Impact of climate change and socio-economic development on the water balance and water quality of the Can Tho River

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Abstract. The Can Tho River plays an important role in ensuring water supply for life and socio-economic activities of Can Tho city. The problem is that the water supply and water demand in the future are difficult to predict. Therefore, it needs an approach which is capable of analyzing the water balance. This study aims to identify the impact of climate change and socio-economic development on the water balance and water quality in the future (2030s and 2050s). We used the Vietnam Water Quality Index (VN-WQI) as an analysis tool and the Water Evaluation and Planning (WEAP) model. Results show that in the period of 2010-2019, both water quality and quantity of the Can Tho River can still meet the water demands. However, the Can Tho River will not be able to use due to pollution of BOD, COD and NH4+ -N matters in the future. The water demand increases significantly under the impacts of rapid urbanization and industrialization. Thus, this also increases wastewater discharged into the Can Tho River. The surface water of the Can Tho River is projected to be declined under the impacts of climate change. We found that the water supply is much higher than the water demand in Can Tho city, so the water quality is the deciding factor for different purposes.

1 Introduction

Freshwater is a vital natural resource for human and all life. The freshwater resources are facing several challenges due to effects of human activities. Recently, the human activities caused a reduction of the freshwater resource availability by decreasing water quantity and polluting the water resources. Thus, it requires to manage the freshwater resources sustainably. Sustainable management of the water resources will assist to exploit and manage them, and this has more importance in developing countries in the context of economic development.

Vietnam, located in Southeast Asia, is a developing country so it is facing severe water scarcity. In addition, the water resources are threatened by a number of natural disasters in a tropical region. These natural disasters are projected to be changed because of climate change impacts. For example, the average rainfall in Vietnam in the 2040s will decrease in the dry season but increase in the wet season. It is evidence that unsuitable infrastructure design can lead to negative effects. The existing infrastructure is not capable of coping with natural disaster impacts, such as floods and droughts. Therefore, water resource management and river basin planning are important measures for enhancing the resilience of the system to mitigate impacts of the natural disasters.
In the recent years, there were some extreme droughts in the upstream of the Mekong basin. These droughts lead to a dramatic decrease of the river discharges. To deal with these challenges, the Vietnam government issued the Resolution 120/NQ-CP dated on November 17th, 2017 on sustainable development of the Mekong Delta in the contexts of the climate change and the upstream development impacts.

The Can Tho River, located in Can Tho City, is a tributary of the Mekong River. It flows through Ninh Kieu, Cai Rang and Phong Dien districts and play an important in supplying water to these districts. According to environmental monitoring, the river and canal network in Can Tho city are being polluted [1]. Therefore, this study aims to identify the impact of climate change and socio-economic development on the water balance and water quality in the future (2030s and 2050s). The outputs of this study will assist the sustainable water management in Can Tho city.

2 Methodology

2.1 Water balance calculation

To investigate the water availability, the water balance analysis is conducted using measured flow data and calculated water demand. The water supply is indicated by the water discharges of the Can Tho River while the water demand is computed based on the need of water use of each activity in the region. The water demand for domestic, agricultural and livestock purposes are considered for water demand computation.

\[
\text{Water availability} = \text{Water supply} - \text{Water demand}
\]

The water supply and demand were computed using a practical tool (WEAP) [2, 3, 4]. The input data for computing the water supply include flow rates of the Can Tho River and meteorological conditions in Can Tho city [5]. The water demand for domestic, agricultural and livestock purposes at 27 sub-regions was computed based on the quantity and water needs of each unit.

\[
\text{Water demand} = \sum_{i=1}^{n} \text{quantity}_i \cdot \text{water need}_i
\]

where \( n \) is the number of water use activities, including the domestic, agricultural and livestock purposes.

2.2 Water quality assessment

The water availability can be used if the water quality is higher than the requirement of the activities. For example, surface water quality is good enough (in the A1 and A2 columns of QCVN 08-MT: 2015/BTNMT) to use for domestic water suppliers [6]. Thus, water quality of the Can Tho River was assessed for the current situation and pollutant loads were projected. For water quality assessment, data of surface water quality from 2010 to 2019 were collected from the Department of Natural Resources and Environment of Can Tho city. Then Vietnamese water quality index (VN-WQI) that was introduced by the Ministry of Natural Resources and Environment, was used to assess the surface water quality in the Can Tho River. The pollutant loads of domestic, agricultural and livestock activities were estimated as below.

