Allocating total emission pollutant control based on water environmental carrying capacity: model establishment and case study

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Abstract

The determination of the total amount of water pollutant emission in different regions is a difficult problem faced by managers and researchers. Previous studies mostly focused on operability and fairness with little attention paid to local water quality. In order to make total emission pollutant control (TEPC) truly serve the improvement of water quality, a water total emission pollutant allocation model was built based on water environmental carrying capacity (WECC) in this paper. This model was used to construct a water pollutant emission control allocation scheme for 28 cities in Henan Province, China. The results showed that the chemical oxygen demand (COD) reduction rates for these cities ranged from 16.8 to 38.6% and ammonia-nitrogen (NH\textsubscript{3}-N) reduction rates ranged from 5.7 to 43.5% in 2020, which were different from the previous targets for these cities without considering their current status of water quality. The largest COD reduction rates for different types of point sources (industrial, urban, and large-scale livestock sources) were 35.4\%, 39.0\%, and 38.0\%, respectively, and the largest NH\textsubscript{3}-N reduction rates were 62.2\%, 42.5\%, and 43.5\%, respectively. This study solves the problem of long-term disconnection between TEPC and water quality improvement in China. The results can also be applied to implement the TEPC to improve water quality in other regions with a similar problem.

Keywords: Central China; Pollutants allocation model; Total emission pollutant control; Water environmental carrying capacity; Water pollution

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1. Introduction

Water environmental pollution is a common concern all over the world caused by a large amount of wastewater emissions with urban and industrial development (Xia et al., 2012; Sun et al., 2015; Song et al., 2018). In recent years, the shortages of water resources and deterioration of water quality have become serious in China, restricting social and economic development (Yu & Lu, 2018). Water environmental carrying capacity (WECC) is a comprehensive evaluation index for the state of the water environment system and is usually used to reflect the bearing capacity of the water environment system under the impacts of human activities. Solving the contradiction between the discharge of water pollutants and WECC is always an urgent job to do in the field of water environment management (Meng et al., 2017). In order to improve water quality, the Chinese government has been trying to take some actions to reduce the discharge of water pollutants. Total emission pollutant control (TEPC) is a commonly used water environment management strategy aiming to improve water quality by controlling a total load of water pollutants within the range of a given WECC, which is one of the major environmental policies implemented in China to control water pollution (Hu et al., 2018). The implementation of TEPC mainly focused on the control of point source pollution, including industrial, urban, and large-scale livestock sources. It was initially piloted in 1988 and was extended nationwide in 1996 with a goal of 10% reduction of targeted pollutants over 5 years. Since 1996, the TEPC has been considered to be a foundation for many environmental policies and regulations and has played a critical role in improving Chinese water quality (Hu et al., 2018). After years of practice, it has become an effective means of restricting pollutant discharge and also served as an important starting point for current environmental protection system. Although the discharge of water pollutants has been reduced dramatically by TEPC, water pollutants still significantly exceed the carrying capacity of the water environment in most parts of China. Over the past two decades, the total load of water pollution source has been reduced remarkably in China; however, water quality still has not improved much. For example, in 2015, the total emissions of chemical oxygen demand (COD, a measure of organic pollutants’ aquatic concentration) and ammonium-nitrogen (NH3-N) were reduced by 12.9%, and 13.0%, respectively, relative to 2010 (MEPC, 2016). According to National Surface Water Environmental Quality Standards of China (GB3838-2002), the water quality was graded into five classes I–V defined as excellent, good, medium, polluted, and very bad. Compared with 2010, the water quality of classes I–III and IV–V in 2015 increased by 4.6% and 3%, respectively, while the water quality worse than class V decreased by 7.6%, whose water qualities were seriously polluted and did not have the function of production water supply (MEPC, 2002, 2016).

