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

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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  $^{13}\text{C}$  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<sup>-1</sup> of dissolved C with 7.7 GT C yr<sup>-1</sup> (92%)  
25 being DIC and remaining (8%) DOC. Asia has the highest within-river dissolved C transport  
26 (5.8 GT C yr<sup>-1</sup>) followed by Europe (2.0 GT C yr<sup>-1</sup>), America (0.4 GT C yr<sup>-1</sup>), and Africa (0.1  
27 GT C yr<sup>-1</sup>). 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<sup>-1</sup> DOC and 0.18 Pg C yr<sup>-1</sup>  
61 POC export; while 0.43 and 0.17 Pg C yr<sup>-1</sup> 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<sup>-2</sup> yr<sup>-1</sup> for DOC and DIC, respectively, are far above the  
69 respective global export averages of 1.4 and 2.6 t C km<sup>-2</sup> yr<sup>-1</sup> (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 CO<sub>2</sub>  
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  $^{13}\text{C}$  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  $^{13}\text{C}$  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  $^{13}\text{C}$  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,  $\text{mm yr}^{-1}$ ) 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 ( $\text{m}^3$   
174  $\text{s}^{-1}$ ) 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,  $\text{mg C l}^{-1}$ ) and inorganic C (DICc,  $\text{mg}$   
178  $\text{C l}^{-1}$ ) and particulate organic C (POCc,  $\text{mg C l}^{-1}$ ) content within rivers. DOCc and DICc are  
179 dissolved organic and inorganic carbon concentrations ( $\text{mg C l}^{-1}$ ), 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 ( $\text{mg C l}^{-1}$ ) in the water samples.  
182 Therefore, total organic C (TOCc,  $\text{mg C l}^{-1}$ ) is computed as a sum of DOCc and POCc, while  
183 total C (TCc,  $\text{mg C l}^{-1}$ ) 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  $DIC_c$  ( $\text{g L}^{-1}$ ) are the corresponding average dissolved organic and  
190 inorganic carbon concentrations,  $Q$  ( $\text{L s}^{-1}$ ) is the average discharge of the river at the  
191 observation point, and  $A$  ( $\text{km}^2$ ) 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 ( $\text{GT C yr}^{-1}$ ) 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  $^{13}\text{C}$  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  $^{13}\text{C}$ , 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  $^{13}\text{C}$  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  $^{13}\text{C}$  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<sup>-1</sup> (Costa Rica: Genereux et al.,  
259 2013), with a mean of 1456 mm yr<sup>-1</sup> (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<sub>c</sub>) averaged 5.30 mg C l<sup>-1</sup>, with values from average 0.7 for some  
267 observations in Puerto Rico (Bhatt and McDowell, 2007) to 19.7 mg C l<sup>-1</sup> in Venezuela  
268 (Paolini et al., 1987). The DIC content (DIC<sub>c</sub>) average was 14.85 mg C l<sup>-1</sup>, which was three  
269 times greater than DOC<sub>c</sub>. POC content (POC<sub>c</sub>) varied from 0.5 mg C L<sup>-1</sup> in Japan (Shibata et  
270 al., 2001) to 24.2 mg C l<sup>-1</sup> in France (Némery et al., 2013), with an average of 5.0 mg C L<sup>-1</sup>.  
271 The corresponding total organic C content (TOC<sub>c</sub>) averaged 11.0 mg C l<sup>-1</sup>. The DIC<sub>c</sub> varied  
272 between 0.6 for observations in the UK (Neal and Hill, 1994) and 64.4 mg C l<sup>-1</sup> for Belgium  
273 (Abril et al., 2000). The overall total C (TC<sub>c</sub>) , the sum of all organic C forms and DIC,  
274 averaged 27.6 mg C l<sup>-1</sup>, with a variation from 6.5 to 82.1 mg C l<sup>-1</sup> (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<sub>c</sub>, DIC<sub>c</sub> and the respective DOC<sub>c</sub>/DIC<sub>c</sub> ratios across  
279 global regions. Asian rivers show the highest within-river DOC<sub>c</sub> (Figure 2A), with an  
280 average of 8.7±1.4 mg C l<sup>-1</sup> (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<sup>-1</sup>, which is not significantly different from Africa (4.2±1.1  
283 mg C l<sup>-1</sup>), North (4.0±1.1 mg C l<sup>-1</sup>) and South America (3.9±1.3 mg C l<sup>-1</sup>). DIC<sub>c</sub> 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  $\text{C l}^{-1}$ ) than the Asian rivers, but significantly higher than the South American rivers ( $12.0 \pm 0.9$   
288  $\text{mg C l}^{-1}$ ). 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 ( $\text{DOC}_F$ ) descended in the following order: Europe ( $0.5 \text{ g}$   
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 ( $\text{DIC}_F$ ) show a similar trend, but with  
293 higher values than  $\text{DOC}_F$  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 ( $\text{DOC}_E$ ) and DIC exports ( $\text{DIC}_E$ ), Asia has  
