⁻¹ for urban and wetlands, respectively. Cropland rivers' DOCc
319 (4.3 ± 1.7 mg C l⁻¹) does not differ significantly from urban and wetlands, but forest rivers are
320 significantly lower (4.1 ± 1.2 mg C l⁻¹). Nevertheless, cropland and forest river DOCc are not
321 significantly different. It is also interesting to observe that grassland (3.6 ± 0.9 mg C l⁻¹) and
322 Savannah (3.7 ± 0.7 mg C l⁻¹) do not differ significantly with forest rivers, but the Savannah
323 rivers show greater variation. Urban (22.5 ± 0.5 mg C l⁻¹) and cropland rivers (26.7 ± 0.9 mg C
324 l⁻¹) show much greater DICc than the other land uses, with cropland being significantly
325 greater (Figure 4B). Grassland rivers (19.9 ± 1.0 mg C l⁻¹) are significantly lower than urban
326 areas, but significantly greater than forest (11.0 ± 0.8 mg C l⁻¹) and Savannah (11.6 ± 0.7 mg C
327 l⁻¹), which is not significantly different. Wetlands had the least significant DICc (7.8 ± 1.0 mg
328 C l⁻¹). The corresponding DOCc/DICc ratios (Figure 4C) show considerably higher values in
329 wetlands (1.7), forests (1.2) and also grasslands (0.9). Urban and Savannah are similar (0.6),
330 while croplands have the least average ratio (0.3). However, wetlands and Savannah show
331 high variability in the ratios.

332

333 **3.2.4 Basin area**

334 DOCc show a general tendency to increase with river basin area (Figure 5A). The DOCc
335 increase from basin areas less than $1 \times 10^3 \text{ km}^2$ ($3.2 \pm 1.4 \text{ mg C l}^{-1}$) to 1×10^3 - $1 \times 10^4 \text{ km}^2$
336 ($3.9 \pm 0.9 \text{ mg C l}^{-1}$), before declining slightly to 1×10^4 - $1 \times 10^5 \text{ km}^2$ ($3.0 \pm 1.1 \text{ mg C l}^{-1}$).
337 However, these three are not significantly different. Basin areas 1×10^5 - $1 \times 10^6 \text{ km}^2$ (6.3 ± 1.4
338 mg C l^{-1}) and $>1 \times 10^6 \text{ km}^2$ ($5.8 \pm 1.4 \text{ mg C l}^{-1}$) show significantly higher DOCc, but are not
339 significantly different between themselves. DICc exhibits a different trend; it tends to
340 increase with basin area up to 1×10^4 - $1 \times 10^5 \text{ km}^2$, followed by a general decrease (Figure 5A).
341 The river DICc on the rising side are all significantly different at 12.3 ± 1.1 , 16.7 ± 0.8 and
342 $18.6 \pm 0.7 \text{ mg C l}^{-1}$ for $<1 \times 10^3$, 1×10^3 - 1×10^4 and 1×10^4 - $1 \times 10^5 \text{ km}^2$, respectively. The other
343 two basin sizes are not significantly different at 14.1 ± 1.2 and $13.7 \pm 1.4 \text{ mg C l}^{-1}$ for 1×10^5 -
344 1×10^6 and $>1 \times 10^6 \text{ km}^2$ respectively, which are not also not significantly different from basin
345 area $<1 \times 10^3 \text{ km}^2$. It is important to observe that DICc on the rising side are characterized by
346 greater variability in comparison to the falling side. The corresponding DOC/DIC ratios
347 exhibit a general decrease followed by a rise (Figure 5C). The 1×10^5 - $1 \times 10^6 \text{ km}^2$ basin area
348 show higher DOC/DIC ratio variability than the rest of the basin sizes.

349

350 **3.2.5 Other important factors that control within-river DOC and DIC fluxes**

351 Although many factors were initially considered, a general lack of quantitative data meant
352 many of them could not be accepted for the current analysis. Table 4 shows the correlations
353 between the accepted factors and C related variables. DOCc correlates positively with
354 latitude and longitude ($r=0.27$), and negatively with both MAT (-0.41) and MAP (-0.29). On
355 the other hand, DICc correlates positively with latitude (0.39) and Na (0.60) only, and
356 negatively with river basin area (-0.25), MAP (-0.34), Q (-0.43), SiO_2 (-0.33) and Si/Na (-
357 0.71). The corresponding DOCc/DICc correlates positively with basin area (0.32), MAP
358 (0.31), Q (0.28) and Si/Na (0.50), but negatively with Na (-0.34). POCc, TOCc and TCc

359 correlate positively with longitude and Na; however, TC_c also correlates negatively with
360 MAP (-0.29), Q (-0.33) and Si/Na (-0.42). DOC_F and DIC_F correlate positively with MAP
361 and Q. Nevertheless, DOC_F correlates negatively with Na (-0.35), while DIC_F also correlates
362 negatively with SiO₂ (-0.35). Multiple correlations depicted by the PCA (Figure 6) suggest
363 that DOC_c and DIC_c tend to simultaneously increase with a combination of MAT and
364 latitude, and to decrease with increasing MAP. In contrast, Q and Si/Na tend to increase with
365 MAP, but tend to decrease with increasing MAT and latitude. The combined influence of
366 river basin area and altitude on DOC_c, DIC_c, Q and Si/Na appears to be very weak.

367

368 **3.3 Potential sources of river dissolved carbon**

369 The Si and Na for rivers of the different climatic zones (i.e. polar, temperate, sub-tropical and
370 tropical region) are plotted on a simple Si-Na plane (Figure 7) in order to help in identifying
371 the potential sources of the river waters. The data points from the polar region exhibit a low
372 Si and Na content, which is indicative of diluted waters (Pradeep et al., 2016). The temperate
373 region points are scattered over the Si-Na plane; however, they are in two distinct groups: one
374 high in Na and low in Si, and the other one low in Na and high in Si content. The sub-tropical
375 region points are scattered over the whole Si-Na plane, while those for the tropical region are
376 enriched in Si compared to Na. Analysis of the relationship between Si/Na and δ DOC shows
377 that δ DOC tends to decrease with increasing Si/Na ratios from -27.9‰ at Si/Na<50 to -
378 31.8‰ at Si/Na>200 (Figure 8).

379

380 **4 Discussion**

381 **4.1 Dissolved C fluxes within rivers: organic versus inorganic**

382 Our current analysis revealed that riverine dissolved C fluxes are 8.4 GT C yr⁻¹. This amount
383 is about 76 % of annual GES anthropogenic emissions, which is considerable. Past data from

384 a study by Probst et al. (1994) on the transport of C and minerals in major world rivers
385 showed that approximately 0.65 GT C yr⁻¹ of dissolved C were exported by world rivers from
386 landscapes to the ocean. Other authors reported dissolved C fluxes ranging from 0.58 GT C
387 yr⁻¹ (Cai, 2011; Li et al., 2017), 0.60 GT C yr⁻¹ (Meybeck, 1982) to 0.9 GT C yr⁻¹ (Degens et
388 al., 1991). Therefore, the current analysis estimated dissolved C fluxes within rivers are
389 almost 12 times higher than estimated dissolved C exports to oceans.

390 One possible explanation for the big difference between current and past dissolved C fluxes is
391 that much less dissolved C reaches the ocean than what the same rivers transport from
392 upstream to downstream zones. Some of the dissolved organic matter decomposes and/or
393 adsorb to some chemical elements/compounds and precipitate out of the within stream
394 transport system (e.g., Chaplot and Robolzi, 2014). These processes can cause significant
395 losses of dissolved C between the upstream and downstream zones of a river system. Another
396 possible explanation could be the enhanced impact of (i) elevated atmospheric CO₂ on rock
397 weathering (in the present study, DIC fluxes are 18 times higher than exports reported by
398 Probst et al. (1994)) and (ii) increased temperature and urbanisation on DOC fluxes. Indeed,
399 the intensification of human activities which has contributed to increased atmospheric CO₂
400 and climate change have likely accelerated DOC and DIC exports through organic matter
401 decomposition and rock weathering in recent decades.