However, unlike other countries in the world like the United States, the water quality in China has not seen any significant improvement since the implementation of the TEPC system, which has raised concerns regarding the continued effectiveness of the TEPC system to control pollution in China (Xue et al., 2013; MEPC, 2014). For a long time, one of the major strategies for the nationwide implementation of the TEPC system was to allocate TEPC quotas to sub-administrative regions (Lou et al., 1995; Zhang et al., 2012; Yang et al., 2015; Li et al., 2018; Wang et al., 2018; Yu & Lu, 2018). These quotas were principally based on the area’s industrialization, historical emissions data, and its facilities’ emission reduction capabilities, and also included the internal opinions of a given region (Geng & Sarkis, 2012). Because the government set a target of 10% reduction for the total pollutant emission in all the cities while not considering the differences in ecosystem conditions and...
environmental carrying capacities across different areas, the TEPC policy based on the above allocation method has always been a controversial topic in China.

The TEPC mainly focused on emission of point sources in each region in China. Formulating an innovative, practical total emission allocation method of pollutants is one of the keys to implementing the TEPC policy. Commonly used methods include equal proportion distribution, reduction distribution according to contribution rate, analytic hierarchy process, Gini coefficient, economic optimization, and total distribution based on environmental quality (Brill et al., 1976; Joshi & Modak, 1989; Takyi & Lence, 1996; Deng et al., 2011; Liu et al., 2014). These methods primarily focus on fair, efficient, and/or quality aspects of pollution load distribution. However, there are still some deficiencies in the actual operation process when these aspects are considered (Liu et al., 2014). Normally in practice, it is difficult to balance all factors. This results in a total emphasis on one factor while ignoring all other factors. Of the aforementioned methods, both the equal proportion distribution and the contribution rate reduction distribution methods are the simplest and easiest to implement but lack scientific rigor and fairness. The analytic hierarchy process accounts for economic, social, technological, and environmental factors but often relies on the subjective assessment of a few experts. The Gini coefficient method, originally used in the field of economic analysis, was first introduced into pollution load distribution by Wu et al. (Wu et al., 2006). Subsequent scholars applied this method to the total distribution of water pollutants (Sun et al., 2010). The Gini-based allocation method was mainly used to calculate the Gini coefficient of economic index and allocation index for each region, and then continuously optimize the allocation result until the Gini coefficient value falls in the fair interval. It is based on an economic perspective and is helpful to maximize the overall economic benefits of society. However, it neglects the fair distribution of social benefits among various subjects. The total maximum daily load (TMDL) program in the United States aims to establish the response relationship between pollution load, water quality, and aquatic ecology (Steinman & Ogdahl, 2015). A TMDL is first used to calculate the maximum amount of a pollutant allowed to enter a waterbody by meeting the water quality standards, and second, to determine a pollutant reduction target and allocate load reductions necessary to all contributing point and nonpoint sources with natural background sources, seasonal variations, and a margin of safety all being taken into account in the allocations (USEPA, 2015). Despite this, difficulties remain in its actual operation when considering the complex response relationship between pollution emissions and environmental quality.

Generally, traditional methods seldom account for the actual water environment status. More critically, they often fail in practical application as they do not consider water environmental management needs. This failure is highlighted by the great differences in social and economic conditions, emission reduction potential, and water environments across different regions in China (Berck et al., 2012; Liu, 2012; Chen et al., 2014; Zhou et al., 2015; Meng et al., 2017; Zhao et al., 2018). Additionally, the Chinese government has paid increasing attention to the carrying capacity of national water environments and urban sustainability in recent years (Liu et al., 2017; He et al., 2018). Importantly, the government has proposed that further economic and social development of cities should be based on their WECC and determines the scale of industry, city, and population by WECC (Bai et al., 2016). In practice, implementing policy based on WECC generates enormous challenges for water pollution emission allocation and water quality management.