295 the highest values at  $0.4$  and  $5.4 \text{ GT C yr}^{-1}$ , respectively, followed by Europe at much lower  
296 values ( $0.2$  and  $1.8 \text{ GT C yr}^{-1}$ , respectively). The other continents have similar  $\text{DOC}_E$  ( $0.04$ ,  
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  $\text{DIC}_E$  ( $0.2 \text{ GT C yr}^{-1}$ ) than both North America ( $0.1 \text{ GT C yr}^{-1}$ )  
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  $5.3 \pm 1.1$ ,  $4.3 \pm 1.4$ ,  $4.8 \pm 1.1$   
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 ( $17.4 \pm 0.7 \text{ mg C l}^{-1}$ ), polar ( $14.0 \pm 0.9 \text{ mg C l}^{-1}$ ) and tropical region ( $10.7 \pm 1.2 \text{ mg C}$   
310  $\text{l}^{-1}$ ). 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  $6.6 \pm 0.7$  and  $5.7 \pm 1.4 \text{ mg C l}^{-1}$  for urban and wetlands, respectively. Cropland rivers' DOCc  
319 ( $4.3 \pm 1.7 \text{ mg C l}^{-1}$ ) does not differ significantly from urban and wetlands, but forest rivers are  
320 significantly lower ( $4.1 \pm 1.2 \text{ mg C l}^{-1}$ ). Nevertheless, cropland and forest river DOCc are not  
321 significantly different. It is also interesting to observe that grassland ( $3.6 \pm 0.9 \text{ mg C l}^{-1}$ ) and  
322 Savannah ( $3.7 \pm 0.7 \text{ mg C l}^{-1}$ ) do not differ significantly with forest rivers, but the Savannah  
323 rivers show greater variation. Urban ( $22.5 \pm 0.5 \text{ mg C l}^{-1}$ ) and cropland rivers ( $26.7 \pm 0.9 \text{ mg C}$   
324  $\text{l}^{-1}$ ) show much greater DICc than the other land uses, with cropland being significantly  
325 greater (Figure 4B). Grassland rivers ( $19.9 \pm 1.0 \text{ mg C l}^{-1}$ ) are significantly lower than urban  
326 areas, but significantly greater than forest ( $11.0 \pm 0.8 \text{ mg C l}^{-1}$ ) and Savannah ( $11.6 \pm 0.7 \text{ mg C}$   
327  $\text{l}^{-1}$ ), which is not significantly different. Wetlands had the least significant DICc ( $7.8 \pm 1.0 \text{ mg}$   
328  $\text{C l}^{-1}$ ). 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  $1 \times 10^3$ - $1 \times 10^4 \text{ km}^2$   
336 ( $3.9 \pm 0.9 \text{ mg C l}^{-1}$ ), before declining slightly to  $1 \times 10^4$ - $1 \times 10^5 \text{ km}^2$  ( $3.0 \pm 1.1 \text{ mg C l}^{-1}$ ).  
337 However, these three are not significantly different. Basin areas  $1 \times 10^5$ - $1 \times 10^6 \text{ km}^2$  ( $6.3 \pm 1.4$   
338  $\text{mg C l}^{-1}$ ) 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  $1 \times 10^4$ - $1 \times 10^5 \text{ km}^2$ , followed by a general decrease (Figure 5A).  
341 The river DICc on the rising side are all significantly different at  $12.3 \pm 1.1$ ,  $16.7 \pm 0.8$  and  
342  $18.6 \pm 0.7 \text{ mg C l}^{-1}$  for  $<1 \times 10^3$ ,  $1 \times 10^3$ - $1 \times 10^4$  and  $1 \times 10^4$ - $1 \times 10^5 \text{ km}^2$ , respectively. The other  
343 two basin sizes are not significantly different at  $14.1 \pm 1.2$  and  $13.7 \pm 1.4 \text{ mg C l}^{-1}$  for  $1 \times 10^5$ -  
344  $1 \times 10^6$  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  $1 \times 10^5$ - $1 \times 10^6 \text{ km}^2$  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),  $\text{SiO}_2$  (-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, TCc also correlates negatively with  
360 MAP (-0.29), Q (-0.33) and Si/Na (-0.42). DOC<sub>F</sub> and DIC<sub>F</sub> correlate positively with MAP  
361 and Q. Nevertheless, DOC<sub>F</sub> correlates negatively with Na (-0.35), while DIC<sub>F</sub> also correlates  
362 negatively with SiO<sub>2</sub> (-0.35). Multiple correlations depicted by the PCA (Figure 6) suggest  
363 that DOCc and DICc 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 DOCc, DICc, 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  $\delta$ DOC shows  
377 that  $\delta$ 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<sup>-1</sup>. 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<sup>-1</sup> 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<sup>-1</sup> (Cai, 2011; Li et al., 2017), 0.60 GT C yr<sup>-1</sup> (Meybeck, 1982) to 0.9 GT C yr<sup>-1</sup> (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 CO<sub>2</sub> 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 CO<sub>2</sub>  
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<sup>-1</sup> dissolved C fluxes estimated in the current  
403 analysis is inorganic C (7.7 GT C yr<sup>-1</sup>), while only and 8% is organic C (0.7 GT C yr<sup>-1</sup>). Both  
404 estimates are significantly higher than 0.24 GT C yr<sup>-1</sup> reported for DOC (Ludwig et al.,  
405 1996), and 0.41 (Huang et al., 2012) and 0.38 GT C yr<sup>-1</sup> (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<sup>-1</sup>) 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<sup>-1</sup> 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 PCO<sub>2</sub> 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 <sup>13</sup>C.