For domestic activity, the pollutant load was calculated based on the population in the region and wastewater per capita per year. The selected indicators to estimate pollutant loads are BOD, COD, NO\(_3\)-N, NO\(_2\)-N, NH\(_4\)+-N and TSS.

\[
Q_{sh} = P \cdot Q_i \cdot 10^3
\]
where $Q_{sh}$ is the annual pollutant load of domestic wastewater (ton/year), $Q_i$ is the emitted rate of the $i$ pollutant in domestic wastewater (kg/person/year), and $P$ is the population in the region.

For agricultural activity, the pollutant emission was calculated based on the farming area. The coefficient of wastewater is varied in accordance with different farming methods.

$$Q_{as} = Q_i \times DT \times t \times 10^3$$

where $Q_{as}$ is the annual pollutant load of agricultural activity (ton/year), $Q_i$ the emitted rate of an agricultural unit (kg/ha/day), DT is the agricultural area (ha), and $t$ is the number of cultivated days (day).

For livestock activity, the pollutant emission was calculated based on the number of cattle and poultry.

$$Q_{cn} = n \times Q_i \times 10^3$$

where $Q_{cn}$ is the annual pollutant load of livestock activity (ton/year), $n$ is the number of cattle and poultry, and $Q_i$ is the emitted waste of each cattle and poultry (kg/year).

### 2.3 Scenario analysis

In order to assess the water availability and water quality in the future, we established a set of scenarios based on the socio-economic development of the Can Tho city for middle term planning (in 2030s and 2050s). The water demand for the different purposes were projected. The required data for the projection are population, population growth rates, socio-economic development, economic growth rates, water supply capacity, water supply rates and water demand rates. Additionally, pollutant emissions of wastewater were also predicted for different activities in the future. The scenarios are described as follows.

**Scenario 1**: We only considered an increase of water demand due to population growth while the other conditions were as the base scenario of the year 2012. The prediction of population was estimated by the Vietnam Institute for Urban and Rural Planning [7, 8, 9].

**Scenario 2**: In this scenario, changes of water discharges of the Can Tho River due to climate change were projected by the Southern Institute of Water Resources Research [7, 9]. The other conditions were as the base scenario.

**Scenario 3**: To investigate the combined effects of socio-economic development and climate change, we took both the increase of water demand due to population growth (Scenario 1) and the changes of water discharges due to climate change impacts (Scenario 2) [7, 9].

### 3 Results and discussion

#### 3.1 The current water balance

The Can Tho River supplied an amount of about 7.1 million m$^3$ in 2012 (Table 1). The water volume was highly varied over the year 2012 and the variation coincides with seasonal variations of the Mekong River. Table 1 shows that the water volume of the Can Tho River is smallest in February, March and April, contributing 7.04%, 7.26% and 7.21% to the annual volume respectively. The highest water volume occurred in October, reaching up to over 803 million m$^3$.

**Table 1.** Average volume of water discharged in the study area in 2012.

| Month | Water volume (million m$^3$) | Percentage (%) |
|-------|------------------------------|----------------|
| 1     | 530.3                        | 7.49           |
| 2     | 498.6                        | 7.04           |
Table 2 shows that the highest volume of water extraction from the Can Tho River was used for agricultural purposes (42.7 million m³), occupied by 61.73% of the total water demand. The water supply plants are the second activities used much water from the Can Tho River which were extracted by 26.5 million m³, accounting for 38.25% of the total water demand. The smallest amount of water from the river was used for domestic purposes of people without freshwater accessibility. It obviously shows that water consumption in agriculture occupied the largest amount. This is explained that the agricultural products occupied the largest percentage of the economy of Can Tho city in 2012 [10, 11, 12].

Table 2. Water consumption for activities in Can Tho city in 2012.

| Water consumption                      | Water demand (million m³) | Percentage (%) |
|----------------------------------------|---------------------------|----------------|
| Water supply plant                     | 26.5                      | 38.25          |
| Agriculture                            | 42.7                      | 61.73          |
| People without freshwater accessibility | 0.015                     | 0.02           |
| **Total**                              | **69.2**                  | **100**        |

The monthly water demand for agriculture was mainly estimated based on the required water consumption for agricultural crops. Therefore, the estimated results of water consumption are slightly different due to seasonal variations of meteorological conditions in Can Tho city. In contrast, estimated water demand for the water supply plants and people without freshwater accessibility is relatively stable because the daily water consumption of these activities is insignificant. Figure 2 clearly shows that the agricultural activities have the greatest consumed amount of water compared to the others. The monthly water demand for agriculture is dramatically fluctuated since it is strongly affected by the monthly meteorological conditions. The highest water demand for agriculture is in March with an amount of 7.7 million m³. The water demand for the water supply plants is stably about 2 million m³ per month. People without freshwater accessibility need to supply an amount of 0.3 million m³ per month.
Figure 1. Monthly water demand for the purposes in 2012.

