Evaluation of non-point source pollution based on grey water footprint method: A case study in the urban agglomeration of Shenzhen, Dongguan and Huizhou

Hongyan Wu1, Shujie Yu1, Wencong Yue1,2, Qiangqiang Rong1,2*

1Research Center for Eco-environmental Engineering, Dongguan University of Technology, Dongguan, China
2Institute of Environmental and Ecological Engineering, Guangdong University of Technology, Guangdong Provincial Key Laboratory of Water Quality Improvement and Ecological Restoration for Watersheds, Guangzhou, China

*Corresponding author: rongqq@dgut.edu.cn

Abstract- Based on a grey water footprint method, NPS pollution in the urban agglomeration of Shenzhen, Dongguan and Huizhou was evaluated in this research. The results showed that the NPS pollution level in this urban agglomeration decreased from 1995 to 2019. The grey water footprint of NPS pollution in the cities of Shenzhen, Dongguan and Huizhou had similar variation characteristic, which showed a trend of first increasing, then decreasing, and finally increasing during the research period. The largest source of grey water footprint of NPS pollution was land use, followed by livestock and poultry breeding. The water pollution level of NPS pollution was highest in Shenzhen and lowest in Huizhou, which was in the same order as gross domestic product (GDP) in this agglomeration. Thus, city governments should attach more importance to prevention and control of NPS pollution in the process of economic development, especially for land use source.

1. Introduction
Evaluation of non-point source (NPS) pollution is difficult due to its extensive pollution sources. Sources of NPS pollution mainly include land use, livestock and poultry breeding, and rural domestic sewage. Abundant researches have been conducted to analyze NPS pollution in agricultural watersheds [1]. However, regional NPS pollution in urbanized areas have not been fully explored. Quantification of NPS pollution and identification of pollution sources become extremely important for management and planning of regional water environment.

In many researches of NPS pollution, pollutant export loads were widely used to analyze the NPS pollution situation [2-4]. When focused on single pollutant, export loads provide accurate information of pollution. However, as various pollutants exist in water bodies, extended indicators are necessary to reflect combined effect of pollutants when assessing water quality. Moreover, as economic activities partly influence pollutant generation, the relationship between NPS pollution level and the development of economy need to be explored.

Grey water footprint, which link pollutants loads with water quality standards, can help understand the pressure of pollution on water resources [5]. Grey water footprint method has been successfully applied in many systems, including industrial processes, crop production, and regional water metabolism [6-8]. However, research of NPS pollution based on grey water footprint method was rarely reported.
The purpose of this research is to introduce grey water footprint method for estimating NPS pollution. To verify the effectiveness of the method, a case study was conducted in the urban agglomeration of Shenzhen, Dongguan and Huizhou.

2. Materials and Methods

2.1. Estimation of NPS pollution

Pollution from land use, livestock and poultry breeding and rural domestic sewage were considered in estimation of NPS pollution in this study.

Pollution loads from land use was calculated based on an empirical model proposed by Schueler [9]. The model framework is shown as follows.

\[
L_{RO(i)} = \frac{([C_F](\varphi)(A)(P)(C_i)) \times 0.01}{(1)}
\]

\[
\varphi = \frac{0.05 + 0.009 \times I}{(2)}
\]

where \(L_{RO(i)}\) represents the pollution loads of pollutant \(i\); \(C_F\) is the correction coefficient which exclude the rainfall events that generated no runoff; \(\varphi\) is the average runoff coefficient. In this study, we use the empirical relationship between \(\varphi\) and \(I\) to attain \(\varphi\); \(I\) is impervious surfaces percentage; \(A\) is catchment area; \(P\) is the annual average precipitation; and \(C_i\) is the concentration of pollutant \(i\), in which event mean concentrations (EMC) are weighted averaged with area proportion of land use types to express the influence of land use patterns.

The pollution load from livestock and poultry breeding were estimated based on an export coefficient method [10].

\[
L_{BR(i)} = \sum_{a=1}^{4} T_a N_a \times (P_{d(i)} \times R_{d(i)} + P_{p(i)} \times R_{p(i)})
\]

where \(L_{BR(i)}\) represents pollution load from livestock and poultry breeding; \(T_a\) is feeding cycle; \(N_a\) is the quantity of animal \(a\); annual slaughter was used to count number of raised poultry and pig of the year; livestock numbers at year-end were applied to represent breeding numbers of cattle and sheep; \(P_{d(i)}\) and \(P_{p(i)}\) respectively represent the contents of pollutant \(i\) in urinary and fecal; \(R_{d(i)}\) and \(R_{p(i)}\) respectively represent ratio of pollutant \(i\) that enter into water bodies. Pollutants generation coefficients of livestock and poultry manure are shown in Table 1.