402 Our data also show that 92% of the 8.4 GT C yr⁻¹ dissolved C fluxes estimated in the current
403 analysis is inorganic C (7.7 GT C yr⁻¹), while only and 8% is organic C (0.7 GT C yr⁻¹). Both
404 estimates are significantly higher than 0.24 GT C yr⁻¹ reported for DOC (Ludwig et al.,
405 1996), and 0.41 (Huang et al., 2012) and 0.38 GT C yr⁻¹ (Meybeck, 1982) for DIC. One
406 possible explanation for the huge differences might be due to the different methodological
407 approaches used to estimate the fluxes. For instance, Meybeck (1982) estimated global DIC
408 fluxes (0.38 GT C yr⁻¹) based on discharge data at exit of 60 (i.e. 63% of global) rivers. The

409 estimations were not based on data derived from river water samples. They used average
410 water temperature to obtain information regarding the dissolved C concentrations, which they
411 used together with discharge data to estimate the dissolved C fluxes. Ludwig et al. (1996)
412 used a similar methodology to estimate the global DOC export of 0.21 GT C yr⁻¹ on the basis
413 of 29 major rivers. The current study used data from 249 rivers worldwide with most of them
414 not discharging directly into the ocean. Therefore, most of the rivers used in the current study
415 are tributaries and this might have affected the ratios between organic and inorganic C. In
416 general, headwaters are likely to show greater DIC concentration, from rock weathering, than
417 fresh waters exiting continents, which are generally characterised by low PCO₂ and thus DIC
418 carrying capacity.

419

420 **4.2 Sources and quality of dissolved C**

421 The present study points to high concentration in Si and low concentration in Na in rivers
422 from tropical climates, which is indicative of the predominance of interflow water (i.e. water
423 moving laterally in soils within hillslopes) in rivers. Tropical regions are characterised by
424 high rainfalls through the whole year, hence interflow into the rivers is always high which
425 correlates with low proportion of inorganic C and fresh and low aromaticity dissolved
426 organic matter. Albéric et al. (2018), who used C isotopes in a tropical humid basin of the
427 Amazon, suggested that although DOC might have originated from soils there were strong
428 chances that it also came from flooded forests and plankton in flooded lakes due to its
429 depletion in ¹³C.

430 A study in a tropical river from the French West Indies indicated that DIC concentration was
431 higher dry spells when water level was low (Lloret et al., 2011). The DIC concentration was
432 lower during rainy seasons due to partial dilution by rainwater. The same study suggested
433 two possible sources of river DIC. The first one is respiration of plant roots and decay of soil

434 organic matter (SOM) characterised by low $\delta^{13}\text{C}$, while the other one characterised by high
435 $\delta^{13}\text{C}$ is atmospheric CO_2 input. In contrast, DOC during low flows might be autochthonous to
436 the rivers and derived from algal development because groundwater is generally depleted in
437 DOC. Therefore, high DOC concentrations during floods might come from mineral
438 desorption and/or solubilisation of SOM and its transfer into rivers via surface runoff and
439 interflow.

440 Results from the current study also point to relatively low DOCc in tropical rivers, which
441 suggests that these river flows are dominated by interflow. Interflow is characterised by
442 depletion in DOC as large amounts of the DOC are adsorbed by clays and/or sesquioxides
443 within soils. Adsorption is a more efficient process of DOC depletion than decomposition
444 (Jardine et al., 1989). Polar region river water shows low Si and Na concentration, which is
445 indicative of an overland flow origin (Pradeep et al., 2016). A study in Chena River, Alaska,
446 revealed that most of the DOC fluxes occurred during Spring peak flows due to ice and
447 snowmelt, which drove high runoff from C rich soils (Cai et al., 2008). The study also
448 reported DIC enrichment of winter water due to higher groundwater contribution.
449 Groundwater contribution might explain the higher Na content in polar than tropical region
450 river observed in the current study (Pradeep et al., 2016). High DOCc/DICc ratios in polar
451 regions might come from peatlands from boreal forest as shown for instance by Elder et al.
452 (2000).

453 The DOC from polar rivers exhibits the lowest $\delta^{13}\text{C}$ among the climates under study, which is
454 indicative of fresh organic matter (Dijkstra et al., 2006). Such organic matter originates not
455 only from snowmelt events that flush elevated DOC from surface soils, but also from riverine
456 primary production (e.g. algal blooms in rivers during summer) (Dijkstra et al., 2006).

457 The present study also points to significant impact of water fluxes, dominant land use and
458 river basin surface area on DOC. For example, DOC increases by 2.5 fold from river basin

459 areas less than 1 million km² to those more than 4 million km². In a study of 109 rivers across
460 the world, Li et al. (2017) reported a significant increase of dissolved C fluxes as water fluxes
461 increased, which the present study confirms but with much lower correlation coefficients of
462 0.55 and 0.48 for DOC_F and DIC_F, respectively, as compared to respectively 0.97 and 0.84.
463 While Li et al. (2017) did not present data on dissolved C content, the current study show that
464 as water fluxes in river basins increase, DOC_c and DIC_c decrease, which is indicative of a
465 dilution effect as elaborated above. Drainage intensity, slope, sediment loads, soil C content
466 and C/N ratio, which are not considered in the current study, also have significant impacts on
467 riverine dissolved C fluxes (Li et al., 2017; 1996; McDowell, 2000).

468 The impact of land use, especially vegetation cover, on dissolved C fluxes is intuitive for
469 organic C. For instance, Mchunu and Chaplot (2012) showed that a decrease in grass basal
470 cover in the process of grassland degradation increased DOC in surface runoff from 3.8 to 7.2
471 g l⁻¹. Other studies reported higher DOC contents under forest and tilled soils than no-tilled
472 croplands (e.g. Mchunu et al., 2011). Furthermore, the anthropological impact on riverine
473 dissolved C has been recognized. For example, Raymond et al. (2008) reported that DIC has
474 dramatically increased in the Mississippi River during the last 70 years in response to the
475 intensification of agriculture, while rivers crossing urbanized areas have notoriously high
476 DOC_c. The enormous amount of dissolved C transported by Asian rivers as compared to
477 other continental rivers is most probably a result of a combination of factors including high
478 content of SOC, urbanisation and intensification of agriculture in the face of climate change.

479

480 **Conclusions**

481 Three main conclusions are drawn from this study involving 843 data points of dissolved C
482 content and fluxes from 249 rivers worldwide. The first conclusion is that most of the
483 dissolved C transported by world rivers is inorganic (92% or 7.7 GT C yr⁻¹); the organic form

484 is a much smaller fraction (8% or 0.67 GT C yr⁻¹). The Asian rivers transport the highest
485 amount (5.8 GT C yr⁻¹) of dissolved C, followed by Europe (2.0 GT C yr⁻¹), America (0.4 GT
486 C yr⁻¹) and Africa (0.1 GT C yr⁻¹). The second conclusion is that most of the tropical river
487 water originates from interflow because the dissolved C in the rivers of this region is mostly
488 young and of low aromaticity. Semi-arid region river water is dominated by groundwater
489 contribution because the dissolved C is more stable, while the polar region rivers show a
490 dominance of both groundwater and surface runoff. The third conclusion is the tendency for
491 dissolved organic C fluxes to dramatically increase with increase in river basin surface area
492 supporting the notion that within stream C production by algae, lixiviation of flooded soils
493 and urbanised areas could be the most significant sources of dissolved organic and inorganic
494 C fluxes. The results of the study also suggest that areas that are getting warmer and wetter,
495 due to climate change, are more likely to experience increased dissolved organic and
496 inorganic C exports due to increased organic matter decomposition and rock weathering as
497 already seen in the polar region where massive amounts of DOC are released from peatlands.
498 In contrast, drying areas will likely experience increased export of old and decomposed
499 organic matter from the water table, which is more likely to be stable during riverine
500 transportation to the ocean. More studies are still needed to confirm the trends observed by
501 the study and their potential impact on the Global C Cycle and their retroactions to climate
502 change. There is finally a need for studies on C fluxes within rivers to consider entire years.

503

504 **Acknowledgements**

505 The authors acknowledge Fantine Nivet for help in data collection, the WRC for supporting
506 our research on carbon dynamics at basin level (Project K52266), the French Institute for

507 Sustainable Development and the Agricultural Research Council-Institute for Agricultural
508 Engineering, South Africa.