Therefore, in order to solve the above problems, a water pollutant emission allocation model was built based on WECC in this paper, which has been applied in the Henan Province in China. In this study, the total pollutant control objectives were first decomposed into individual regions based on the different
WECC for each region of the Henan Province in China. Then, they were further decomposed into corresponding major water pollutant control sources (e.g., industrial sources, urban sources, and large-scale livestock sources). This study combines TEPC with WECC, which solves the problem of long-term disconnection between TEPC and water quality improvement in China. It can be applied to the implementation of TEPC with water quality target as the core in other regions, which serves as a practical guide for the formulation and distribution of future total pollutant control targets. It also points out the direction for the reform and development of China’s TEPC system.

2. Methods

2.1. Case description

Henan Province is located in the middle eastern region of China, which includes the middle and lower reaches of the Yellow River as well as the southwest of the Yellow Sea plain. Going from east to west across China, Henan Province is in the middle zone of economic development. This is due to its location at the junction of the open coastal areas and the central and western regions. Importantly, this has led to Henan’s unique regional advantages in the national deployment strategy to promote the development of the central region.

Geographically, Henan Province is latitudinally bounded by 31°23′ and 36°22′ and longitudinally by 110°21′ and 116°39′. The total provincial area is 167,000 km², ranking 17th across all Chinese provinces, autonomous regions, and municipalities. This land area accounts for approximately 1.7% of the total area of the country. The province itself includes 18 provincial cities and 10 provincial counties. Henan is the most populous Chinese province and at the end of 2014, it had a total population of 106.62 million, an urbanization rate of 45.2%, and a population density of 564 people/km². In 2014, the total production value of the province was 3.5 trillion yuan. Henan has a serious water shortage: Water resources per capita are 266 m³, with a per capita water consumption of 224 m³. According to environmental situation bulletin of Henan Province 2015, the surface water quality of Henan Province for classes I–III and class worse than class V was 43.4% and 22.9%, respectively, and the main pollution indices were COD and NH₃-N (MEPC, 2002; HEPD, 2016a). According to the annual report of environmental statistics of Henan Province 2015, the total COD and NH₃-N emissions were 1.3 and 0.1 million tons, respectively, which were higher than the national average of 0.7 and 0.07 million tons, respectively (HEPD, 2016b; MEPC, 2016). Figure 1 provides an administrative map of Henan Province.

2.2. WECC model

The generation, output, reduction, and entry of pollutants involve complex environmental changes in the water environment system. These are further influenced by discharge modes, rainfall, air temperature, and other factors. The WECC is a comprehensive evaluation index for the water environment system, which is calculated using different water indicators. It should be noted that the carrying capacity of a single factor cannot reflect the overall carrying capacity of the water environment system. In this study, the conventional pollutants COD and NH₃-N are the water environmental management objectives in China and were, therefore, selected as the WECC evaluation indices. The WECC was based on water
environmental capacity and environmental quality for both COD and NH$_3$-N. The model was built using three steps: (1) calculate the water environmental capacity index, (2) calculate the water environmental quality index, and (3) calculate the final WECC by integrating the water environmental capacity with water environmental quality.

(1) Water environmental capacity index

Water environmental capacity is narrowly defined as the WECC, which can be evaluated on the basis of water environmental capacity. The WECC can be assessed according to the index of water environmental capacity, which is represented by the ratio of water environmental capacity to pollutant discharge to a body of water. The WECC refers to the ratio of regional environmental carrying capacity (i.e., the current value of each environmental factor index) to the threshold value of the environmental carrying capacity.
capacity of the region or basin. Using this approach, the index of water environmental capacity can show
the gap between the current situation and the ideal value of a certain region; moreover, it can evaluate
the status of WECC. The index of water environmental capacity is defined as follows:

\[
CI_i = \frac{PD_i}{EC_i},
\]

where \(CI_i\) is the water environmental capacity index, \(PD_i\) and \(EC_i\) are pollutant discharge to a body of
water and water environmental capacity, respectively, and \(i\) is a pollutant type. In this scenario, \(i\) refers to
COD and NH\(_3\)-N.

