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Comparison of subtropical surface water chemistry between the large Pearl River in China and small mountainous rivers in Taiwan

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ABSTRACT

Small mountainous rivers in Oceania typically have higher sediment yields than larger rivers because of their steep gradients and frequent tropical storm-induced high rainfall. The high sediment yields of these small mountainous rivers enable them to transport a large amount of terrigenous material to the oceans. However, data are unfortunately sparse on this topic. In this study, we investigated the water quality and sediment geochemistry of 35 small rivers in Taiwan and compared these data with that of the large Pearl River.

Although Taiwan and the Pearl River Basin are both traversed by the Tropic of Cancer, and thus have similar weather patterns, their water chemistry is quite different. The most notable difference is that despite higher rainfall in Taiwan, and hence, a larger dilution effect, the total dissolved solid concentration (TDS), Mg^{+2}, Na^{+}+K^{+}, Cl^{-}, and SO_4^{-2} are generally higher in the Taiwanese rivers compared to the Pearl River. On the other hand, the sediment load in Taiwanese rivers is higher compared with the Pearl River, as expected. These observations reflect the higher rate of chemical weathering and denudation in Taiwan due to its steeper terrain and the larger impact of typhoons, hence episodic heavy rains in that region. The pattern of distribution vs. altitude is also different, with higher TDS, Ca^{+2}, Mg^{+2}, SO_4^{-2}, HCO_3^- and pH values at higher altitudes in the Pearl River Basin, whereas these values are lower at higher elevations in Taiwan. We see this difference because the upper reaches of the Pearl River are primarily covered with limestone, whereas the high mountains of Taiwan are mainly composed of slate and schist that are more resistant to chemical weathering and less affected by acid rain compared with limestone. Pollution-related parameters such as non-sea-salt SO_4^{-2} (nss-SO_4^{-2}), nss-SO_4/(Na^{+}+K^{+}) and Cl^{-}/(Na^{+}+K^{+}) also suggest that rivers in Taiwan are much more polluted than the Pearl River Basin, perhaps due to the widespread burning of coal and plastic-laden refuse in Taiwan.

1. Introduction

The Pearl River (Zhujiang; Fig. 1a) is the 13th or 14th largest river in the world and the second largest in China (after the Yangtze River) in terms of water discharge (326×10^9 m^3 yr^{-1}). It is also the second largest river (after the Mekong River) entering the South China Sea (SCS). In total, there are eight tributaries of the Pearl River with drainage areas larger than 10,000 km^2, and 49 distributaries with drainage areas larger than 1000 km^2. The total drainage area is 453,700 km^2, with 442,100 km^2 of that area inside China, making up 4.6% of the total area of China. The remaining 11,600 km^2 of the drainage area is in Vietnam. The total length of these tributaries reaches 36,000 km, with 14,000 km of them navigable, making up 1/8 of the total navigable waterways in China (Seto, 2002). There are three major tributaries, namely, the Xijiang (West), Beijiang (North) and Dongjiang (East) Rivers (Fig. 1).

The Pearl River drainage area covers the provinces of Yunnan, Guizhou, Hunan, Jiangxi, Guangxi and Guandong, as well as Hong Kong and Macau. The runoff from the tributaries enters the northern SCS via eight major outlets: Humen, Jiaomen, Hongqimen, Hengmen, Modaomen, Jitimen, Hutiaomen and Yamen. Because the Tropic of Cancer crosses the Pearl River Basin, the entire river basin is warm and humid. The annual rainfall on the Yun-Gui Plateau, where the Xijiang River originates, is generally above

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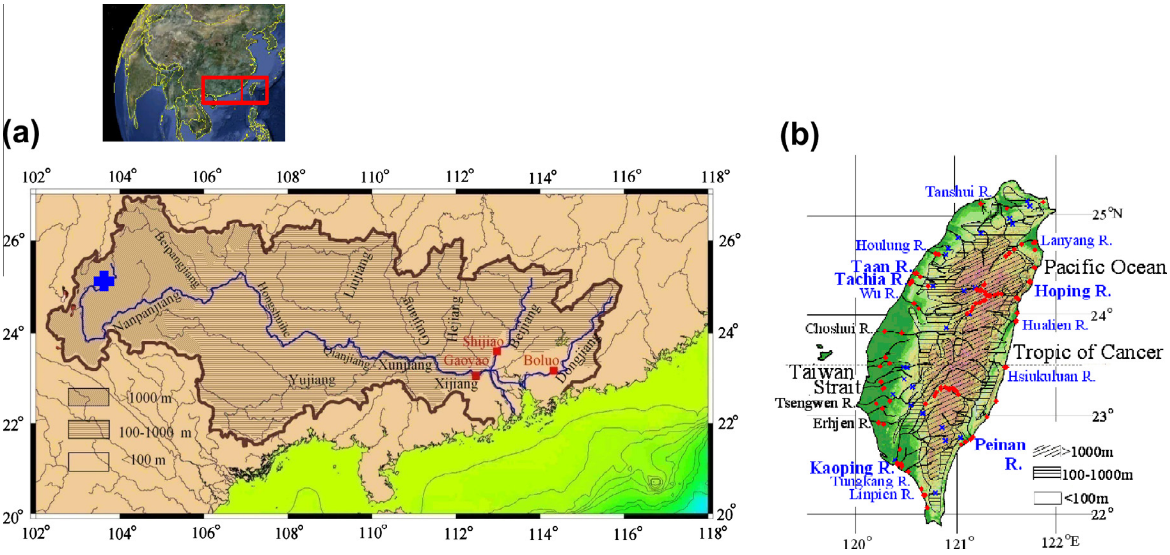

Fig. 1. The (a) Pearl River Basin and (b) rivers sampled in Taiwan (the red dots).