509

510

511 **References**

- 512 Abril G, Etcheber H, Borges AV, Frankignoulle M. 2000. Excess atmospheric carbon dioxide
513 transported by rivers into the Scheldt estuary. *Comptes Rendus de l'Académie des*
514 *Sciences - Series IIA - Earth and Planetary Science* 330 (11), 761–768.
- 515 Aitkenhead-Peterson JA, McDowell WH, Neff JC. 2003. Sources, production and regulation
516 of allochthonous dissolved organic matter input to surface waters. In: Findlay S and
517 Sinsabaugh RL (Eds) *Aquatic Ecosystems: Interactivity of Dissolved Organic Matter*.
518 Academic Press: USA, 25–70.
- 519 Albéric P, Pérez M, Moreira-Turcq P, Benedetti M, Bouillon S, Abril G. 2018. Variation of
520 the isotopic composition of dissolved organic carbon during the runoff cycle in the
521 Amazon River and the floodplains. *C. R. Geoscience* 350 (2018) 65–75
- 522 Alin SR, Aalto R, Goni MA, Richey JE, Dietrich WE. 2008. Biogeochemical characterization
523 of carbon sources in the Strickland and Fly rivers, Papua New Guinea. *Journal of*
524 *Geophysical Research: Earth Surface* 113 (F1): F01S05.
- 525 Amiotte-Suchet P, Aubert D, Probst JL, Gauthier-Lafaye F, Probst A, Andreux F, Viville D.
526 1999. $\delta^{13}\text{C}$ pattern of dissolved inorganic carbon in a small granitic catchment: The
527 Strengbach case study (Vosges Mountains, France). *Chemical Geology* 159, 129–145.
- 528 Amiotte-suchet P, Linglois N, Leveque J, Andreux F. 2007. ^{13}C composition of dissolved
529 organic carbon in upland forested catchments of the Morvan Mountains (France):
530 influence of coniferous and deciduous vegetation. *Journal of Hydrology* 335: 354 –
531 363.
- 532 Arain R. 1987. Persisting Trends in Carbon and Minerals Transport Monitoring of the Indus
533 River. In: Degens ET, Kempe S and Soliman H (Eds) *Transport of carbon and*

534 *minerals in major world rivers, vol 4*. SCOPE/UNEP Sonderband: Hamburg, 417–
535 421.

536 Balesdent J, Mariotti A. 1996. Measurement of soil organic matter turnover using ¹³C natural
537 abundance. In: Boutton TW and Yamasaki SI (Eds.), *Mass spectrometry of soils*,
538 Marcel Dekker, New York (1996), pp. 83-111.

539 Bass AM, Munksgaard NC, Leblanc M, Tweed S, Bird MI. 2014. Contrasting carbon export
540 dynamics of human impacted and pristine tropical catchments in response to a short-
541 lived discharge event. *Hydrological Processes* 28 (4), 1835–1843.

542 Baudin F, Tribouvillard N, Trichet J. 2007. *Géologie de la Matière Organique*. Société
543 Géologique de France, Vuibert, Paris, France (2007), p. 272

544 Bhatt MP, McDowell WH. 2007. Controls on major solutes within the drainage network of a
545 rapidly weathering tropical watershed. *Water Resources Research* 43 (11): W11402,
546 doi: 10.1029/2007WR005915.

547 Boeglin J-L, Probst J-L, Ndam-Ngoupayou J-R, Nyeck B, Etcheber H, Mortatti J, Braun J-J.
548 2005. Soil carbon stock and river carbon fluxes in humid tropical environments: the
549 Nyong river basin (south Cameroon). In: Roose EJ, Lal R, Feller C, Barthes B and
550 Stewart BA (eds) *Soil Erosion and Carbon Dynamics*. CRC Press: Boca Raton, 275–
551 287.

552 Bouillon S, Yambélé A, Spencer RGM, Gillikin DP, Hernes PJ, Six J, Merckx R, Borges AV.
553 2012. Organic matter sources, fluxes and greenhouse gas exchange in the Oubangui
554 River (Congo River basin). *Biogeosciences* 9 (6), 2045–2062.

555 Bouillon S, Abril G, Borges AV, Dehairs F, Govers G, Hughes HJ, Merckx R, Meysman
556 FJR, Nyunja J, Osburn CL, Middelburg JJ. 2009. Distribution, origin and cycling of
557 carbon in the Tana River (Kenya): a dry season basin-scale survey from headwaters to
558 the delta. *Biogeosciences* 6 (11), 2475–2493.

559 Bradley C, Baker A, Cumberland S, Boomer I, Morrissey IP. 2007. Dynamics of water
560 movement and trends in dissolved carbon in a headwater wetland in a permeable
561 catchment. *Wetlands* 27 (4), 1066–1080.

562 Brunet F, Gaiero DM, Probst J-L, Depetris PJ, Gauthier Lafaye F, Stille P. 2005. $\delta^{13}\text{C}$ tracing
563 of dissolved inorganic carbon sources in Patagonian rivers (Argentina). *Hydrological*
564 *Processes* 19 (17), 3321–3344.

565 Cai W-J. 2011. Estuarine and coastal ocean carbon paradox: CO₂ sinks or sites of terrestrial
566 carbon incineration? *Annual Review of Marine Science* 3, 123–145.

567 Cai Y, Guo L, Douglas TA. 2008. Temporal variations in organic carbon species and fluxes
568 from the Chena River, Alaska. *Limnology and Oceanography* 53 (4), 1408–1419.

569 Chaplot V, Ribolzi O. 2014. Hydrograph separation to improve understanding of dissolved
570 organic carbon dynamics in headwater catchments. *Hydrological Processes* 28, 5353-
571 5366.

572 Dai M, Yin Z, Meng F, Liu Q, Cai W-J. 2012. Spatial distribution of riverine DOC inputs to
573 the ocean: an updated global synthesis. *Current Opinion in Environmental*
574 *Sustainability* 4, 170–178.

575 Degens ET, Kempe S, Richey JE (Eds). 1991. *Biogeochemistry of major world rivers*. Wiley:
576 Chichester.

577 Depetris PJ, Cascante E. 1985. Carbon transport in the Paraná river. In: Degens ET, Kempe S
578 and Soliman H (Eds) *Transport of carbon and minerals in major world rivers*, vol 3.
579 SCOPE/UNEP Sonderband: Hamburg, 299–304.

580 Dijkstra P, Ishizu A, Doucett R, Hart SC, Schwartz E, Menyailo OV, Hungate BA. 2006. ^{13}C
581 and ^{15}N natural abundance of the soil microbial biomass. *Soil Biology and*
582 *Biochemistry* 38 (11), 3257-3266.

583 Druffel ERM, Williams PM. 1992. Importance of isotope measurements in marine organic
584 geochemistry. *Marine Chemistry* 39, 209–216.

585 Elder JF, Rybicki NB, Carter V. 2000. Sources and yields of dissolved carbon in northern
586 Wisconsin stream catchments with differing amounts of peatland. *Wetlands* 20, 113–
587 125.

588 Ferguson PR, Dubois KD, Veizer J. 2011. Fluvial carbon fluxes under extreme rainfall
589 conditions: Inferences from the Fly River, Papua New Guinea. *Chemical Geology* 281
590 (3), 283–292.

591 Galy V, Peucker-Ehrenbrink B, Eglinton T. 2015. Global carbon export from the terrestrial
592 biosphere controlled by erosion. *Nature* 521, 204–207.

593 Genereux DP, Nagy LA, Osburn CL, Oberbauer SF. 2013. A connection to deep groundwater
594 alters ecosystem carbon fluxes and budgets: Example from a Costa Rican rainforest.
595 *Geophysical Research Letters* 40 (10), 2066–2070.

596 Giesler R, Mörth C-M, Karlsson J, Lundin EJ, Lyon SW, Humborg C. 2013. Spatiotemporal
597 variations of pCO₂ and δ¹³C-DIC in subarctic streams in northern Sweden. *Global*
598 *Biogeochemical Cycles* 27 (1), 176–186.

599 Gomi T, Asano Y, Uchida T, Onda Y, Sidle RC, Miyata S, Kosugi K, Mizugaki S, Fukuyama
600 T, Fukushima T. 2010. Evaluation of storm runoff pathways in steep nested
601 catchments draining a Japanese cypress forest in central Japan: a geochemical
602 approach. *Hydrological Processes* 24, 550-566.