At its core, a water environmental capacity index is a method for comparing total emissions, which
represents the utilization ratio of the water environmental capacity. Due to the influence of the mode of
pollution discharge, meteorological conditions, and other uncertainties, even if the pollutant discharge to
the river does not reach the target of water environmental capacity, the measured concentration may still
exceed the target concentration for water quality. Given this limitation, it is necessary to incorporate
water quality status into a WECC evaluation system to fully and more accurately reflect the real
status of the carrying capacity of the water body.

(2) Water environmental quality index

A second important consequence of water environmental overload is that pollutant concentration in
the water body exceeds its target. As mentioned before, the water quality concentration is related to the
WECC. Therefore, the ratio of measured to target concentration for water quality can be used to
indirectly characterize the carrying capacity of a given water environment system. Different from
WECC, water quality indicators represent the actual state of the water environment system and partially
reflect its real carrying capacity. The index of water environmental quality is defined as follows:

\[
QI_i = \frac{AC_i}{TC_i},
\]

where \(QI_i\) is the water environmental quality index, \(AC_i\) and \(TC_i\) are measured and target water quality
concentrations for the monitored sections, respectively, and \(i\) is a pollutant type. In this scenario, \(i\) refers
to COD and NH\(_3\)-N.

Although the water environmental quality index reflects the WECC quality factors, the total emission
amount is not accurately considered. As mentioned previously, water quality may be affected by a var-
iety of factors, including the particular monitoring location and/or the sampling method. As a result, this
measure also does not fully reflect the overall carrying capacity of the water environmental system.

(3) Water environmental carrying capacity

The water environmental capacity and quality indices only reflect some WECC characteristics, such
as total emission amount and water quality. The WECC evaluation needs to integrate both water
environmental capacity and water environmental quality, as this would allow the results of a WECC
evaluation to reflect both the supply and demand of the total pollution amount and the water quality
standards. However, there is no precedent that can be used to reference how to couple water quality with capacity. Here, the water environmental capacity index is the basis used to calculate the WECC; the water environmental quality index is the correction used for the water environmental capacity index. Under ideal conditions, there is a positive correlation between the indices for water environmental capacity and water environmental quality—an increase in water environmental capacity index results in an increase in the water environmental quality index. If the water environmental capacity index is greater than one, the water environmental quality index is also greater than one; otherwise, both will be simultaneously less than one. In special cases, when the former is one, the latter should also be one. However, uncertainties may arise that result in one of three different situations: first, the water environmental capacity index is greater than one, while the environmental quality index is less than one; second, the former is less than one, while the latter is greater than one; and third, both are greater than, or less than, or equal to one. In the first and second scenarios, the two characterization indices are inconsistent. More specifically, one is overloaded, while the other is not. If this is the case, the indices need to be evaluated and revised. In the third scenario, the relationship between the two characterization indices is consistent and can be integrated.

Here, we made the following assumption: WECC is individually and directly proportional to the water environmental capacity and water environmental quality indices. Based on this assumption, we propose the following formula for calculating the WECC using the coupling correction for the water environmental capacity index and the water environmental quality index:

$$W_i = \sqrt{CI_i \times QI_i}.$$  

where $W_i$ is the WECC for each pollutant and $i$ is a pollutant type. In this scenario, $i$ refers to COD and NH$_3$-N. All other terms have been previously defined.

As more than one pollution index was evaluated in this study—and considering both the average carrying capacity of different indicators and prominent limiting pollution factors—the Nemero index method was used to integrate the results of the two different indices. The WECC evaluation formula is thus defined as follows:

$$ECI = \sqrt{\frac{W_{i_{\text{max}}}^2 + W_{i_{\text{avg}}}^2}{2}}.$$  

where ECI is the comprehensive WECC for multiple indices.