For rural domestic pollution, an empirical model was used to calculate the pollution loads that drained into water bodies.

\[
L_{RU(i)} = \lambda \sum_{a}^{i} a_i R
\]

where \(L_{RU(i)}\) represents rural domestic pollution load of pollutant \(i\); \(\lambda\) is the percentage of the rural domestic sewage that enter into water bodies; \(a_i\) is the daily per capita emission of pollutant \(i\) from rural domestic sewage; and \(R\) is the rural population. The daily per capita emission of total nitrogen (TN), total phosphorus (TP) and chemical oxygen demand (COD) were set to 1.56, 0.16 and 64 g, respectively. The percentage of the rural domestic sewage that enter into water bodies was set to 0.05 [11].

| Table 1: Pollutant generation and discharge coefficients in manure from livestock and poultry |
|---------------------------------------------------------------|
| **Coefficients** | **Pollutants** | **Cattle manure** | **Cattle urine** | **Pig manure** | **Pig urine** | **Sheep manure** | **Poultry manure** |
| Pollutants generation coefficients (kg · d⁻¹) | / | 20.00 | 10.00 | 2.00 | 3.30 | 2.60 | 0.13 |
| Content of Pollutants (kg · t⁻¹) | COD | 31.00 | 6.00 | 52.00 | 9.00 | 4.63 | 45.65 |
| | TN | 4.37 | 8.00 | 5.88 | 3.30 | 7.50 | 10.42 |
| | TP | 1.18 | 0.40 | 3.41 | 0.52 | 2.60 | 5.79 |
| Discharge coefficients (%) | COD | 6.16 | 50.00 | 5.58 | 50.00 | 5.50 | 8.59 |
| | TN | 5.68 | 50.00 | 5.34 | 50.00 | 5.30 | 8.47 |
| | TP | 5.50 | 50.00 | 5.25 | 50.00 | 5.20 | 8.42 |
2.2. Grey water footprint and relevant indexes

2.2.1. Grey water footprint: Grey water footprint is defined as the volume of fresh water needed to assimilate the pollutants that enter the water bodies [5]. When assessing the grey water footprint of an activity, the grey water footprint for each pollutant considered has to be quantified separately. As water can assimilate kinds of pollutants simultaneously, the overall grey water footprint depends on the largest grey water footprint among all types of pollutants.

\[ F_{\text{grey}(i)} = \frac{L_i}{c_{\text{max}(i)} - c_{\text{min}(i)}} \]  

where \( F_{\text{grey}(i)} \) is the grey water footprint of pollutant \( i \); \( L_i \) is the pollution load of pollutant \( i \) entering water bodies. \( c_{\text{max}(i)} \) and \( c_{\text{min}(i)} \) represent the maximum acceptable and natural background concentrations of pollutant \( i \) in a water body, respectively. The values of the maximum acceptable concentrations depend on water environmental quality standards issued by local governments.

2.2.2. Grey water footprint intensity: Grey water footprint intensity can measure the influence of economic development on water resources [12]. The calculation formula is as follows.

\[ GWI = \frac{F_{\text{grey}}}{GDP} \]  

where \( F_{\text{grey}} \) represents grey water footprint of a district; and \( GDP \) is regional gross domestic product.

2.2.3. NPS pollution level: Water pollution level measures the pressure of water pollution on water resource, while NPS pollution level measures the pressure of NPS pollution on water resource. The calculation formula is as follows.

\[ WPL = \frac{F_{\text{grey}}}{W} \]  

where \( W \) represents regional water resources quantity.

3. Case Study

3.1. Study area
Urban agglomeration of Shenzhen, Dongguan and Huizhou is located on the east bank of the Pearl River estuary. It has a total area of 15600 km². With a subtropical monsoon climate, the urban agglomeration receives 1700 to 2500 mm rainfall a year on average. The situation of water resources and GDP are shown in Table 2. The three cities of the urban agglomeration have close cooperation in economy, industry and environment. Taking this region as the research area can provide method support for NPS pollution assessment in Guangdong-Hong Kong-Macao Greater Bay Area and similar urbanized regions.

| Year | Water Resource (10^8 m³) | Gross Domestic Product (10^9 yuan) |
|------|--------------------------|-----------------------------------|
|      | Shenzhen | Dongguan | Huizhou | Shenzhen | Dongguan | Huizhou |
| 2000 | 22.00    | 24.00    | 137.44  | 221.92   | 82.11    | 43.92   |
| 2005 | 20.00    | 24.00    | 126.93  | 503.58   | 218.95   | 80.51   |
| 2010 | 18.70    | 24.98    | 115.60  | 1000.22  | 433.98   | 172.36  |
| 2015 | 18.49    | 23.04    | 125.68  | 1801.41  | 666.53   | 309.02  |
| 2019 | 26.60    | 25.70    | 145.50  | 2692.71  | 948.25   | 417.74  |

