The estimation of the load of non-point source nitrogen and phosphorus based on observation experiments and export coefficient method in Three Gorges Reservoir Area

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Abstract. In this paper, Three Gorges Reservoir Area (TGRA) was chosen to be the study area, the export coefficients of different land-use type were calculated through the observation experiments and literature consultation, and then the load of non-point source (NPS) nitrogen and phosphorus of different pollution sources such as farmland pollution sources, decentralized livestock and poultry breeding pollution sources and domestic pollution sources were estimated. The results show as follows: the pollution load of dry land is the main source of farmland pollution. The order of total nitrogen load of different pollution sources from high to low is livestock breeding pollution, domestic pollution, land use pollution, while the order of phosphorus load of different pollution sources from high to low is livestock breeding pollution, domestic pollution, land use pollution, Therefore, reasonable farmland management, effective control methods of dry land fertilization and sewage discharge of livestock breeding are the keys to the prevention and control of NPS nitrogen and phosphorus in TGRA.

1. Introduction
The three gorges reservoir area (TGRA) is an important fresh water source, and is also one of the important supply water source for south-to-north water transfer project in China. The nitrogen and phosphorus concentration of branches in TGRA is relatively high, the blooms have happen frequently since the filling of Three Gorges Dam (TGD) due to the backwater and water-level rise. The non-point source (NPS) pollution has gradually become the main cause of the water environment pollution in reservoir area as the point source pollution has been effectively controlled. Therefore, NPS nitrogen and phosphorus load estimation research will have theoretical and realistic significance for reservoir water environment security and water pollution control.

Water pollution governance steps into new stage with the progress of the national major water projects, NPS pollution control and management has become important topic. The export coefficient model plays an important role in NPS pollution load simulation and analysis research and it is widely used due to small data demand and simple application, the research results all indicate that export coefficient model has obvious advantages in estimation of NPS pollution in data-lacked area[1-13]. In the meantime, the results also indicated that the calculated parameters of export coefficient model were determined through theoretical calculation and literature consultation in those articles, the field observations of the study area were rarely concerned.

In this paper, the NPS pollution load in TGRA was estimated based on export coefficient model with the field observations and literature consultation.

2. Study area
TRGA is located in the downstream of Yangtze River, between 106°16’to 111°28’ E longitude and 28°56’to 31°44’N latitude(Figure 1); it covers four counties of Hubei Province and 22 counties of Chongqing Municipality. The area of TGRA is 57000 km², the climate of the study area is sub-tropical monsoon type with an average annual precipitation of 1000-1800 mm occurs during the monsoon period. Land use types in the TGRA are reclassified as forest land, grassland, dry land, paddy field, urban land, water area and unutilized field (Table 1 and Figure 2).

With the construction process of TGD, the population had a remarkable growth due to the massive immigration in TGRA, the agricultural population of TGRA in 2010 is 12.136 million according to the Ecological Environment Monitoring Bulletin of Three Gorges Project of Yangtze River[14]. The livestock and poultry are mainly divided into four types including big livestock, pig, poultry and sheep according to the statistical yearbooks of counties in TGRA. Specifically, livestock and poultry statistics of TGRA are shown in Table 2.

![Figure 1. The spatial location of study area](image1)

![Figure 2. The spatial distribution of land-use of TGRA](image2)
Table 1. The land use types of TGRA

| Sorts             | Area (km²) |
|-------------------|------------|
| Urban land        | 1286.89    |
| Paddy field       | 6766.29    |
| Dry land          | 15788.01   |
| Forest land       | 28987.95   |
| Grassland         | 3184.43    |
| Water area        | 1293.97    |
| Unutilized field  | 28.46      |
| Total (km²)       | 57336      |

Table 2. Livestock and poultry statistics of TGRA

| Sorts                                  | Quantity  |
|----------------------------------------|-----------|
| Big livestock (10⁴ head)               | 80.05     |
| Pig (10⁴ head)                         | 2839.12   |
| Sheep (10⁴ sheep unit)                 | 266.05    |
| Poultry (10⁴ poultry unit)             | 11834.34  |

3. Model and calculation

The traditional agricultural management called as “high plough into but low yield” is used due to the large number of population and scarce land resources in TGRA. Therefore, the NPS pollution caused by soil erosion, excessive fertilizer use and loss, livestock and poultry breeding swage discharge are the main causes of water pollution and eutrophication of TGRA, total nitrogen (TN) and total phosphorus (TP) were considered as the main pollution types of TGRA. It has been indicated three main kinds of TN and TP pollution sources in TGRA include land use, rural residential areas, and livestock and poultry breeding.

In this paper, typical observation area were selected in different land use area of TGRA, the unit area pollution load of typical observation area were observed by field scale monitoring and rainfall simulation, the land use export coefficients were calculated using the results of observation, and finally the TN and TP pollution loads were calculated based on export coefficient model.

The human excrement and sewage from rural areas were used as the main rural sources to determine the rural residential export coefficients, as well as the sewage and excrement of livestock and poultry were used to determine the livestock and poultry export coefficients. Based on the rural residential pollution and the amounts of livestock and poultry, the TN and TP loads from rural residential area and livestock and poultry were calculated.