603 Hart RC. 1987. Carbon transport in the Upper Orange River. In: Degens ET, Kempe S and
604 Soliman H (Eds) *Transport of carbon and minerals in major world rivers*, vol 4.
605 SCOPE/UNEP Sonderband: Hamburg, 509–512.

606 Hilton RG. 2017. Climate regulates the erosional carbon export from the terrestrial biosphere
607 *Geomorphology* 277, 118-132.

- 608 Huang T-H, Fu Y-H, Pan P-Y, Chen C-TA. 2012. Fluvial carbon fluxes in tropical rivers.
609 *Current Opinion in Environmental Sustainability* 4 (2), 162–169.
- 610 Hunt CW, Salisbury JE, Vandemark D. 2011. Contribution of non-carbonate anions to total
611 alkalinity and overestimation of pCO₂ in New England and New Brunswick rivers.
612 *Biogeosciences* 8 (10), 3069–3076.
- 613 Jambu M. 1991. Exploratory and Multivariate Data Analysis, Academic, Orlando, Fla.
- 614 Jantze EJ, Laudon H, Dahlke HE, Lyon SW. 2015. Spatial Variability of Dissolved Organic
615 and Inorganic Carbon in Subarctic Headwater Streams. *Arctic, Antarctic and Alpine*
616 *Research* 47 (3), 529–546.
- 617 Jardine PM, Weber NL, McCarthy JF. 1989. Mechanisms of dissolved organic carbon
618 adsorption on soil. *Soil Science Society of America Journal* 53, 1378-1385.
- 619 Kanduč T, Szramek K, Ogrinc N, Walter LM. 2007. Origin and cycling of riverine inorganic
620 carbon in the Sava River watershed (Slovenia) inferred from major solutes and stable
621 carbon isotopes. *Biogeochemistry* 86 (2), 137–154.
- 622 Kempe S. 1988. Freshwater carbon and the weathering cycle. In: Lerman A and Meybeck M
623 (Eds) *Physical and Chemical Weathering in Geochemical Cycles*. Springer Science &
624 Business Media: Dordrecht, Boston, London, 197–223.
- 625 Köppen W. 1936. Das geographische System des Klimate. In: Köppen W and Geiger R (Eds)
626 *Handbuch der Klimatologie*. Gebrüder Borntraeger: Berlin, 1–44.
- 627 Ladouche B, Probst A, Viville D, Idir S, Baqué D, Loubet M, Probst J-L, Bariac T. 2001.
628 Hydrograph separation using isotopic, chemical and hydrological approaches
629 (Strengbach catchment, France). *Journal of Hydrology* 242, 255-274.
- 630 Lalah JO, Wandiga SO. 2006. Extinction Coefficients and Dissolved Organic Carbon Content
631 in Freshwater in Kenya. *Bulletin of Environmental Contamination and Toxicology* 77
632 (4), 533–542.

633 Lambs L. 2004. Interactions between groundwater and surface water at river banks and the
634 confluence of rivers. *Journal of Hydrology* 288, 312-326.

635 Li ZX, Bogdanova SV, Collins AS, Davidson A, De Waele B, Ernst RE, Fitzsimons ICW,
636 Fuck RA, Gladkochub DP, Jacobs J, Karlstrom KE, Lu S, Natapov LM, Pease V,
637 Pisarevsky SA, Thrane K, Vernikovsky V. 2008. Assembly, configuration, and break-
638 up history of Rodinia: A synthesis. *Precambrian Research* 160 (1), 179–210.

639 Lichtfouse É, Dou S, Girardin C, Grably M, Balesdent J, Behar F, Vandenbroucke M. 1995.
640 Unexpected ¹³C-enrichment of organic components from wheat crop soils: evidence
641 for the in situ origin of soil organic matter. *Organic Geochemistry* 23, 865-868.

642 Lloret E, Dessert C, Gaillardet J, Albéric P, Crispi O, Chaduteau C, Benedetti MF. 2011.
643 Comparison of dissolved inorganic and organic carbon yields and fluxes in the
644 watersheds of tropical volcanic islands, examples from Guadeloupe (French West
645 Indies). *Chemical Geology* 280 (1–2), 65–78.

646 Lloret E, Dessert C, Pastor L, Lajeunesse E, Crispi O, Gaillardet J, Benedetti MF. 2013.
647 Dynamic of particulate and dissolved organic carbon in small volcanic mountainous
648 tropical watersheds. *Chemical Geology* 351, 229–244.

649 Lloret E, Dessert C, Buss HL, Chaduteau C, Huon S, Albéric P, Benedetti MF. 2016. Sources
650 of dissolved organic carbon in small volcanic mountainous tropical rivers, examples
651 from Guadeloupe (French West Indies). *Geoderma* 282, 129–138.

652 Lu YH, Bauer JE, Canuel EA, Chambers RM, Yamashita Y, Jaffé R, Barrett A. 2014. Effects
653 of land use on sources and ages of inorganic and organic carbon in temperate
654 headwater streams. *Biogeochemistry* 119 (1–3), 275–292.

655 Ludwig W, Probst J-L, Kempe S. 1996. Predicting the oceanic input of organic carbon by
656 continental erosion. *Global Biogeochemical Cycles* 10 (1), 23–41.

657 Martins O. 1983. Transport of carbon in the Niger River. *Mitt. Geo1.-Palaeont. Inst., Uniu.*
658 *Hamburg*, 55, 435449.

659 Mayorga E, Hedges JI, Llerena C, Quay PD, Gudeman J, Krusche AV, Richey JE,
660 Aufdenkampe AK. 2007. Organic matter in the Peruvian headwaters of the Amazon:
661 Compositional evolution from the Andesto the lowland Amazon mainstream. *Organic*
662 *Geochemistry* 38, 337–364.

663 Mayorga E, Aufdenkampe AK, Masiello CA, Krusche AV, Hedges JI, Quay PD, Richey JE,
664 Brown TA. 2005. Young organic matter as a source of carbon dioxide outgassing
665 from Amazonian rivers. *Nature* 436 (7050), 538–541.

666 Mchunu C, Manson A, Jewitt G, Lorentz S, Chaplot V. 2011. No-Till impact on soil and Soil
667 organic carbon erosion under crop residues scarcity in South Africa. *Soil Science*
668 *Society America Journal* 75 (4), 1503–1512.

669 Mchunu C, Chaplot V. 2012. Land degradation impact on soil carbon losses through water
670 erosion and CO₂ emissions. *Geoderma* 177-178, 72–79.

671 Meybeck M. 1982. Carbon, Nitrogen, and Phosphorus Transport by World Rivers. *American*
672 *Journal of Science* 282 (4), 401–450.

673 Meybeck M, Ragu A. 1995. *River Discharges to the Oceans: An Assessment of Suspended*
674 *Solids, Major Ions and Nutrients*. UNEP.

675 Moyer RP, Bauer JE, Grotoli AG. 2013. Carbon isotope biogeochemistry of tropical small
676 mountainous river, estuarine, and coastal systems of Puerto Rico. *Biogeochemistry*
677 112 (1–3), 589–612.

678 Mutema M, Chaplot V, Jewitt G, Chivenge P, Blöschl G. 2015. Annual water, sediment,
679 nutrient, and organic carbon fluxes in river basins: A global meta-analysis as a
680 function of scale. *Water Resources Research* 51 (11), 8949–8972.

681 Mutema M, Chaplot V. 2018. Changes in streamflow contributions with increasing spatial
682 scale in Thukela basin, South Africa. *Physics and Chemistry of the Earth* 105, 32-43.

683 Neal C, Hill S. 1994. Dissolved inorganic and organic carbon in moorland and forest streams:
684 Plynlimon, Mid-Wales. *Journal of Hydrology* 153 (1): 231–243.

685 Némery J, Mano V, Coynel A, Etcheber H, Moatar F, Meybeck M, Belleudy P, Poirel A.
686 2013. Carbon and suspended sediment transport in an impounded alpine river (Isère,
687 France). *Hydrological Processes* 27 (17), 2498–2508.

688 Pall P, Vilbaste S, Kõiv T, Kõrs A, Käiro K, Laas A, Nõges P, Nõges T, Piirsoo K, Toomsalu
689 L, Viik M. 2011. Fluxes of carbon and nutrients through the inflows and outflow of
690 Lake Võrtsjärv, Estonia. *Estonian Journal of Ecology* 60 (1), 39–53.

