SWMM-based Daily Substance Flow Analysis for urban drainage system: a case study in Northern Kunming

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Summary of key findings

This paper establishes a SWMM-based substance flow analysis (SFA) model to support daily quantified research for urban drainage system. The pathways and intensities of water, COD, TN TP, NH_4-N are simulated in the northern drainage district of the Central Kunming. It is estimated water, COD, TN TP, NH_4-N inputting into the system were 90.0 million tons, 23946.2 t, 20983.9 t, 2604.2 t, 358.6 t, 1908.7 t in 2011, respectively. From the full year aspect, WWTPs was identified as the most significant pathway for pollutant emissions to receiving waterbodies. Nevertheless, daily results varied due to rushes of rainwater. Direct discharge of rainwater and direct surface rainwater contributed 22.1% of water fluxes, but 69.5% of COD load in the rainy season. Even more, severe CSO and flooding came out on the maximum rainfall day, which contributed 132.5t (12.5%) and 72.7t COD (6.9%) separately. It signifies enormous potential to cut down the load by LID, BMP, storage tanks and other practices.

Background and relevance

In the past ten years, China funded National Water Pollution Control Program for the Dianchi Lake basin. Kunming, as the main city of the basin, plays an important role in the program. As current drainage system is actually a hybrid of combined and separated sewers, rain-derived pollution control has become urgent to cut down the total load to Dianchi Lake. Some researchers have used SFA as a tool for urban water system and management. There are not so much studies focusing on the whole urban drainage system (UDS) by SFA. Moreover, existing researches are mostly static SFA based on relatively simple chemical mass balance (CMA) principle, giving the average results of substance flows between units. Nevertheless, UDS is a dynamic system, especially during the storm period when runoff brings intense impact to UDS. As for rain-derived pollution, it is much more meaningful to recognise the loads in the daily time scale. This paper aims to describe daily flows of water, COD, TN, TP and NH_4-N through an UDS, quantificationally, based on Storm Water Management Model (SWMM) simulation. The results could be used as a guide to Total Maximum Daily Loads (TMDL) process and to support water pollution control plans and engineering measures.

The urban drainage system in the northern district of Kunming (NK-UDS) is relatively independent and intact. The NK-UDS is a much typical system in Kunming and even in China, which contains two WWTPs (WWTP4 & WWTP5), a hybrid of combined and separated sewers, open channels. For the purpose of reducing pollution (i.e. CSOs) entering into rivers, intercepting sewers were constructed, leading to the mixture of sewage and rainwater at somewhere downstream which were separated upstream. That is called a hybrid sewer system. The district is about 42 km^2, with an estimated population of 0.69 million.

The SWMM-based model of SFA is a dynamic and quantitative model with the principle of mass balance in the daily time scale. Considering daily changes of municipal wastewater and groundwater infiltrating into pipes (MGW), the "triangle method" (G. Weiss et al., 2002) is used to estimated loads of MGW_i ($MGW_{4,i}$, entering the WWTP4 hybrid sewer system; $MGW_{5,i}$, entering the WWTP5 hybrid sewer system). The "i" refers to water quantity, COD, SS, TN, TP and NH_4-N loads. By using the information of daily precipitation and the established SWMM model (modelling substance flow process in hybrid sewer system rainwater sewers), collected wastewater by WWTPs ($CW_{4,i}$+$CW_{5,i}$), pumped wastewater (PW_i) from WWTP4 to WWTP5, flooding (F_i), combined sewer overflows (CSO_i), direct discharge of rainwater (DDR_i) collected by rainwater sewers, and direct surface runoff (DSR_i) could be simulated, which are showed in Figure 1. According to mass balance analysis (MBA),

$RR_{1,i}$ (rainwater runoff entering the hybrid sewer system)=$CW_{4,i}+CW_{5,i}+F_i+CSO_i-MGW_{4,i}-MGW_{5,i}$; $RR_{1,i}$ (rainwater runoff entering the rainwater sewers)=DDR_i. The uncollected wastewater (UCW_i) could be calculated as follows: $UCW_i=MGW_i/WCR-MGW_i$. WCR is the wastewater collection rate. The effluent of WWTP4 and WWTP5 could be calculated by the following functions, separately: $TW_{4,i}=(CW_{4,i}-PW_i)\times RC_{4,i}$, $TW_{5,i}=(CW_{5,i}+PW_i)\times RC_{5,i}$. $RC_{4,i}$ and $RC_{5,i}$ are the pollutant remove coefficients by WWTP4 and WWTP5, separately. $RC_{4,i}=RC_{5,i}=1$, when "i" refers to water quantity.