2.3 Total emission pollutant allocation model

The target of TEPC is an environmental goal put forward from actual water management, but there is no direct connection between TEPC and actual water quality improvement in China (Lou et al., 1995; Zhang et al., 2012; Yang et al., 2015; Wang et al., 2018; Yu & Lu, 2018). However, how to achieve the optimal allocation of regional pollutant emission is an important issue that remains to be solved in the practical determination of the total pollutant emission targets for a given city (Zhang et al., 2012; Wang & Zeng, 2013; Li et al., 2016a, 2016b). In this study, we accounted for comprehensive environmental
and human factors and proposed a regional, WECC-based pollutant allocation model. In this approach, the better the WECC of a given city, the more emissions pollutant allocated.

We achieved total emission pollutant allocation using this model in two steps. In the first allocation, the total reduction rate was calculated according to the provincial TEPC target, and the provincial reduction target was allocated to each city according to the principle of equal proportion reduction and the provincial TEPC target. The maximum reduction potential for each city was calculated from three aspects of emission reduction, which were improvements to management mode, structural adjustments, and pollution treatment projects. The minimum permitted emissions were used as constraints for proportional distribution. This step primarily considered the fairness and feasibility of the distribution results. Given the correction for the maximum reduction potential of each city, it would be possible for the total emissions of all cities to be higher than the province’s allowable emissions. Therefore, we need to further increase the reduction amounts in some cities; that is, there is an issue of a second allocation. In the second allocation, we introduced the WECC factors for various cities. To further allocate the reduction targets for these cities that have reduced margins, we used the current WECC index as the weight factor. Figure 2 shows the framework for this two-step allocation method.

![Diagram showing the framework for the two-step allocation method.](image-url)
The formula for the first allocation is as follows:

\[ \text{FP}_{ij} = \text{MAX}(\text{EP}_{ij}, \text{AP}_{ij} - \text{PP}_{ij}) \]

\[ \text{EP}_{ij} = \left( \frac{\text{RR}_{ij} \cdot n}{\sum_{i} \text{RR}_{ij}} \right) \frac{\text{TCP}_{j} \cdot \text{AP}_{ij}}{\text{TAP}_{j}} \]

\[ \text{PP}_{ij} = \sum_{ij} \text{AP}_{ij} \times \left( 1 - \frac{\text{OPI}_{ij}}{\text{API}_{ij}} \right) \]

where FP is the first allocation emission of the city; EP, AP, and PP are the allocation emissions based on the principle of equal proportion reduction and the provincial TEPC target, actual emissions, and maximum reduction potential of the city, respectively; RR is the provincial pollution reduction rate; TCP and TAP are the actual emission and provincial TEPC target, respectively; OPI is the optimal emission intensity of the pollutants; API is the actual emission intensity of the pollutants; \(i\) and \(j\) indicate the city and type of pollutant; and \(n\) is the total number of cities in the province.

The formula for the second allocation is as follows:

\[ \text{OP}_{ij} = \text{FP}_{ij} - \left( \text{TCP}_{j} - \sum_{i} \text{FP}_{ij} \right) \frac{\text{ECI}_{i}}{\sum_{i} \text{ECI}_{i}} \]

where OP is the second allocation emission of the city. All other terms have been previously defined.

The allocation emission of the city was allocated according to three different types of pollution sources, such as industrial, urban, and large-scale livestock, according to their reduction potential. The formula for this allocation is as follows:

\[ \text{OP}_{ijr} = \frac{\text{AP}_{ijr} - \text{PP}_{ijr}}{\sum_{r} \text{AP}_{ijr} - \text{PP}_{ijr}} \times \text{OP}_{ij} \]

where \(r\) is the type of pollution source. All other terms have been previously defined.

