



Carbon dioxide and methane emissions from Tanswei River in Northern Taiwan

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ABSTRACT

To investigate the Green House Gas (GHG) emissions from rivers in Taiwan, environmental conditions, water qualities, and emissions of CO₂ and CH₄ were determined in the Tanswei River of Northern Taiwan, and the correlations between GHG emissions and water quality were also studied. Atmospheric CO₂ concentrations were 347.4–409.7, 342.8–417.3 and 348.5–417.0 ppm in the up-, mid- and down-stream areas, respectively; while atmospheric CH₄ concentrations were 1.59–1.98, 1.74–2.20 and 1.60–2.43 ppm, respectively. Using the headspace method with brown color bottle, CO₂ concentrations were 665–6 917, 1 485–9 369 and 1 443–9 637 ppm, respectively; while CH₄ concentrations fell into the range of 11.8–309.0, 66.0–6 288.2 and 24.1–4 627.5 ppm, respectively. Using the static-chamber method, CO₂ emission rates were –22.3–140.5, –31.7–194.7 and –27.5–226.6 mg m^{–2} h^{–1}, respectively; and CH₄ emission rates were 0.02–5.52, 1.55–144.54 and 0.11–14.10 mg m^{–2} h^{–1}, respectively. CO₂ and CH₄ emission rates had higher values in the mid- and down-stream areas than those in the up-stream area because of the input of industrial, livestock and domestic wastewaters in mid- and down-stream areas. CO₂ emission rates were negative might be because of the measurement times were at noon and some photosynthetic microbes and microalgae in the water were undergoing active photosynthesis. There is a good correlation between the results of headspace and static-chamber methods. CO₂ emissions had very significant positive correlations with Biochemical Oxygen Demand (BOD) and Suspended Organic Matter (SOM); and significant negative correlation with Dissolved Oxygen (DO). CH₄ emission had very significant positive correlations with BOD, SOM and ammonium nitrogen (NH₄-N); significant positive correlation with Suspended Inorganic Matter (SIM); very significant negative correlation with DO; and significant negative correlation with redox potential (Eh). DO, Eh, SOM, SIM and NH₄-N were the major factors that affected CO₂ and CH₄ emissions from water. In the assessment of carbon deposited amount from river to ocean, the annual carbon flows of Tanswei River were estimated with the annual flow amounts and COD, it were 8.9×10³, 1.8×10⁴, 3.9×10⁴, 2.7×10⁴ and 1.2×10⁴ tons in 2003, 2004, 2005, 2006 and 2007, respectively.

Keywords: Greenhouse gas emissions, river, emission rate, water quality, carbon flow

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1. Introduction

Carbon dioxide and methane are the important long-lived Green House Gases (GHGs) because of their high potentials for thermal absorption, and they contribute 9–26% and 4–9% to global warming, respectively (Kiehl and Trenberth, 1997; Schmidt et al., 2010). Increasing concentrations of the long-lived GHGs have led to a combined Radiative Forcing (RF) of 2.63±0.26 W m^{–2}, and 9% increase since 1998 (Cicerone and Oremland, 1988; Forster et al., 2007). In nature, carbon is cycled among various atmospheric, oceanic, land biotic, marine biotic and mineral reservoirs. The largest fluxes occur between the atmosphere and terrestrial biota, and between the atmosphere and surface water of ocean (Chen, 2002; Abril et al., 2005; Hirota et al., 2007; Han et al., 2012). Carbon predominantly exists in its oxidized form as CO₂ in the atmosphere. Atmospheric CO₂ is part of this global carbon cycle, and therefore, its fate is a complex function of geochemical and biological processes. CH₄ affects the concentrations of water vapor and ozone in the stratosphere and plays a key role in stratospheric chlorine chemistry (Simpson et al., 2006). Climate changes will follow an increase in atmospheric levels of GHGs, and there is intense interest in the sources and emissions of these gases. River respiration of organic matter is a potentially major source of CO₂, and plays a major role in contributing to the atmospheric concen-

trations of other GHGs (Battin et al., 2008; Butman and Raymond, 2011).