691 Paolini JE, Hevia R, Herrera R. 1987. Transport of Carbon and Minerals in the Orinoco and
692 Caroni Rivers during the Years 1983-1984. In: Degens ET, Kempe S and Soliman H
693 (Eds) *Transport of carbon and minerals in major world rivers, vol 4*. SCOPE/UNEP
694 Sonderband: Hamburg, 325–338.

695 Pradeep K, NapolianM, Anandhan P, Chandran, Kaviyarasan R, Prasanna MV, Chidambaram
696 S. 2016. A study on variation in dissolved silica concentration in groundwater of hard
697 rock aquifers in Southeast coast of India. *IOP Conference Series: Materials Science
698 and Engineering* 121, 012008, doi:10.1088/1757-899X/121/1/012008.

699 Probst JL, Amiotte Suchet P, Ludwig W. 1994. Continental erosion and river transport of
700 carbon to oceans. *Trends in Hydrology* 1, 453–468.

701 Raymond PA, Hartmann J, Lauerwald R, Sobek S, McDonald C, Hoover M, Butman D,
702 Striegl R, Mayorga E, Humborg C, Kortelainen P, Dürr H, Meybeck M, Ciais P, Guth
703 P. 2013. Global carbon dioxide emissions from inland waters. *Nature* 503, 355–359.

704 Raymond PA, Bauer JE. 2001. Riverine export of aged terrestrial organic matter to the North
705 Atlantic Ocean. *Nature*, 409, 497-499.

706 Raymond PA, Oh NH, Turner RE, Broussard W. 2008. Anthropogenically enhanced fluxes
707 of water and carbon from the Mississippi River. *Nature* 451, 449– 52.

708 Regnier P, Friedlingstein P, Ciais P, Mackenzie FT, Gruber N, Janssens IA, Laruelle GG,
709 Lauerwald R, Luysaert S, Andersson AJ, Arndt S, Arnosti C, Borges AV, Dale AW,
710 Gallego-Sala A, Godd ris Y, Goossens N, Hartmann J, Heinze C, Ilyina T, Joos F,
711 LaRowe DE, Leifeld J, Meysman FJR, Munhoven G, Raymond PA, Spahni R,
712 Suntharalingam P, Thullner M. 2013. Anthropogenic perturbation of the carbon fluxes
713 from land to ocean. *Nature Geoscience* 6 (8), 597–607.

714 Safiullah S, Mofizuddin M, Iqbal Ali SM, Enamul Kabir S. 1987. Biogeochemical Cycles of
715 Carbon in the rivers of Bangladesh. In: Degens ET, Kempe S and Soliman H (Eds)
716 Transport of carbon and minerals in major world rivers, vol 4. SCOPE/UNEP
717 Sonderband: Hamburg, 435–442.

718 Saunders JF, Lewis WM. 1988. Transport of phosphorus, nitrogen, and carbon by the Apure
719 River, Venezuela. *Biogeochemistry* 5 (3), 323–342.

720 Schlesinger WH. 1977. Carbon balance in terrestrial detritus. *Annual Review of Ecology and*
721 *Systematics* 8, 51– 81.

722 Semp r  R, Charri re B, Van Wambeke F, Cauwet G. 2000. Carbon inputs of the Rh ne
723 River to the Mediterranean Sea: Biogeochemical implications. *Global*
724 *Biogeochemical Cycles* 14: 669–681.

725 Shibata H, Mitsunashi H, Miyake Y, Nakano S. 2001. Dissolved and particulate carbon
726 dynamics in a cool-temperate forested basin in northern Japan. *Hydrological*
727 *Processes* 15 (10), 1817–1828.

728 Sholkovitz ER. 1976. Flocculation of dissolved organic and inorganic matter during the
729 mixing of river water and seawater. *Geochimica et Cosmochimica Acta* 40 (7), 831–
730 845.

731 Teodoru CR, Nyoni FC, Borges AV, Darchambeau F, Nyambe I, Bouillon S. 2015.
732 Dynamics of greenhouse gases (CO₂, CH₄, N₂O) along the Zambezi River and major
733 tributaries, and their importance in the riverine carbon budget. *Biogeosciences* 12 (8),
734 2431–2453.

735 Tian Q, He H, Cheng W, Bai Z, Wang Y, Zhang X. 2016. Factors controlling soil organic
736 carbon stability along a temperate forest altitudinal gradient. *Scientific Reports* 6,
737 18783, doi: 10.1038/srep18783.

738 Tipping E, Marker AFH, Butterwick C, Collett GD, Cranwell PA, Ingram JKG, Leach DV,
739 Lishman JP, Pinder AC, Rigg E, Simon BM. 1997. Organic carbon in the Humber
740 rivers. *Science of The Total Environment* 194–195: 345–355.

741 Trumbore SE, Druffel ERM. 1995. Carbon isotopes for characterizing sources and turnover
742 of non-living organic matter. In: Zepp RG and Sonntag C (Eds) *Role of Non-living*
743 *Organic Matter in the Earth's Carbon Cycle*. John Wiley & Sons Ltd: Chichester, 7–
744 22.

745 Tweed S, Leblanc M, Bass A, Harrington GA, Munksgaard N, Bird MI. 2015. Leaky
746 savannas: the significance of lateral carbon fluxes in the seasonal tropics.
747 *Hydrological Processes* 30 (6), 873–887.

748 Vihermaa LE, Waldron S, Garnett MH, Newton J. 2014. Old carbon contributes to aquatic
749 emissions of carbon dioxide in the Amazon. *Biogeosciences* 11 (13), 3635–3645.

750 Walsh G, Vigneault Y. 1986. Analyse de la qualité de l'eau de rivières de la Côte-Nord du
751 golfe St-Laurent en relation avec les processus d'acidification. Direction de la
752 recherche sur les pêches, Ministère des pêches et des océans: Cap Diamant, 118.

753 Wang L, Song C, Song Y, Guo Y, Wang X, Sun X. 2010. Effects of reclamation of natural
754 wetlands to a rice paddy on dissolved carbon dynamics in the Sanjiang Plain,
755 Northeastern China. *Ecological Engineering* 36 (10), 1417–1423.

- 756 Yang YH, Fang JY, Guo DL, Ji CJ, Ma WH. 2010. Vertical patterns of soil carbon, nitrogen
757 and carbon: nitrogen stoichiometry in Tibetan grasslands. *Biogeosciences*
758 *Discussions*, 7, 1-24.
- 759 Zhao D, Wang G, Liao F, Yang N, Jiang W, Guo L, Liu C, Shi Z. 2018. Groundwater-surface
760 water interactions derived by hydrochemical and isotopic (^{222}Rn , deuterium, oxygen-
761 18) tracers in the Nomhon area, Qaidam Basin, NW China. *Journal of Hydrology*,
762 650-661.
- 763 Zheng PP, Dian LW, Yü WZ, Bolin X. 1987. Carbon transport into the Bohai Gulf from the
764 Lower Haihe River Basin (Tianjin Metropolitan Region). In: Degens ET, Kempe S
765 and Soliman H (Eds) *Transport of carbon and minerals in major world rivers*, vol 4.
766 SCOPE/UNEP Sonderband: Hamburg, 139–152.