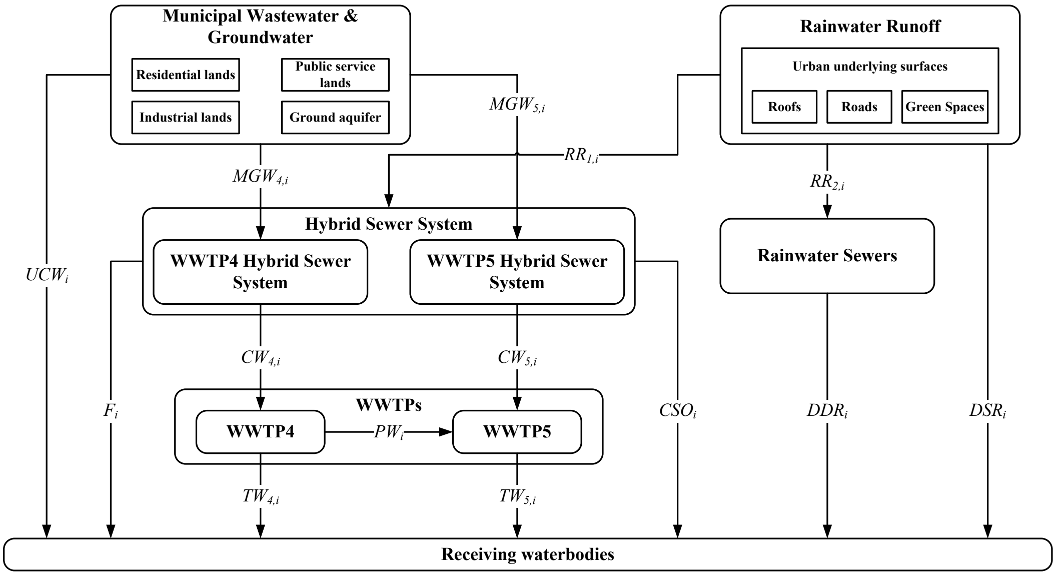

Figure 1 Framework of NK-UDS and substance flow paths

Results

Figure 2 illustrates the simulation results of NK-UDS in 2011. The water quantity, COD, SS, TN, TP and NH_4-N are displayed with the values denoting the scales of substance fluxes.

Figure 3 illustrates the proportion variety day by day, taking water quantity and COD load for example. The horizontal axis is every single day, which is not ranked in chronological order but in ascending order of daily precipitation instead. And if the precipitation equals, it is ranked in ascending order of treated wastewater quantity by WWTPs.