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  $\text{CO}_2$  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 km<sup>2</sup> to those more than 4 million km<sup>2</sup>. 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<sub>F</sub> and DIC<sub>F</sub>, 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 shows that  
464 as water fluxes in river basins increase, DOC<sub>c</sub> and DIC<sub>c</sub> 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<sup>-1</sup>. 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<sub>c</sub>. 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<sup>-1</sup>); the organic form

484 is a much smaller fraction (8% or 0.67 GT C yr<sup>-1</sup>). The Asian rivers transport the highest  
485 amount (5.8 GT C yr<sup>-1</sup>) of dissolved C, followed by Europe (2.0 GT C yr<sup>-1</sup>), America (0.4 GT  
486 C yr<sup>-1</sup>) and Africa (0.1 GT C yr<sup>-1</sup>). 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

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509

510

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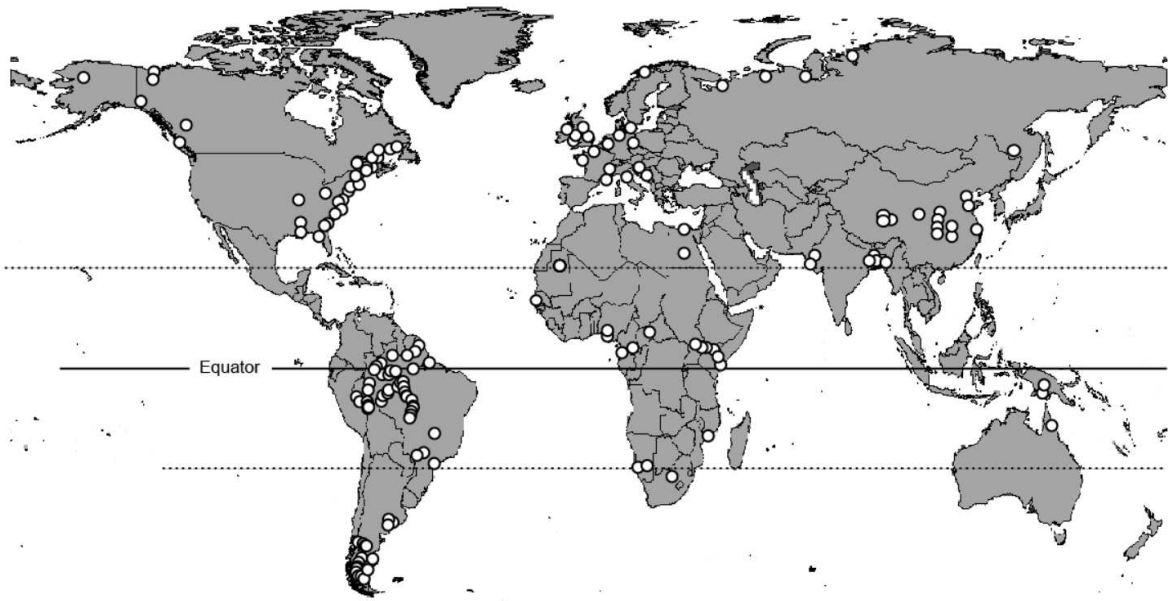
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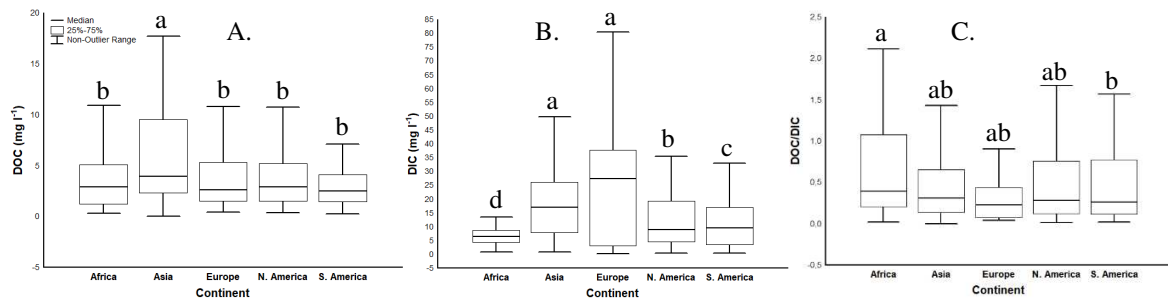
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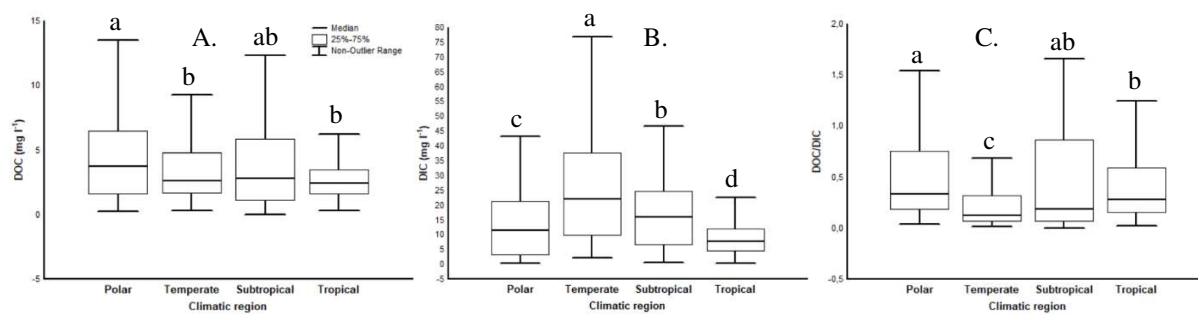


**Figure 1.** Location of the sampling data points

a

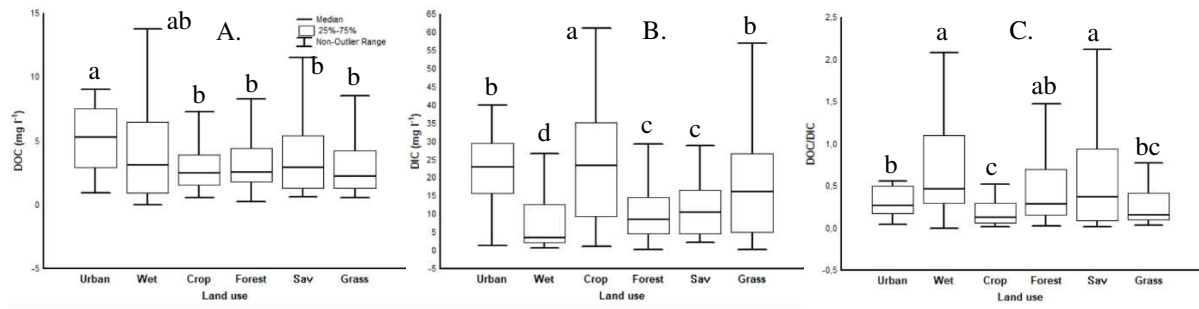


**Figure 2.** Comparisons of DOCc, DICc and DOCc/DICc from different continents. Box plots accompanied by similar small letters in each figure are not significantly different ( $p < 0.05$ ).