3. Results and discussion

3.1. WECC in Henan Province

As shown in Figure 3, the WECC in Henan Province and its cities is consistent with the actual situation observed in 2015. The average WECC index in Henan Province was 1.03. According to one pollutant, the NH\(_3\)-N WECC was worse than that for COD; more specifically, the COD WECC was 0.9, and the NH\(_3\)-N WECC was 1.1. Because the water environmental capacity index was far more than 100\%, the WECC of Zones 21 and 4 was the highest among all the examined cities; correspondingly, the WECC of Zones 15 and 19 was the lowest. However, the status of Zones 21 and 4 was different, with the WECC of COD being higher than the WECC of NH\(_3\)-N in Zone 21. The opposite pattern was observed in Zone 4.
As compared with other parts of China, these values are related to the TEPC across the country, where the control process and time of COD are longer than those of NH$_3$-N (Liu, 2015; Wang et al., 2015). More specifically, only COD was controlled before 2010, while both COD and NH$_3$-N have been controlled after 2010 (Liu, 2015; Wang et al., 2015). When comparing the water environmental capacity and water environmental quality indices in Henan Province, the former is more important. Given this, the water environmental capacity is the limiting factor for development (He, 2015). Although the water environmental capacity of Henan Province is insufficient, its water environmental quality is marginally better due to the implementation of a series of pollution reduction measures and water environment control projects (HEPD, 2016a, 2016b). Collectively, these results of WECC show that the restriction factors across the examined cities are different (COD/NH$_3$-N), and the degree of TEPC is also expected to be different for each city in Henan Province. These results also highlight the need for difference in TEPC.

3.2. Total emission pollutant allocation for each city in Henan Province

(1) First allocation

The first allocation of total emission pollutant in Henan Province was calculated according to the actual emissions, equal proportion emissions, and potential pollutant reductions. The pollutant emission intensity of each city in 2014 was found to be markedly different across cities. This is one of the major reasons behind the WECC difference observed in each city. The calculation parameters used are shown in Figure 4. By analyzing 108 samples from 28 cities in Henan Province, we calculated the maximum, minimum, and 10% quantile from small to large emission intensities (Table 1). In order to reduce pollutant emissions maximally, with the pollutant reduction technology of each city considered, the 10% quantile of emission intensity was selected as the optimal regional emission level. Given these parameters, the reduction potential for each city was then calculated.

Based on the principle of equal proportion reduction, the results of the first allocation of pollutant emissions across each city were obtained and are shown in Figure 5. The first allocation results indicated that the larger the pollutant emission status, the larger the emissions allocation (reference Zones 16 and 17) and the larger the pollutant reduction. This is the result of the principle of proportionate reduction, which is also related to the level of regional economic development. The principle of fairness is also reflected in these results.
According to the first allocation results, the total COD and NH₃-N emission amounts in Henan Province were 710,413.0 t and 97,252.1 t, respectively, after point source emission reductions were considered for each city. When compared with the TEPC target for the entire province and based on Fig. 4. Pollutant emission intensities for each city in 2014. (a) Per GDP industrial emissions, (b) per capita life emissions, and (c) per livestock emissions.

Fig. 4. Pollutant emission intensities for each city in 2014. (a) Per GDP industrial emissions, (b) per capita life emissions, and (c) per livestock emissions.

According to the first allocation results, the total COD and NH₃-N emission amounts in Henan Province were 710,413.0 t and 97,252.1 t, respectively, after point source emission reductions were considered for each city. When compared with the TEPC target for the entire province and based on
COD and NH$_3$-N reduction rates of 18.4% and 16.6%, respectively, the total emission amounts for COD and NH$_3$-N exceeded 12,361.4 t and 2,377.1 t, respectively. These results indicate that it remains difficult to achieve the total emission reduction target for the entire province when using the reduction of potential calculation and equal proportion distribution. In actual management conditions to achieve the entire provincial target, a unified approach would need to be adopted to increase the proportion reduction rate of each city. However, to achieve the entire provincial target, we distributed the above