3.1. Model introduction

Export coefficient model was developed by Johns [15] in 1996. This model is a kind of method to estimate watershed NPS pollution load by the export coefficient of pollutant. The model simplifies the process of pollutant formation, improves the sensitivity of the land use change, reduces monitoring costs and the dependency of monitoring data. It provides a more efficient estimation method for the calculation of NPS pollution load in large watershed.

The model used in this paper is shown as follow:

\[ L = \sum_{i=1}^{n} E_i [A_i(l_i)] + P \]
Where, \( L \) is the total loss load of nutrients (generally refer to nitrogen and phosphorus in this paper); \( n \) is the number of the year; \( E_i \) is the export coefficient of the \( i \)-th nutrients source; \( A_i \) is the area of different land use types, or the number of population, or the number of livestock and poultry; \( I_i \) is the nutrient input for the \( i \)-th nutrient source. \( P \) is the nutrient input from rainwater.

Based on the existing research [16-19], the nutrient input from rainwater can be ignored as it is much smaller than the nutrient from land use and livestock and poultry. Therefore, the nutrient from rainwater was ignored in the NPS pollution load calculation of the study area in this paper.

### 3.2. Coefficients determination

#### 3.2.1. Land use export coefficient

The coefficients of different land use types were determined through the methods such as field observation and literature consultation. The field observation method is defined as that the long-series observations data of water quality and quantity are used to calculate the NPS pollution load and the coefficients of different land use types are calculated. This method can provide more accurate results, nevertheless, it is a waste of time and money. The other method for parameter determination is literature consultation.

In this paper, both literature consultation method and field observation method were combined for the parameters determination. Some typical small watersheds in TGRA were chosen to be the observation stations to obtain data in this paper.

Six runoff yield processes of 12 different typical land use watershed in TGRA were observed and collected, the results are shown in Table 3.

| No. | Land cover type     | Area(m²) | Slope(°) | Runoff(m³) | TN(mg/L) | TP(mg/L) |
|-----|---------------------|----------|----------|------------|----------|----------|
| 01  | Aspen               | 20X5     | 20       | 3.307      | 1.625    | 0.02     |
| 02  | Aspen               | 20X5     | 20       | 8.316      | 2.443    | 0.019    |
| 03  | Cypress             | 20X5     | 20       | 11.282     | 2.943    | 0.019    |
| 04  | Cypress             | 20X5     | 20       | 13.519     | 0.297    | 0.019    |
| 05  | Aspen + Cypress     | 20X5     | 20       | 15.907     | 0.365    | 0.02     |
| 06  | Aspen + Cypress     | 20X5     | 20       | 18.126     | 0.531    | 0.019    |
| 07  | Okra melon          | 20X5     | 20       | 22.0118    | 2.772    | 0.019    |
| 08  | Okra melon          | 20X5     | 20       | 25.983     | 2.993    | 0.018    |
| 09  | Weed                | 20X5     | 20       | 28.704     | 1.429    | 0.017    |
| 10  | Weed                | 20X5     | 20       | 30.805     | 1.346    | 0.016    |
| 11  | Control group       | 20X5     | 20       | 34.787     | 0.36     | 0.015    |
| 12  | Control group       | 20X5     | 20       | 39.092     | 0.157    | 0.013    |

As it shown in Table 3, the 12 different land cover types can be classified into 3 different land use types, those are dry land(control group, okra melon), forest land(aspen, cypress), grass land(weed). The export coefficients of these three land use types can be determined by the observation data. The export coefficients of other land use types in TGRA can be determined by the export coefficients research results of some existing articles [11,20-21]. The export coefficients values of different land use in TGRA which were determined in this paper are shown in Table 4.

| Sorts            | Export coefficient (t/km²a) |
|------------------|-----------------------------|
|                  | TN                          |
|                  | TP                          |

Table 4. The export coefficients values of different land use in TGRA
3.2.2. Livestock and poultry export coefficient

The livestock and poultry resource of rural households in small typical watersheds of TGRA were investigated by author of this paper. The investigation data are shown in Table 5.

| No. | Big livestock | Pig | Poultry |
|-----|---------------|-----|---------|
|     | Amount | excrement disposal | Total inventory | Marketable fattened stock | excrement disposal | Total inventory | Marketable fattened stock | excrement disposal |
| 1   | 2      | Stack locally | 2 | 1 | Organic fertilizer | 3 | 2 | Organic fertilizer |
| 2   | 2      | Stack locally | 1 | 2 | Organic fertilizer | 10 | 2 | Organic fertilizer |
| 3   | 1      | Stack locally | 2 | 0 | Organic fertilizer | 0 | 0 | Organic fertilizer |
| 4   | 2      | Stack locally | 0 | 2 | Organic fertilizer | 0 | 0 | Organic fertilizer |
| 5   | 1      | Stack locally | 2 | 2 | Organic fertilizer | 2 | 1 | Organic fertilizer |
| 6   | 1      | Stack locally | 0 | 0 | Organic fertilizer | 5 | 10 | Organic fertilizer |
| 7   | 2      | Stack locally | 1 | 1 | Organic fertilizer | 3 | 2 | Organic fertilizer |
| 8   | 1      | Stack locally | 0 | 0 | Organic fertilizer | 5 | 2 | Organic fertilizer |
| 9   | 1      | Stack locally | 3 | 1 | Organic fertilizer | 2 | 0 | Organic fertilizer |
| 10  | 2      | Stack locally | 2 | 2 | Organic fertilizer | 4 | 2 | Organic fertilizer |