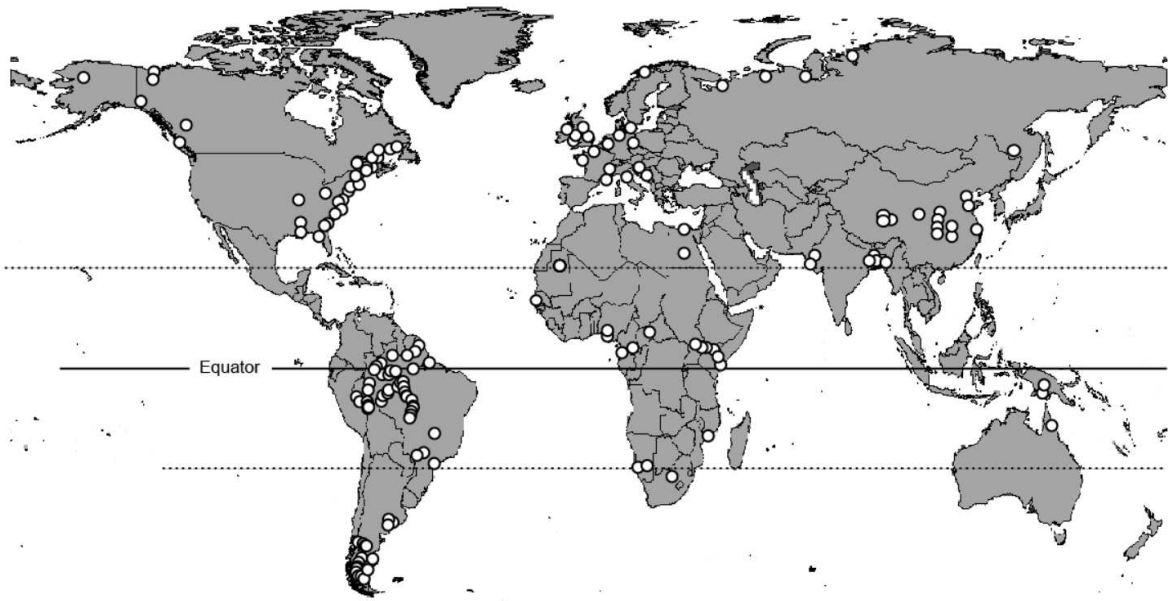


Figure 1. Location of the sampling data points

a

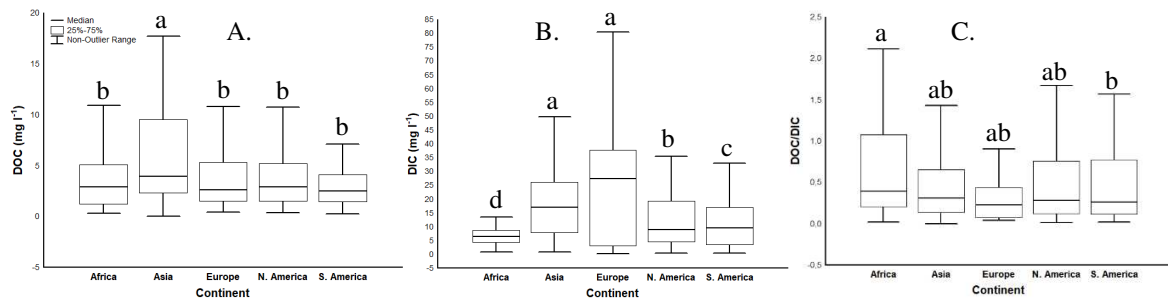


Figure 2. Comparisons of DOCc, DICc and DOCc/DICc from different continents. Box plots accompanied by similar small letters in each figure are not significantly different ($p < 0.05$).

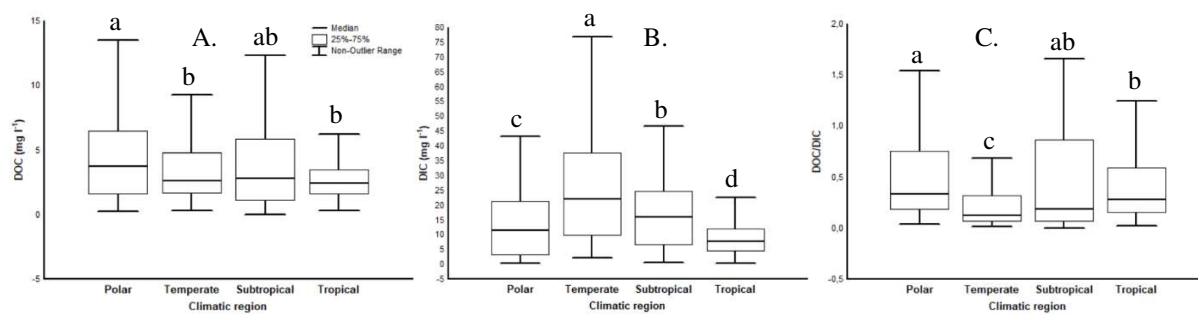


Figure 3. Comparisons of DOC_c, DIC_c and DOC_c/DIC_c from different climatic regions. Box plots accompanied by similar small letters in each figure are not significantly different ($p < 0.05$).

b

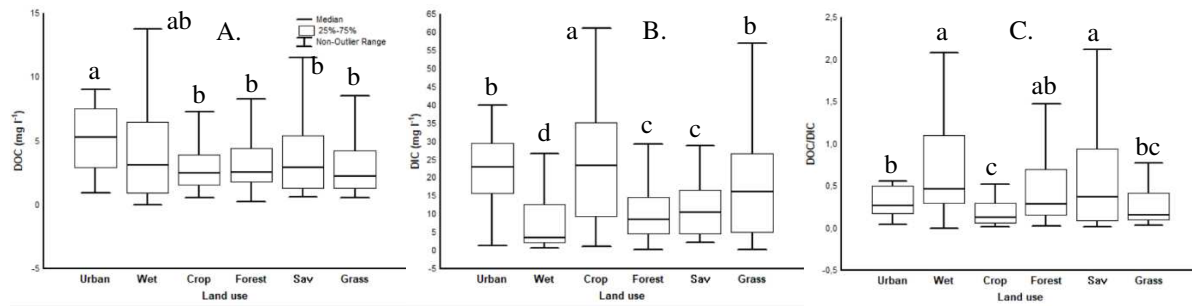


Figure 4. Comparisons of DOCc, DICc and DOCc/DICc in river basins from different land uses/land covers. Box plots accompanied by similar small letters in each figure are not significantly different ($p < 0.05$).

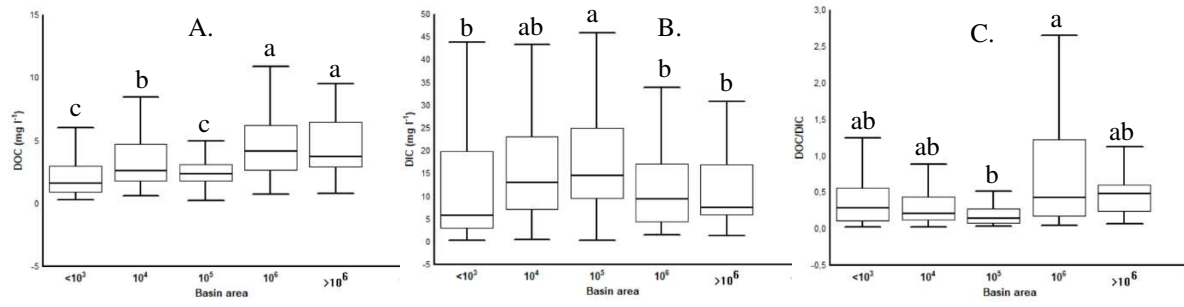


Figure 5. Comparisons of DOCc, DICc and DOCc/DICc from different basin areas. Box plots accompanied by similar small letters in each figure are not significantly different ($p < 0.05$).

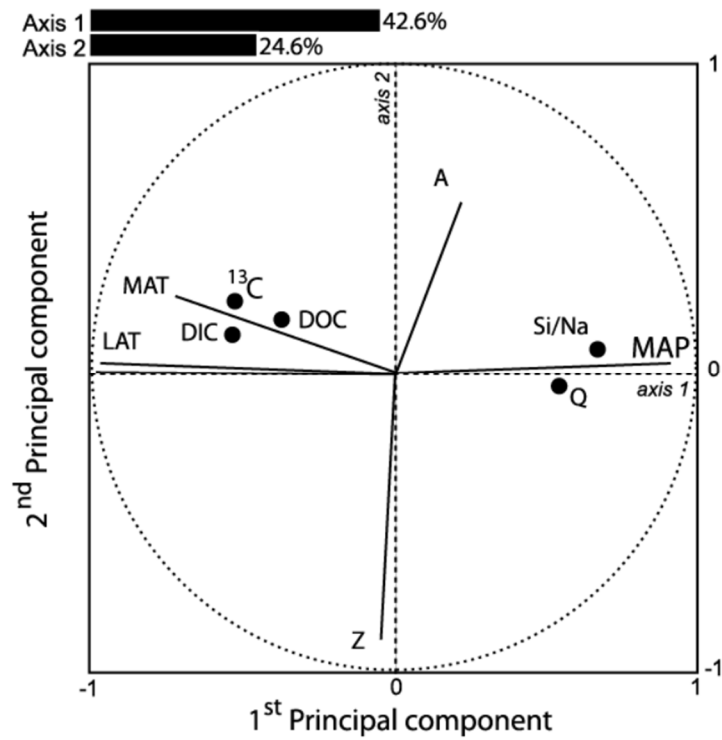


Figure 6. Principal Component Analysis (PCA) using mean annual precipitation (MAP), mean annual temperature (MAT), basin surface area (A), latitude (LAT), altitude (Z) as variables for the analysis and river dissolved organic carbon (DOCc), dissolved inorganic carbon (DICc) content and Si/Na ratio.