In comparison, the water demand is much smaller than the water supply from the Can Tho River. The water demand only occupies 1% of the water supply. This happens because the water demand was estimated for the three districts at the upstream of the Can Tho River. The Can Tho River also supplies water to other downstream districts. Noticeably, the surface water can only be used for the mentioned activities if water quality meets the required level of each activity.

3.2 Changes in surface water quality in the Can Tho River

Figure 3 presents VN-WQI of the Can Tho River over the last decade. VN-WQI values at Ninh Kieu, Cai Rang and Phong Dien stations increased from 2010 to 2019. Based on the classification of the General Department Environment, the water quality in 2010 was very poor, with VN-WQI ranging from 33 to 51 in the dry season and from 35 to 37 in the rainy season and the poor water quality is indicated by the orange color. Although the water quality has been improved by 2011 but it is insignificantly. The water quality can only be used for water-transportation or other similar purposes. From 2012 onwards, the VN-WQI values increased and fluctuated in range of 51-75. These values indicate that the surface water can be used for agricultural irrigation purposes. VN-WQI in 2014 is approximately twice higher than that in 2010. From 2014 to 2019, the VN-WQI values fluctuate between 76 and 90. This presents that the water quality is suitable for domestic water supply, but it needs to be treated. In summary, the water quality in the Can Tho River was increased during the last decade. A reason for the increase of VN-WQI index from 2014 is the positive impacts of the city's urban upgrading project. At the same time, environmental management of the human activities along the Can Tho River has been improved so this has positive impacts on the water quality.
The water quality index in Cai Rang and Phong Dien districts from 2010 to 2019 was slightly better than that in Ninh Kieu district. Due to less influence from human activities compared to Ninh Kieu district, water quality in Cai Rang and Phong Dien are classified as *average* and *good* in the VN-WQI classification introduced by the Vietnam Environment Administration. The results agree with the water quality monitoring of the Southwest Water Monitoring Program that was conducted by the Center for Environmental Monitoring in November 2014.

Similar to Ninh Kieu, the water quality in Cai Rang and Phong Dien was improved over the last decade. However, the water quality in 2010 and 2011 was only used for transportation and irrigation purposes. This can be explained that Ninh Kieu district is the central of Can Tho city which is densely populated and includes a lot of commercial centers and markets located along the Can Tho River. These human activities directly influence the surface water quality due to their wastewater.

In the baseline scenario, the water quantity was able to supply to the local activities and the water quality was satisfied for treated water supply, except the Ninh Kieu district. The surface water resource in the Ninh Kieu district can be only used for irrigation.

### 3.3 Wastewater uptake capacity of the Can Tho River

Table 3 presents the current pollutant loads and the maximum uptake capacity of the Can Tho River. It obviously shows that only TSS and NO$_3^-$-N do not exceed the maximum capacity of the Can Tho River while COD, BOD and NH$_4^+$-N exceed the standards. The surface water was polluted by wastewater sources, with high concentrations of COD, BOD and NH$_4^+$-N. This indicates pollution of organic pollutants. These results are consistent with the observations of the Can Tho Center for Natural Resources and Environmental Monitoring.

| Parameters     | TSS | BOD | COD | NO$_3^-$-N | NH$_4^+$-N |
|----------------|-----|-----|-----|------------|------------|
| Water discharge (m$^3$/s) | 191 | 191 | 191 | 191        | 191        |

![Figure 3. Changes of water quality index (VN-WQI) in the Can Tho River.](image-url)
3.4 Prediction of water balance

The Can Tho River is a major tributary of the Hau River, flowing through Can Tho city. Therefore, water volumes of the Can Tho River are depended on the discharges of the Hau River. Besides, there is also a significant contribution of rainfalls to the water volume during the rainy season [11, 13]. Results of the WEAP model shows the possibility of the total annual water amount of the Can Tho River, as presented in Table 3. It clearly shows that the surface water supply capacity of the Can Tho River slightly increases in 2030s and 2050s. Climate change will increase the water supply of the Can Tho River by 143 million m$^3$. The water demand of the three districts in 2020s, 2030s and 2050s are shown in Table 4. Generally, the water demand will decrease from 73.2 million m$^3$ to 68 million m$^3$. The decrease of water demand is caused by the reduction of agricultural areas. The agricultural areas will be converted to other types using less water.