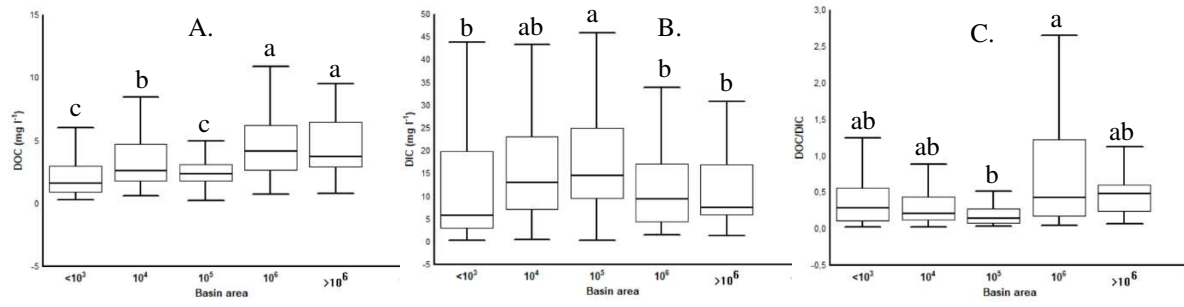


**Figure 3.** Comparisons of DOC<sub>c</sub>, DIC<sub>c</sub> and DOC<sub>c</sub>/DIC<sub>c</sub> from different climatic regions. Box plots accompanied by similar small letters in each figure are not significantly different ( $p < 0.05$ ).

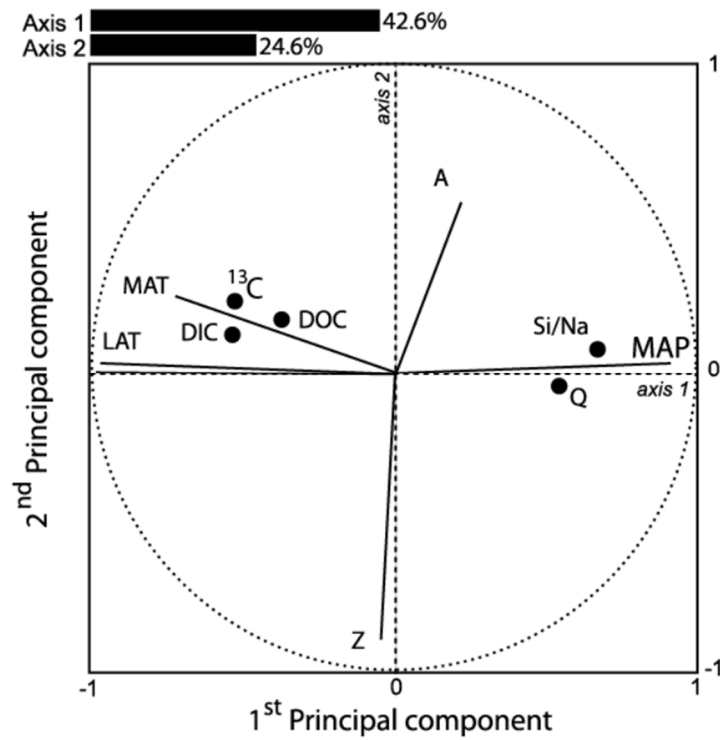
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**Figure 4.** Comparisons of DOCc, DICc and DOCc/DICc in river basins from different land uses/land covers. Box plots accompanied by similar small letters in each figure are not significantly different ( $p < 0.05$ ).