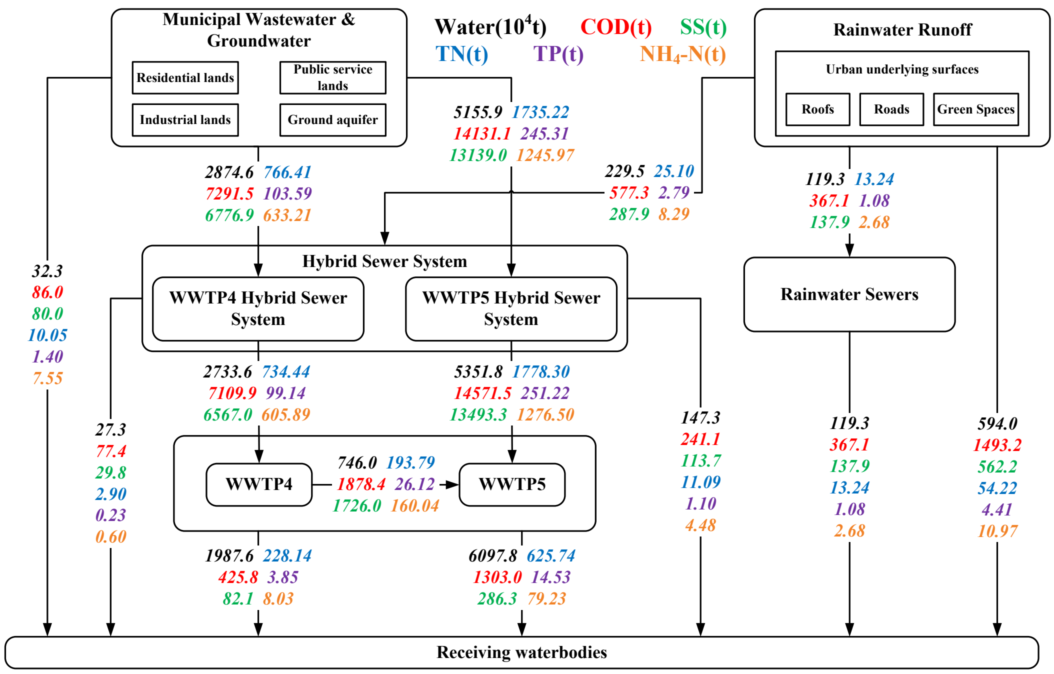

Figure 2 Substance flows through NK-UDS in 2011

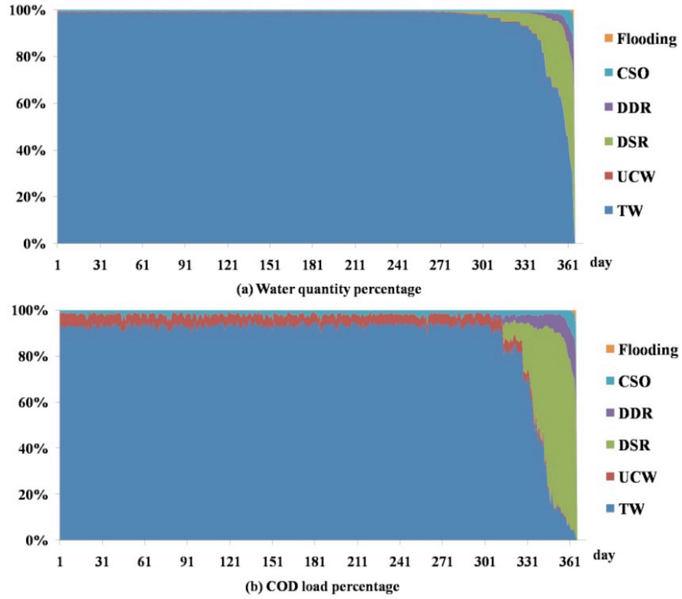

Figure 3 Daily ratios of different sources entering waterbodies

Discussion

(1) In 2011, the collection rate of municipal wastewater was about 99.6%. Rainwater runoff contributed 9.4 million tons of water, 2437.6 tons of COD, 988.0 tons of SS, 92.6 tons of TN, 8.3 tons of TP and 21.9 tons of NH_4-N, including 24.3% of water entering the hybrid sewer system which meant combination with municipal wastewater. Because WWTP4 used MBR process to treat wastewater which was sensitive to inflows, a pump station was constructed to transfer excess wastewater to WWTP5. The receiving waterbodies accepted various kinds of water through various pathways. The effluent of WWTPs contributed nearly 90% of the total 90 million tons of water, but the contribution rates of COD, SS, TN, TP, NH_4-N were 43.3%, 28.5%, 90.3%, 69.1%, 76.9%, separately, which were relatively much lower. That signifies rain-derived pollution (i.e. CSOs, flooding, direct discharge of rainwater, etc) should be paid much more attention, considering municipal wastewater has been mostly collected and treated. It is just from the perspective of a whole year. However, storms occur with short duration and high intensity and its influence sustains one day or two, thus bringing a more portion of pollution loads.

(2) There were 106 rainy days, thus the first 259 days in Figure 3 did not contain rain-derived pollution and effluent of WWTPs accounted for a vast majority both in quantity and quality. As the precipitation increased, rain-derived pollution increased rapidly. During those 106 rainy days, DDR and DSR delivered 22.1% contribution of flux into receiving waterbodies, but 69.5% of COD load. Even more, DDR and DSR contributed 69.9% of flux and 79.4% of COD load on the last day in Figure 3 when the precipitation is 77mm. Severe CSO and flooding came out on that day, which contributed 132.5t (12.5%) and 72.7t COD (6.9%) separately. It implies there is enormous potential to reduce pollution during rainy seasons. Improving rainwater-collection system and setting storage tanks can reduce pollution discharge into receiving waterbodies.

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