In aquatic ecosystems, CH₄ is formed under anaerobic conditions in the bottom sediment and transported by diffusion in the water layer via molecular diffusion, bubbles and plants (Yang and Chang, 1998). The major sites of biological CH₄ production are sediments, rice paddies, animal wastes, ruminants, termite digestive systems, landfills and wetlands under highly reduced environments (Yang, 1998; Chang and Yang, 2003; Hegde et al., 2003; Yang et al., 2003; Hirota et al., 2007; Chen et al., 2008; Chang et al., 2009a; Chang et al., 2009b; Kim and Yi, 2009; Yang et al., 2009). Recently, the importance of lakes and wetlands as the major natural sources of atmospheric CH₄ has been shown both regionally and globally (Chang and Yang, 2003; Huttunen et al., 2003; Abril et al., 2005; Guerin et al., 2007; Hirota et al., 2007). In Taiwan, there are five longitudinal mountain ranges which occupy half area of the island, so the rivers are short and steep. The rainfall distribution is highly uneven, both temporally and spatially, and about 78% of rainfall is concentrated in raining seasons from May to October. The annual rainfall in mountain area is more than 8 000 mm, while it is less than 1 200 mm in plain (Water Resources Agency/Taiwan, 2012). There are 129 rivers and about 80 reservoirs and diversion dams in Taiwan that supply 180 hundred million tons of water each year. Total length of the major rivers is 2 933.9 km. 1 912.3 km (65.2%)

was classified as fair, 264.9 km (9.0%) was slightly polluted, 632.2 km (21.5%) was moderately polluted, and 124.5 km (4.2%) was heavily polluted in 2010 (Environmental Protection Administration/Taiwan, 2012). In addition, the deteriorated or polluted condition continuously increased at the rate of $1.1\% \text{ y}^{-1}$. Methane production of sediments had good correlations with Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and organic matter contents (Yang, 1998). Thus, it is worth paying attention to the CO_2 and CH_4 emissions from freshwater, especially from heavily polluted rivers in Taiwan. Until now, however, there have been limited studies on the annual fluxes of GHGs in rivers of subtropical regions, and the data available are not sufficient to evaluate the potential contribution of water CO_2 and CH_4 to the global carbon budget (Hirota et al., 2007; Colwell et al., 2008; Butman and Raymond, 2011; Han et al., 2012). Based on the indexes of pollution, such as Dissolved Oxygen (DO), BOD_5 , suspended solids, and $\text{NH}_4\text{-N}$, the extent of river pollution (river pollution index) would normally be classified into four classes in Taiwan: (1) class A indicates little or no contamination; (2) class B is slight contamination; (3) class C is medium contamination; and (4) class D is heavy contamination. In this study, three sites at classes B, D and C were selected for the aquatic CO_2/CH_4 emissions at the up-, mid- and down-stream areas of Tanswei River in northern Taiwan. The major factors of water qualities/sediment characteristics were determined. Richey et al. (2002) showed that the outgassing of CO_2 from the Amazon River network was roughly equivalent to terrestrial sequestration and over ten times greater than fluvial CO_2 export. Cole et al. (2007) reported that inland waters received roughly 1.9 Pg C y^{-1} from anthropogenic and natural sources, which was roughly twice as much C that was exported from land to the sea. This implies that there are major losses of CO_2 to the atmosphere during transit. Therefore, we estimated the annual carbon deposited amount from Tanswei River to ocean with annual flow amounts and COD. CO_2 and CH_4 concentrations and emission rates were measured with homemade apparatus to offer the information for environmental protection and GHGs emissions from fresh water.