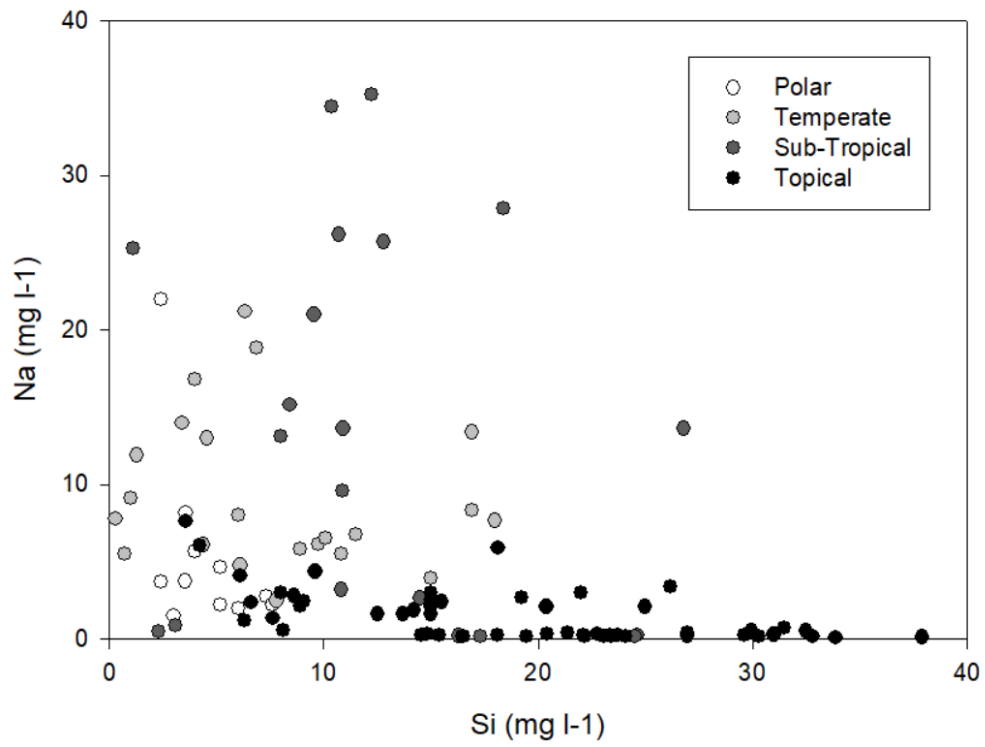


**Figure 5.** Comparisons of DOCc, DICc and DOCc/DICc from different basin areas. Box plots accompanied by similar small letters in each figure are not significantly different ( $p < 0.05$ ).

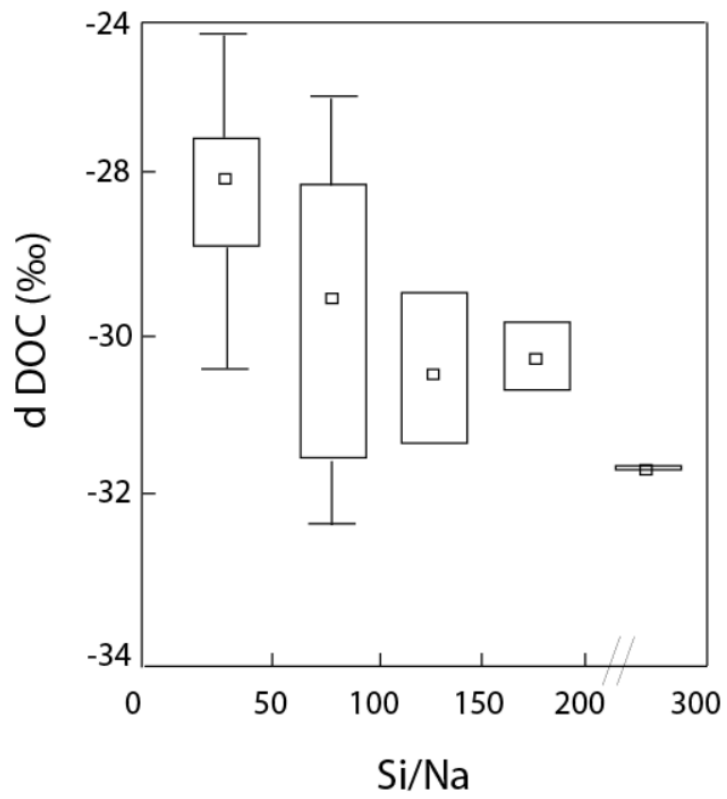


**Figure 6.** Principal Component Analysis (PCA) using mean annual precipitation (MAP), mean annual temperature (MAT), basin surface area (A), latitude (LAT), altitude (Z) as variables for the analysis and river dissolved organic carbon (DOCc), dissolved inorganic carbon (DICc) content and Si/Na ratio.