3.2. Input data and sources
Data of livestock and poultry breeding amounts and rural population were obtained from Rural Statistical Yearbook of Guangdong Province. Precipitation was obtained from Guangdong Water Resources Bulletin. The area of different land use types was obtained from Resource and Environment Science and Data Center and GlobeLand 30 land cover dataset prepared by Ministry of Natural
Resources of the People's Republic of China (http://www.globallandcover.com/). The land use patterns in the urban agglomeration during the research period is shown in Figure 1.

The event mean concentrations (EMC) of different land use types were obtained from a relevant literature (Table 3) [13]. According to standard of surface water environmental quality, the maximum acceptable concentrations for TN, TP and COD were set to 2.0, 0.4, and 40 mg/L, respectively. The natural concentrations of the three pollutants were set to zero.

![Figure 1: Land use types in the urban agglomeration of Shenzhen, Dongguan and Huizhou](image)

(Note: AGL, FOL, GRL, WAA and COL represent agricultural land, forestland, grassland, water area and construction land, respectively.)

| Land use types          | COD     | TN   | TP   |
|-------------------------|---------|------|------|
| Arable land             | 82.00   | 33.50| 1.87 |
| Forest land             | 4.50    | 3.12 | 0.14 |
| Grass land              | 5.30    | 3.08 | 0.12 |
| Water                   | 5.30    | 3.08 | 0.12 |
| Construction land       | 298.81  | 16.19| 2.12 |
| Others                  | 5.10    | 3.01 | 0.07 |

4. Results and Discussion

4.1. Temporal variation of NPS pollution loads in the urban agglomeration of Shenzhen, Dongguan and Huizhou

The temporal variations of the NPS pollution loads in the cities of Shenzhen, Dongguan and Huizhou were similar, showing a trend of first increasing, then decreasing, and finally increasing from 1995 to 2019. Land use was the major source of NPS pollution in this urban agglomeration, especially for COD and TN.

The three cities in this urban agglomeration faced different challenges in NPS pollution control. Shenzhen had largest TN load compared with the other two cities, which possibly related to the rapidly urbanization and large percentage of impervious surface. As for Huizhou, the percentage of TP load from livestock and poultry breeding was increasing during the research period.
Figure 2 NPS pollution loads in urban agglomeration of Shenzhen, Dongguan and Huizhou
(Note: LPB, RDW, LUT represent livestock and poultry breeding, rural domestic wastewater and land use, respectively.)

4.2. Grey water footprint of NPS pollution in the urban agglomeration of Shenzhen, Dongguan and Huizhou

The variation of pollution loads and grey water footprint of NPS pollution were highly similar, which had a trend of first increasing, then decreasing, and finally increasing during 1995-2019. Among the three cities in the urban agglomeration, grey water footprint of NPS pollution in Huizhou was the largest, while the amount in Shenzhen and Dongguan were smaller. For the Huizhou City, the dominant factor of grey water footprint of NPS pollution was land use, followed by livestock and poultry breeding, which contributed more during the research period. In terms of Shenzhen and Dongguan, the proportion of grey water footprint from land use were increasing.
4.3. Grey water footprint intensity and pollution level of NPS pollution in urban agglomeration of Shenzhen, Dongguan and Huizhou

Grey water footprint intensity of NPS pollution in the urban agglomeration of Shenzhen, Dongguan and Huizhou was reduced from 1995-2019, which represents decreased NPS pollution along with the development of economy. The NPS pollution level in the urban agglomeration fluctuated in a certain range but remained below 0.5 in the research period, which indicated the NPS pollution would consume less than 50% of available water resource. The water pollution level of NPS pollution was highest in Shenzhen and lowest in Huizhou, which was in the same order as GDP in this agglomeration. Therefore, city governments should attach more importance to prevention and control of NPS pollution in the process of economic development, especially for land use source.

5. Conclusions

This study evaluated the NPS pollution in urban agglomeration of Shenzhen, Dongguan and Huizhou, based on a grey water footprint method. The NPS pollution level of the cities in the urban agglomeration was below 0.5. Land use was the major source of NPS pollution in this region. Therefore, NPS pollution risk should be considered for rational land use planning. In addition to land use, livestock and poultry breeding was the second largest contributor of NPS pollution in this urban agglomeration. Effective
measures such as partly relocation and cleaner production of the breeding industry should be implemented to reduce pollution loads.

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