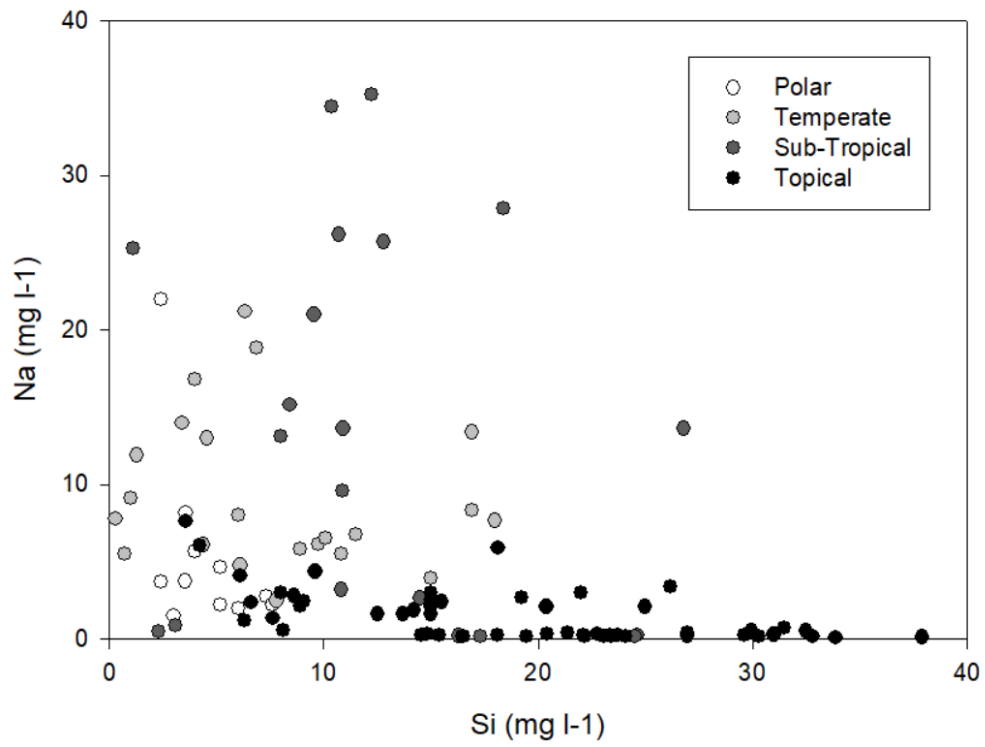


Figure 7. Si and Na content in rivers for the different climatic regions of the world (polar, temperate, sub-tropical and tropical).

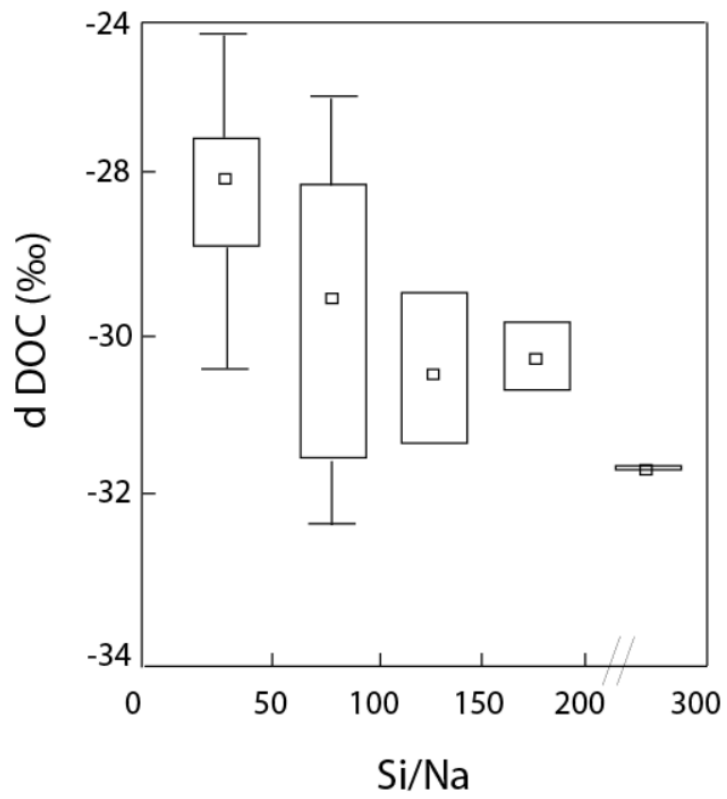


Figure 8. Relationship between river Si/Na and δDOC (‰).

Table 1. Summary database showing author name/s and year source paper was published, number of sampling data points (n); mean upstream surface area of sampling points (A); mean annual temperature (MAT) and precipitation (MAP) for the river basin; and mean dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) content of the river water at the sampling points.