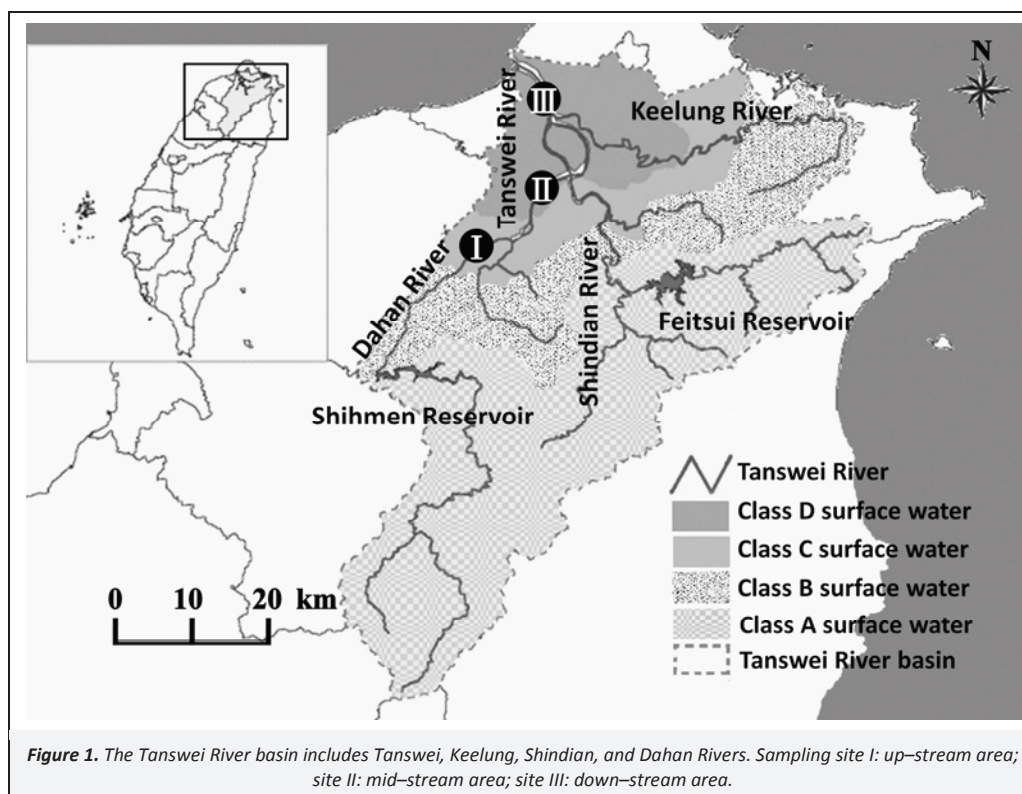
2. Materials and Methods

2.1. Sampling sites

Up-stream (site I, Guan-Yuan Bridge, $\text{N}24^\circ57'58.4''$, $\text{E}121^\circ23'37.7''$), mid-stream (site II, Ta-Han Bridge, $\text{N}25^\circ02'14.8''$, $\text{E}121^\circ27'40.0''$) and down-stream (site III, Kung-Du Bridge, $\text{N}25^\circ07'32.0''$, $\text{E}121^\circ27'15.3''$) areas that contained or represented the various extents of pollution in Tanswei River were chosen (Figure 1). The Tanswei River has an area of $2\,726 \text{ km}^2$ and is 323.4 km in length. It is one of the most important water resources in northern Taiwan, especially for Taipei City and New Taipei City. The up-, mid- and down-stream areas can be classified as classes B, D and C, respectively; and three sites were selected for the aquatic CO_2 and CH_4 emissions determinations. The water samples, sediments and air samples of each measurement sites were collected around 200 m in length and 20 m in width.

2.2. Gas sampling method

CO_2 and CH_4 across the air–water interface were collected with floating acrylic barrel-type static chambers (top diameter 25 cm , bottom diameter 28 cm , height 32 cm and volume 18 L) that were equipped with a dry battery driven fan, a thermometer and a sampling hole on the top. A life buoy of 61 cm diameter surrounded the chamber as a buoyancy apparatus and three replicate chambers were deployed every 50 m along the bank. For CO_2 and CH_4 emission measurements, the chamber was installed at the water surface (at least 1.5 m away from the riverside) and three replicate chambers were deployed in each measurement. Gas samples from the chamber were manually withdrawn with 50 mL syringes at 0 and 30 min after deployment, and injected by the replacement method into glass serum bottles (13 mL), which had been sealed by butyl rubber stoppers and flushed with oxygen-free nitrogen gas (Chang and Yang, 2003; Wu et al., 2007).



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