The export coefficients of livestock and poultry were determined by the investigation results of livestock and poultry manure disposal and also the literature consultation\[22\]. The results are shown in Table 6.

| Sorts    | TN[kg/(ca•a)] | TP[kg/(ca•a)] |
|----------|--------------|--------------|
| Big livestock | 7.320        | 0.310        |
| Pig      | 1.39         | 0.142        |
| Sheep    | 1.400        | 0.045        |
| Poultry  | 0.060        | 0.005        |

3.2.3. Rural residential export coefficient

There are various ways for the rural residents in TGRA to dispose human excrement. According to the investigation results of rural residents excrement and sewage disposal, 90% of the rural households dispose the excrement into farmland as organic fertilizer, while only 1% of them discharge the
excrement and sewage into water area or on the roadside, and the rest of them collect the excrement together for other purpose.

There are some existing articles about the export coefficients of rural residents excrement and sewage, Du [21] made an investigation of rural residential NPS pollution in TGRA, the results showed that the daily TN and TP loss for one adult are 5.715kg and 1.17kg. Combining with the investigation results in this paper we know that almost all of the rural life sewage and 21% of the human excrement discharge into water system. Therefore, the export coefficients human excrement were determined as 1.872 kg/(ca•a) for TN and 0.214 kg/(ca•a) for TP.

3.3. Estimation results
Based on the export coefficients determined in this paper and basic data of TGRA, the TN and TP load of different pollution sources in TGRA in 2010 were estimated. The estimation results are shown in Table 7. Comparing with the results of some existing articles we know that the estimation results of this paper are reasonable and dependable[23-25].

| Land use       | Rural life | Livestock and poultry | Total     |
|----------------|------------|-----------------------|-----------|
| TN             | 19166.15   | 22718.59              | 49893.73  | 91778.47 |
| TP             | 7956.68    | 2597.10               | 4352.14   | 14905.93 |

4. Discussions

4.1. The characteristics analysis of TN and TP load of different land use
The TN and TP load of different land use in TGRA were estimated based on the land use export coefficients determined in this paper, as shown in Table 8. The contribution figures of TN and TP of different land use are shown in Figure 3.

| Sorts              | Area(km²) | Load(t)        | Sorts              | Area(km²) | Load(t)        |
|--------------------|-----------|----------------|--------------------|-----------|----------------|
| TN                 |           |                | TP                 |           |                |
| Urban land         | 1286.89   | 921.4132       | Urban land         | 1286.89   | 508.3216       |
| Paddy field        | 6766.29   | 3653.797       | Paddy field        | 6766.29   | 1251.764       |
| Dry land           | 15788.01  | 9914.87        | Dry land           | 15788.01  | 4878.495       |
| Forest land        | 28987.95  | 3014.747       | Forest land        | 28987.95  | 985.5903       |
| Grassland          | 3184.43   | 898.0093       | Grassland          | 3184.43   | 117.8239       |
| Water area         | 1293.97   | 750.5026       | Water area         | 1293.97   | 212.2111       |
| Unutilized field   | 28.46     | 12.807         | Unutilized field   | 28.46     | 2.47602        |
| Total              | 57336     | 19166.15       | Total              | 57336     | 7956.682       |
As shown in Table 8 and Figure 3, the order of TN and TP load of different land use from high to low is dry land, paddy field, forest land, urban land, water area, grass land and unutilized field. The dry land area is 27.54% of the total area, but the contribution rates of TN and TP load are both more than 50%. That is to say, dry land is the main source of land use source pollution, the reasonable dry land management is the key to the land use pollution control.

4.2. The characteristics analysis of TN and TP load of different pollution sources

The TN and TP load of different pollution sources is shown in Figure 4.

The Figure 4 indicates that the order of TN load of different sources in TGRA from high to low is livestock and poultry breeding, rural life, land use, the order of TP load of different sources in TGRA from high to low is land use, livestock and poultry breeding, rural life. Therefore, the key of TN loss
control is to control the livestock and poultry sewage discharge, while the key of TP loss control is to optimize agricultural management in farmland, especially in dry land.

5. Conclusions

1) The TN and TP load of NPS pollution of TGRA in 2010 were estimated based on export coefficient model.
2) The export coefficients of different sources were determined by field observation and literature consultation.
3) The main source of land use pollution is dry land, the reasonable dry land management is the key to the land use pollution control.
4) Reasonable agricultural management, especially optimized fertilization management and livestock sewage discharge control are the keys of NPS pollution control in TGRA.

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