| Value          | COD emission intensity | NH$_3$-N emission intensity |
|----------------|------------------------|-----------------------------|
|                | Per GDP industrial emissions (kg/10,000 yuan) | Per capita life emissions (tons/10,000 people) | Per livestock emissions (tons/10,000 heads) | Per GDP industrial emissions (kg/10,000 yuan) | Per capita life emissions (tons/10,000 people) | Per livestock emissions (tons/10,000 heads) |
| Minimum        | 0.01                   | 22.60                       | 5.80                          | 0.00                      | 7.51                       | 0.90                          |
| Maximum        | 3.68                   | 236.37                      | 636.32                        | 0.15                      | 34.21                      | 32.61                        |
| 10% quantile   | 0.08                   | 34.19                       | 28.69                         | 0.00                      | 10.58                      | 3.48                         |

Fig. 5. First allocation emission amounts of pollutants for each city in 2020. (a) COD and (b) NH$_3$-N.
surplus pollutants that would need to be reduced from each city based on the WECC of each city (i.e., second allocation).

(2) Second allocation

The second allocation was performed to distribute the excess total emissions to cities that had not reached their maximum possibilities. This second allocation was based on the WECC of each city. As shown in Figure 6, the surplus pollutants that needed to be reduced (12,361.4 t COD and 2,377.1 t NH₃-N) were allocated to each city. Although the pollutant emission status of Zones 21 and 4 was not the largest because the WECC of them was larger, they needed to have more pollutant reduction to achieve water quality improvement targets. Conversely, Zone 15 needed little additional allocation as they did not need much further reduction. Taken together, these results show the different characteristics of the water environmental quality in each city.

Based on the reduction potential calculation of the three different pollution sources, the reduction margin for each city was allocated to the pollution sources. Figure 7 details the second allocation emission reduction rate for the total pollutants for each city in 2020. The results of the COD allocation indicate that there are obvious differences in the rate of COD reduction among the different cities using the requirement of 18.4% reduction of COD across the whole province. The results showed that the difference between the maximum and the minimum was 21.8 percentage points, with a COD reduction rate of 18.4% across the whole province.
reduction rate across each city ranging from 16.8 to 38.6%. The NH$_3$-N allocation results also showed significant differences in NH$_3$-N reduction rates across the different cities when using the requirement of a 16.6% reduction of NH$_3$-N across the province. There was a difference of 37.8 percentage points between the maximum and the minimum, with NH$_3$-N reduction rates ranging from 5.7 to 43.5%.

Indirectly, the second allocation results indicate that identical proportional reduction rate is extremely unreasonable in some areas. For example, the reduction rate in some areas was higher than the average reduction rate of the whole province. The main reason for this finding is that both the WECC and water environment quality for these areas were relatively poor. Collectively, these results indicate that regional differences must be accounted for in TEPC allocation. Indirectly, these findings indicate that it is unreasonable to divide the previous year’s TEPC. These results are instructive for the practical allocation of TEPC targets in Henan Province in recent years.