1000 mm, whereas the rainfall increases to approximately 2000 mm downstream of the Guangxi and Guangdong provinces (Seto, 2002).

The Tropic of Cancer also traverses Taiwan, which has a mean annual rainfall of 2500 mm and a total area of 36,000 km^2, which is the equivalent to only 7.93% of the drainage area of the Pearl River. The large contrasts of dissolved ions and chemical weathering conditions of source rocks between the small rivers in Taiwan and the large Pearl River are the subject of this study. To begin with, there are 156 peaks higher than 3000 m in Taiwan; however, there are none that reach 3000 m in the Pearl River Basin. No location in Taiwan is more than 75 km from the coast, and the longest river in Taiwan, the Choshui River, is only 187 km long, compared with the 2214 km long Xijiang River. The largest watershed in Taiwan is that of the Kaoping River, with an area of 3257 km^2, which is only 1/140th of the catchment area of the Zhujiang River (Chen et al., 2004a).

Although the material fluxes of rivers in Taiwan are not extremely high, owing to their small catchment areas, these rivers have rather large per unit area discharges, and sediments in areas as far away as the southern Okinawa Trough and the northern South China Sea contain detrital material from Taiwan (Kao et al., 2005, 2008; Liu et al., 2008). For instance, as in Papua New Guinea (Milliman, 1995), the steep terrain and high rainfall, coupled with earthquakes, deforestation, road construction and agriculture on the mountain slopes, have made many rivers in Taiwan rather muddy. Table 1 summarizes the top 20 rivers worldwide in terms of sediment yield (T/km^2/yr) that originate from elevations above 3000 m and have a catchment area larger than 300 km^2. Eight rivers in Taiwan are included in and have a high rank in this list, including the top-ranked river (the Peinan River), with a sediment yield of 37,712 T/km^2/yr. Based on the study of Zhang et al. (2008), the multi-year average sediment yield for the main channel stations and major tributaries of the Pearl River ranged from 96.6 to 327.5 T/km^2/yr.

Table 2 summarizes the world's top 20 rivers in terms of sediment yield for rivers with a unit-area runoff exceeding 1.8×10^6 T/km^2/yr, excluding creeks with a catchment area smaller than 300 km^2. Despite a clear correlation between the sediment yield and the unit-area runoff, their relationship is not linear. For example, the top-ranked river in terms of sediment yield, the Jaba River in New Zealand (NZ) (56,522 T/km^2/yr), ranks only 23rd in the world in terms of unit-area runoff. Additionally, the top-ranked river in terms of unit-area runoff, the Hokitika River in New Zealand (8.857×10^6 T/km^2/yr), ranks only seventh in terms of sediment yield. The third- and fourth-ranked rivers in terms of unit-area runoff, the Haast River (NZ) (6.452×10^6 T/km^2/yr) and the Speel Pacific River (USA) (5.345×10^6 T/km^2/yr), respectively, rank 13th and 14th, respectively, in terms of sediment yield. It is noteworthy that 13 rivers in Taiwan are ranked in the top 20 in Table 2.

Table 3 lists the top 20 rivers worldwide in terms of sediment yield. Again, only rivers with a catchment area larger than 300 km^2 are listed. Twelve rivers in Taiwan are included, highlighting the importance of the role of small catchments in sediment transport in the Asia-Oceania region. Of particular interest is that Southeast Asia is known as the largest exporter of terrestrial material to the oceans due to its high denudation rates (McLennan, 1993; Milliman and Syvitski, 1992; Dadson et al., 2003). It is thus interesting to examine how erosion and weathering processes affect the water as well as sediment chemistry. Here, we present differences in dissolved chemical composition between the large Pearl River and 35 small rivers in Taiwan, and then we discuss the impacts of anthropogenic activities on the dissolved constituents in these rivers. We also compared chemical weathering of source rocks in these two regions with the help of suitable index to substantiate the interpretations of water chemistry data.

2. Methods

Ten expeditions to the Xijiang, Beijiang and Dongjiang Rivers for water and sediment sampling took place between September 2003 and January 2010. Most sampling stations were downstream of Gaoyao, Shijiao, and Boluo and are not marked on the map, as there are too many. The sampling station furthest upstream is marked by the cross on Fig. 1a. Surface water samples were collected, and saturated $HgCl_2$ was added to all samples, except those that were used to determine the total dissolved solids (TDS). Sampling locations of the Taiwanese rivers conducted over the past three decades both for water and bottom sediment samples are given in Fig. 1b.

Field pH was measured on site using a Hanna HI 9025 microcomputer pH meter. Two standard buffer solutions with a pH of 4.00 and a pH of 7.00 were used to calibrate the electrode. The pH precision was better than ±0.02. Preserved water samples were brought back and measured in the laboratory. Laboratory pH was