### Table 3. Projected water supply of the Can Tho River in 2020s, 2030s and 2050s.

| Scenarios | 2020 (mil m$^3$) | 2030 (mil m$^3$) | 2050 (mil m$^3$) |
|-----------|-----------------|-----------------|-----------------|
| Scenario 1 | 7 081.4          | 7 081.4          | 7 081.4          |
| Scenario 2 | 7 099.2          | 7 205.3          | 7 224.5          |
| Scenario 3 | 7 099.2          | 7 205.3          | 7 224.5          |

### Table 4. Projected water demand in in 2020s, 2030s and 2050s.

| Scenarios | 2020 (mil m$^3$) | 2030 (mil m$^3$) | 2050 (mil m$^3$) |
|-----------|-----------------|-----------------|-----------------|
| Scenario 1 | 73.2            | 71.4            | 68.0            |
| Scenario 2 | 69.2            | 69.2            | 69.2            |
| Scenario 3 | 73.2            | 71.2            | 68.0            |

3.5 Prediction of water quality and pollutant loads

The maximum uptake capacity and projected pollutant loads of the Can Tho River are presented in Table 5 and 6. An estimation of the average total amount of pollutants was 87.4 ton/day in 2012. The total amount will be about twice higher than in 2030s (122 ton/day) and approximately three times in 2050 (141 ton/day). This indicates that the surface water polluted by various sources of organic pollutants from domestic wastewater. Therefore, it is necessary to have specific methods for wastewater treatment plants in the future, as well as the governmental management agencies to improve quality of the polluted water affecting to the public health [14].
Table 5. The maximum uptake capacity and projected pollutant loads of the Can Tho River in 2030s.

| Parameters       | TSS   | BOD      | COD      | NO3-N   | NH4-N   |
|------------------|-------|----------|----------|---------|---------|
| L_{ad} = C_{qc} x Q_s x 86.4 | 495.0 | 99.0     | 247.5    | 82.5    | 5       |
| L_{am} = C_{am} x Q_s x 86.4 | 412.6 | 209.6    | 305.3    | 13.2    | 8.3     |
| L_t = C_t x Q_t x 86.4 | 66.1-76.2 | 19.8 - 44,904 | 118.3-22.0 | 0.41   | 1.7     |
| F_s              | 0.5   | 0.5      | 0.5      | 0.5     | 0.5     |
| L_{at}= (L_{ad} - L_{am} - L_t) x F_s | 3.1 – 8.0 | (-64.9) – (-77.7) | (-34.6) - (-39.9) | 69.3 | (-4.2) |

Table 6. The maximum uptake capacity and projected pollutant loads of the Can Tho River in 2050s.

| Parameters       | TSS   | BOD      | COD      | NO3-N   | NH4-N   |
|------------------|-------|----------|----------|---------|---------|
| L_{ad} = C_{qc} x Q_s x 86.4 | 495.1 | 99.0     | 247,536  | 82,512  | 4,951   |
| L_{am} = C_{am} x Q_s x 86.4 | 412.1 | 209.6    | 305,294  | 13,202  | 8,251   |
| L_t = C_t x Q_t x 86.4 | 66.0-78.3 | 24.1-58.0   | 13.4-27.8 | 50.3-50.4 | 2.2-2.2 |
| F_s              | 0.5   | 0.5      | 0.5      | 0.5     | 0.5     |
| L_{at}= (L_{ad} - L_{am} - L_t) F_s | 2.1-8.3 | (-67.3)- (-84.3) | (-35.6)- (-42.7) | 34.6 | (-2.8)-(-2.2000)) |

4 Conclusions
Water quality in the Can Tho River has significantly been improved over the past 10 years (2010-2019), but most of the pollutant parameters still exceeded the regulated values of the National Technical Regulation (QCVN 08-MT:2015/BTNMT), except for pH. Regarding to the pollution capacity of the Can Tho River according to the 2030-2050 scenarios, the river discharge will be enough for agriculture use and domestic water demand but need to be treated to meet the water supply standard.

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