Figure 7 shows that the reduction rate of cities has changed greatly after the second allocation based on WECC. Pollutant reduction rates in most cities were higher than before. The largest reduction rate of COD and NH$_3$-N before the allocation was 34.7% and 24.9%, respectively, and the largest reduction rate of COD and NH$_3$-N after the second allocation was 38.6% and 43.5%, respectively. The results also indirectly show that each city needs a larger reduction under the requirement of WECC. After the second allocation, the cities with the largest/smallest reduction rates, which were originally based on economic development and pollution emissions, have also changed. The results show that the original goals are irrational and indirectly prove the necessity of this study (Yu & Lu, 2018). Examining the final emission amounts for each city, the final allocation scheme did equate to the simple formula of ‘larger reductions for larger pollution loads’ (Li et al., 2016a, 2016b). Rather, the scheme accounted for social and economic factors in addition to the WECC. The results of Zones 4 and 14 can reflect the influence of these factors. For example, the current COD emissions for Zones 4 and 14 in 2015 were 492,000 t and 620,000 t, respectively. Despite this difference, their respective allocations for emission reductions were virtually identical at 11,400 t. The average GDP of Zone 4 in 2014 was 33,016 yuan, and the WECC in 2015 was 3.5, both of which were higher than those of Zone 14 (23,359 yuan and 1.6, respectively). This difference indicated that Zone 4 needed to improve the quality of its water environment and had the ability to support the economic investment needed for pollutant reduction (Liu & Wang, 2012). The distribution of NH$_3$-N pollution was similar to that of COD. The top four cities accounted for 35.8% of the total emissions and the proportion of reduction reached 34.8%. This result was also in line with the principle of fairness (Li et al., 2016a, 2016b; Zhou et al., 2017).

In order to evaluate the reasonableness of the allocation results presented here, we considered the pollutant emission status of each city and calculated the pollutant reduction rates for three different pollutant sources in each city. Figure 8 shows the allocation emission amounts for the three different pollution sources in each city, which is the ultimate allocation target of each city with the TEPC system in Henan Province. The emissions for different pollution sources in each city were reduced. In the actual management process, the total emission amounts for corresponding pollution sources can be controlled.

As shown in Figure 8, the results of the reduction rates for the different pollution sources are different. The COD reduction rates for the different pollution sources ranged from 0 to 39.0%, while the rates for NH$_3$-N reduction ranged from 0 to 62.2%. The pollutant emission status for Zones 19, 20, 21, and 22 was lower since their respective WECC was worse. As a result, their reduction rates were higher. The COD reduction rates for industrial, urban, and intensive livestock sources were 22.1%, 19.1%, and 20.7%, respectively, and the NH$_3$-N reduction rates were 23.7%, 16.3%, and 20.1%, respectively.
Industrial sources had the highest rates of reduction, followed by large-scale livestock sources. The urban sources had the lowest rate of reduction. These findings are consistent with the current Chinese emission reduction path (Zhang et al., 2016). As pollution sources do not have emission reduction potential, the urban sources in Zones 1, 8, and 11 do not need to reduce COD. Similarly, the large-scale livestock sources in Zones 8 and 20 do not need to reduce NH₃-N. These results met the different requirements for the reduction efforts across the three sources of pollution, indicating that a variety of management measures should be adopted in the future management of pollution from different sources.

4. Conclusions

In this study, an optimal allocation model based on WECC was developed for COD and NH₃-N load allocation from different types of pollution sources. The model was applied to 28 different cities in Henan Province, which has to be constrained given the region’s EPC. After two allocations, the targets of TEPC for each city in Henan Province reflected the characteristics of fairness, rationality, and regional differences. The allocation process was mainly affected by the reduction potential of pollution sources and the WECC for each city. Worse WECC meant a higher pollutant reduction rate. The
reduction rate for industrial sources was higher than for both large-scale livestock and urban sources, which was consistent with China’s current emission reduction path. The reduction ratio of cities and point sources for each city varied, which made the correct implementation of TEPC in each city much more important. This approach showed good application for TEPC in Henan Province in recent years. The waste load allocation results will be useful to guide for regional development and an emission permitting system for the different departments in Henan Province. The aim of this study was to create a water pollutants allocation model based on WECC to solve the problem of long-term disconnection between TEPC and water quality improvement in China. The model considered potential pollutant reduction together with WECC for the first time. The results suggest that this approach is applicable and effective for water pollutants allocation in central China and that the approach could also be applied in other regions with a similar problem. The results would be valuable for guiding China’s future TEPC allocation. The calculation of WECC is the foundation of the allocation model; however, there are still some uncertainties in the calculation of WECC (e.g., changes in hydrological and discharge conditions), and so further studies are needed to address these issues.

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