Author/s and Year	Country	n	A Km ²	MAT °C	MAP mm yr ⁻¹	L km	Q × 10 ⁻³ m ³ s ⁻¹	T _w °C	pH	DOCc	DICc	POCc mg C L ⁻¹	TOCc	TCc
1. Abril et al., 2000	Belgium	5	3612	10.0	771		9.1			10.1	64.4	7.6	17.7	82.1
2. Kanduč et al., 2007	Slovenia	14	713	8.2	1218	74	1189	10.7	8.3	3.1	31.6			
3. Pall et al., 2011	Estonia	10	629	5.0	797	58	11.8			19.7	43.2		22.6	65.8
4. Paolini et al., 1987	Venezuela	2	465500	27.0	967		46.4		6.4	4.4	1.4	1.1	5.5	6.9
5. Zheng et al., 1987	China	4	260000	17.0	510		0.1			16.3	37.5		23.8	61.3
6. Alin et al., 2008	Papua NG	7	75000	26.0	1300	1000	7.3	27.5	7.8	3.8	15.3	2.1	5.9	21.2
7. Arain, 1987	Pakistan	26		26.0	224					8.6	11.0	5.6	14.2	25.2
8. Bass et al., 2014	Australia	2		23.5	2784	7			6.1	6.4	4.7			
9. Bhatt and McDowell, 2007	Puerto Rico	3	3	21.0	4200			19.4	6.4	0.7	5.8			
10. Boeglin et al., 2005	Cameroon	6	5890	25.0	1745		11.2			14.0	1.1	2.1	16.1	17.2
11. Bouillon et al., 2009	Kenya	21	120000	21.5	1027		33.3	23.7	7.9	1.0	14.0	2.0	3.0	17.0
12. Bouillon et al., 2012	DR Congo	28	489000	25.0	1540	489	7.7	28.7	7.3	5.1	5.2	1.1	6.2	11.4
13. Bradley et al., 2007	UK	4	38	8.0	770					13.4	32.2			
14. Brunet et al., 2005	Argentina	65	27229	10.1	253		14.4	12.7	7.7	2.7	18.1			
15. Cai et al., 2008	USA	28	5200	-3.1	313	118	8.3	5.0	7.4	4.5	19.1	1.0	5.5	24.7
16. Degens et al., 1991	Various	19	1618895	17.8	943		9.5			13.5	31.9	20.8	32.4	64.3
17. Depetris and Cascante, 1985	Argentina	1	2800000	18.0	955	900	5.4			9.3	4.9	2.1	11.4	16.3
18. Ferguson et al., 2011	Papua NG	124	23825	26.0	3309		110	29.0	8.0	2.2	12.2			
19. Genereux et al., 2013	Costa Rica	2	0	25.1	4341		239			1.4	30.8			
20. Giesler et al., 2013	Sweden	6	124	-1.0	321	115	20.0			1.5	2.0			
21. Hart, 1987	South Africa	3		18.0	361			15.8	7.8	2.5	6.9	1.1	3.5	10.4
22. Hunt et al., 2011	USA & Canada	14	72	4.6	1096				6.4	7.4	4.7			
23. Jantze et al., 2015	Sweden	32	59	0	304		1521		7.5	1.2	3.5			
24. Kempe, 1988	Germany & Brazil	4	5385003	20.8	2139		28.3		5.4	2.9	3.3	1.3	4.2	7.5
25. Lalah and Wandiga, 2006	Kenya	4		20.0	1234				7.5	4.6	14.6			
26. Lloret et al., 2011	Guadeloupe	35	12	23.4	3151		122	23.7	7.6	1.7	5.3			
27. Lloret et al., 2013	Guadeloupe	10	15	23.6	3474		94.2			1.7	3.6	15.1	16.8	20.3
28. Lloret et al., 2016	Guadeloupe	2	22	24.0	3410		69.5	26.5	7.5	1.3	5.6			
29. Lu et al., 2014	USA	36		14.0	1284			14.5	5.9	4.7	22.3	0.9	5.6	27.9
30. Martins, 1983	Nigeria	13	1240000	27.0	1484	4200	0.3			3.3	7.2			
31. Mayorga et al., 2005	Various	88	370272	20.9	1774			25.4	6.6	4.9	9.1	2.4	7.2	16.4
32. Meybeck and Ragu, 1995	Various	55	797329	11.7	1008	2365	12.6	14.6	7.2	6.2	17.4	6.4	7.4	24.7
33. Moyer et al., 2013	Puerto Rico	42	125	25.5	2593		13.0			1.9	21.1	7.6	9.5	30.6
34. Neal and Hill, 1994	UK	7	1	7.5	2336		59.3		4.7	1.6	0.6			
35. Némery et al., 2013	France	6	5570	22.0	800		57.9			2.3	19.3	24.2	26.5	45.7
36. Raymond and Bauer, 2001	USA	2	4350	14.0	1118		11.2			6.9	5.5	0.6	7.5	12.9
37. Raymond et al., 2013	USA	5	155	9.0	1155		15.4			9.1	9.8	0.8	9.9	19.7
38. Safuillah et al., 1987	Bangladesh	22	82	25.0	1823		5228		7.9	3.1	30.7			
39. Saunders and Lewis, 1988	Venezuela	2	167000	27.0	1545		11.4			6.2	12.2	3.7	9.9	22.1
40. Sempéré et al., 2000	France	35	97800	14.0	574	816	29.7			2.6	36.2	6.1	8.7	44.8
41. Shibata et al., 2001	Japan	1	9	6.0	1189	4	31.9			1.6	4.3	0.5	2.2	6.5
42. Sholkovitz, 1976	UK	4		8.0	1271				6.8	8.0	0.9			
43. Teodoru et al., 2015	Mozambique	1	1379423	25.0	940	3083	2.7	30.1	7.3	2.2	30.8	2.6	4.8	35.6
44. Tipping et al., 1997	UK	11	1927	8.8	992		23.4			6.5	26.9	11.0	17.5	44.4
45. Tweed et al., 2015	Australia	3	1833	24.0	481		21.5	21.1	6.8	3.0	3.6	2.5	5.5	9.1
46. Vihermaa et al., 2014	Peru	12	4003	26.0	2000	210			6.2	2.9	2.9	3.8	6.7	9.5
47. Walsh and Vigneault, 1986	Canada	3	14314	1.3	1007	400			6.4	5.2	0.6			
48. Wang et al., 2010	China	14		13.8	1062					7.3	17.7			
	Mean			16.7	1456	923	259	20.6	7.0	5.3	14.9	5.0	11.0	27.6
	Median			19.0	1137	400	20.0	23.7	7.3	4.1	10.4	2.4	7.5	21.1
	Minimum			-3.1	224	4	0.1	5.0	4.7	0.7	0.6	0.5	2.2	6.5
	Maximum			27.0	4341	4200	5228	30.1	8.3	19.7	64.4	24.1	32.4	82.1
	CV%			53	71	139	355	38	12	81	93	121	71	73

Table 2. Definitions of the climatic regions used in the current analysis

Climatic region	Characteristics
Polar	Cold and frigid region Temperature $<10^{\circ}\text{C}$ Precipitation $<800\text{ mm yr}^{-1}$
Temperate	Cool and arid to moist Temperature $10\text{-}20^{\circ}\text{C}$ Precipitation $<800\text{ mm yr}^{-1}$
Sub-tropical	Warm and arid to humid Temperature $>20^{\circ}\text{C}$ Precipitation $300\text{-}1000\text{ mm yr}^{-1}$
Tropical	Hot and wet Temperature $>20^{\circ}\text{C}$ Precipitation $>1000\text{ mm yr}^{-1}$

Table 3. Mean annual temperature (MAT), mean annual precipitation (MAP), mean of dissolved organic (DOC_c) and inorganic C concentration (DIC_c), mean of dissolved organic (DOC_F) and inorganic C fluxes (DIC_F) within rivers, drainage basin area (A) and estimated within-river DOC_F and DIC_F per world region. Data computed for the whole Africa, Asia, North and South America. Numbers accompanied by similar letters in the same column are not significantly different (p<0.05).

Continent	MAT	MAP	DOC _c	DIC _c	DOC _F	DIC _F	Si/Na	A	DOC _F	DIC _F	
	°C	mm yr ⁻¹	-----mg C L ⁻¹ -----		---g C s ⁻¹ km ⁻² ---			×10 ⁶ km ²	--GT C yr ⁻¹ --		
Africa	23.80	1277	4.19 b	8.84 d	0.04	0.08	5.87	30.37	0.04	0.08	
Asia	24.40	2355	8.73 a	23.90 a	0.30	3.86	1.01	44.58	0.42	5.43	
Europe	7.80	761	4.63 b	24.12 a	0.53	5.73	0.39	10.18	0.17	1.84	
North America	6.90	943	3.95 b	14.04 b	0.07	0.13	1.53	24.71	0.05	0.10	
South America	20.60	1877	3.87 b	11.97 c	0.10	0.42	77.77	17.84	0.06	0.24	
Mean	17.50	1591	5.08	16.57	0.25	2.50	31.05	Sum	127.68	0.74	7.68

Table 4. Correlations between variables (DOC: dissolved organic carbon, DIC: dissolved inorganic carbon, DOC/DIC ratio, POC: particulate organic carbon, TOC: total organic carbon, TC: total carbon, and DOC_F and DIC_F for DOC and DIC fluxes, respectively) and factors of control (LAT: latitude, LONG: longitude, Z: altitude, MAT: mean annual temperature, MAP: mean annual precipitation, Q: discharge and L: river length). Correlations accompanied by a star (*) are significant (p<0.05).

Variable	DOC _c	DIC _c	DOC _c /DIC _c	POC _c	TOC _c	TC _c	DOC _F	DIC _F
	----- mg C L ⁻¹ -----						-mg C L ⁻¹ s ⁻¹ km ² -	
LAT (°)	0.27*	0.39*	-0.24	0.04	0.08	0.22	0.05	0.24
LONG (°)	0.27*	0.23	-0.02	0.29*	0.32*	0.35*	0.11	0.23
Area (km ²)	0.12	-0.25*	0.32*	-0.05	-0.03	-0.12	0.18	-0.22
Z (masl)	-0.19	-0.13	0.02	-0.10	-0.13	-0.15	-0.01	-0.04
MAT (°C)	-0.41*	-0.21	0.11	-0.05	-0.10	-0.17	-0.17	-0.14
MAP (mm yr ⁻¹)	-0.29*	-0.34*	0.31*	-0.15	-0.19	-0.29*	0.34*	0.33*
Q (m ³ s ⁻¹)	-0.18	-0.43*	0.28*	-0.17	-0.19	-0.33*	0.55*	0.48*
L (km)	0.11	-0.03	0.05	0.22	0.23	0.18	-0.01	-0.22
SiO ₂ (mg L ⁻¹)	-0.19	-0.33*	0.07	0.03	0	-0.13	-0.19	-0.35*
Na (mg L ⁻¹)	-0.10	0.60*	-0.34*	0.29*	0.27*	0.46*	-0.35*	-0.05
Si/Na	-0.17	-0.71*	0.50*	-0.16	-0.18	-0.42*	0.23	-0.24