**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  $\delta$ DOC (‰).

**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 <sup>2</sup>	MAT °C	MAP mm yr <sup>-1</sup>	L km	Q × 10 <sup>-3</sup> m <sup>3</sup> s <sup>-1</sup>	T <sub>w</sub> °C	pH	DOCc	DICc	POCc mg C L <sup>-1</sup>	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			
	<b>Mean</b>			<b>16.7</b>	<b>1456</b>	<b>923</b>	<b>259</b>	<b>20.6</b>	<b>7.0</b>	<b>5.3</b>	<b>14.9</b>	<b>5.0</b>	<b>11.0</b>	<b>27.6</b>
	<b>Median</b>			<b>19.0</b>	<b>1137</b>	<b>400</b>	<b>20.0</b>	<b>23.7</b>	<b>7.3</b>	<b>4.1</b>	<b>10.4</b>	<b>2.4</b>	<b>7.5</b>	<b>21.1</b>
	<b>Minimum</b>			<b>-3.1</b>	<b>224</b>	<b>4</b>	<b>0.1</b>	<b>5.0</b>	<b>4.7</b>	<b>0.7</b>	<b>0.6</b>	<b>0.5</b>	<b>2.2</b>	<b>6.5</b>
	<b>Maximum</b>			<b>27.0</b>	<b>4341</b>	<b>4200</b>	<b>5228</b>	<b>30.1</b>	<b>8.3</b>	<b>19.7</b>	<b>64.4</b>	<b>24.1</b>	<b>32.4</b>	<b>82.1</b>
	<b>CV%</b>			<b>53</b>	<b>71</b>	<b>139</b>	<b>355</b>	<b>38</b>	<b>12</b>	<b>81</b>	<b>93</b>	<b>121</b>	<b>71</b>	<b>73</b>

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

<b>Climatic region</b>	<b>Characteristics</b>
Polar	Cold and frigid region Temperature <10°C Precipitation <800 mm yr <sup>-1</sup>
Temperate	Cool and arid to moist Temperature 10-20°C Precipitation <800 mm yr <sup>-1</sup>
Sub-tropical	Warm and arid to humid Temperature >20°C Precipitation 300-1000 mm yr <sup>-1</sup>
Tropical	Hot and wet Temperature >20°C Precipitation >1000 mm yr <sup>-1</sup>

**Table 3.** Mean annual temperature (MAT), mean annual precipitation (MAP), mean of dissolved organic (DOC<sub>c</sub>) and inorganic C concentration (DIC<sub>c</sub>), mean of dissolved organic (DOC<sub>F</sub>) and inorganic C fluxes (DIC<sub>F</sub>) within rivers, drainage basin area (A) and estimated within-river DOC<sub>F</sub> and DIC<sub>F</sub> 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 <sub>c</sub>	DIC <sub>c</sub>	DOC <sub>F</sub>	DIC <sub>F</sub>	Si/Na	A	DOC <sub>F</sub>	DIC <sub>F</sub>	
	°C	mm yr <sup>-1</sup>	-----mg C L <sup>-1</sup> -----		---g C s <sup>-1</sup> km <sup>-2</sup> ---			×10 <sup>6</sup> km <sup>2</sup>	--GT C yr <sup>-1</sup> --		
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	
<b>Mean</b>	<b>17.50</b>	<b>1591</b>	<b>5.08</b>	<b>16.57</b>	<b>0.25</b>	<b>2.50</b>	<b>31.05</b>	<b>Sum</b>	<b>127.68</b>	<b>0.74</b>	<b>7.68</b>

**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<sub>F</sub> and DIC<sub>F</sub> 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 <sub>c</sub>	DIC <sub>c</sub>	DOC <sub>c</sub> /DIC <sub>c</sub>	POC <sub>c</sub>	TOC <sub>c</sub>	TC <sub>c</sub>	DOC <sub>F</sub>	DIC <sub>F</sub>
	----- mg C L <sup>-1</sup> -----						-mg C L <sup>-1</sup> s <sup>-1</sup> km <sup>2</sup> -	
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 <sup>2</sup> )	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 <sup>-1</sup> )	-0.29*	-0.34*	0.31*	-0.15	-0.19	-0.29*	0.34*	0.33*
Q (m <sup>3</sup> s <sup>-1</sup> )	-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 <sub>2</sub> (mg L <sup>-1</sup> )	-0.19	-0.33*	0.07	0.03	0	-0.13	-0.19	-0.35*
Na (mg L <sup>-1</sup> )	-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