Science of the Total Environment 759 (2021) 143533

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Towards the formulation of rural sewage discharge standards in China

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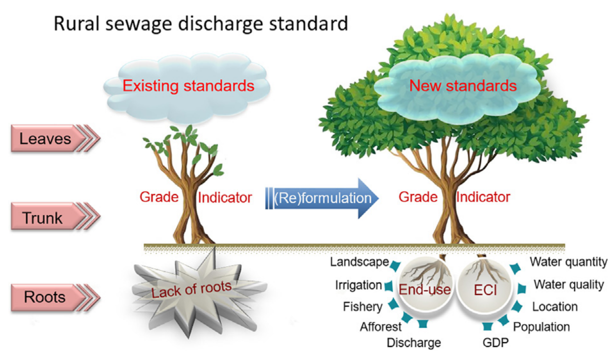
HIGHLIGHTS

- Current status of rural discharge standards in 31 provinces of China is reviewed.
- Rural sewage discharge standards based on local conditions are proposed.
- (Re)formulation of standards based on end-use/environmental capacity are discussed.
- Environmental capacity index as a new standard determinant is proposed.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 19 May 2020
Received in revised form 9 August 2020
Accepted 21 October 2020
Available online 17 November 2020

Editor: Huu Hao Ngo

Keywords:
Rural sewage discharge standard (RSDS)
(Re)formulation end-use
Environmental capacity index (ECI)

ABSTRACT

In China, most rural areas lack specific sewage discharge standards. Even though China governments proposed a series of local standards, the most of the existing China's rural sewage discharge standards are still similar to urban discharge standards. This research analyses comprehensively the data of rural sewage discharge standards in the 31 provinces and cities in China in terms of grade and indicator, and forms a structural framework for the formulation and revised standards in rural areas of China. In the formulation, we use 2 components, end-use and environmental capacity, to reflect local characteristics of the grades and indicators, and also propose the methods of combining discharge standards with relevant water quality standards to save energy. And we also use the mathematical model to illustrate environmental capacity in different regions. The paper shows the great potential in guiding the design of discharge standards formulation and revision for rural wastewater treatment in China and other developing countries as well.

1. Introduction

As of 2018, China's urban sewage treatment capacity was 1.7×10^8 m^3/d, with a removal efficiency of up to 90% (China Urban Construction Statistics Yearbook, 2018). This represents a 119% increase relative to the 2008 level (Lu et al., 2019), which is comparable to that of developed countries. It is this increasing sewage volume that drives government attention to developing sewage treatment discharge standards to considering wastewater as a water resource rather than a hazardous waste (Vilların and Merel, 2020).

The development of urban sewage discharge standards in China has gone through several stages, the process is shown in Table 1. In 2002, the "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plants" (GB18918-2002) (Ministry of Environmental Protection of the People's Republic of China (MEP), 2002a) were promulgated, and have been implemented up to now. This reformulated standard proposed limits for total nitrogen and hygiene indicators and adjusted

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https://doi.org/10.1016/j.scitotenv.2020.143533
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Table 1
Development of national urban sewage discharge standards in China.

Date	Items	Organization
1973	"Three-wastes" Discharge Standard, the "first environmental protection standard"(Building commission of the People's Republic of China, 1973)	Building commission of the People's Republic of China
1988	Integrated Wastewater Discharge Standard (MEP, 1988)	MEP
1996	Integrated Wastewater Discharge Standard (MEP, 1996)	MEP
2002	Discharge Standard of Pollutants for Municipal Wastewater Treatment Plants (MEP, 2002a)	MEP

the requirements for ammonia-nitrogen and phosphorus. Also, this standard is applied in all parts of the country without distinction. Since 2005, wastewater treatment plants (WWTPs) have implemented large-scale upgrading projects in China and successively strived to achieve the Grade I-A standard (MEP, 2002a). Moreover, the concept of quasi-class IV standards put forward in 2015, has required the effluent quality indicators of some urban WWTPs to be nearly consistent with Grade-IV of the "Environmental Quality Standards for Surface Water" (GB3838-2002) (MEP, 2002b). However, better effluent quality comes at the cost of increased energy consumption. For all of China's WWTPs to meet this standard, 78% more electricity would need to be consumed to achieve only limited improvements in pollutants removal (Lu et al., 2019; Ayoub et al., 2016). Thus, indiscriminately raising the discharge standards for all WWTPs in China might be unreasonable (Lu et al., 2017; Kate et al., 2019), particularly in rural areas.

Rural areas follow the "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plants" (GB18918-2002) (MEP, 2002a) as well as cities. But unlike urban areas, many rural areas are plagued by a shortage of funding for water pollution treatment and low awareness of environmental protection. Meanwhile, the receiving water quality, the patterns and requirements for sewage discharge, collection, treatment and effluent discharge in rural areas are different from those in urban areas in China. Consequently, a large amount of rural sewage is discharged without a suitable discharge standard, resulting in increasingly severe pollution of the water and soil in rural areas (Burt et al., 2011). Jin et al. (2014) showed that the construction of WWTPs and their treatment capacities had marked regional distribution characteristics. That means, relatively loose discharge standards may apply in areas with good self-purification capacity (e.g., rural areas) (Lyu et al., 2015; Fan et al., 2018). An appropriate standard directly affects the effectiveness and cost of treatment (Wang et al., 2015; Dong et al., 2012). Therefore, rural areas need to set discharge standards by considering the prevailing local conditions, instead of implementing uniform standards or applying needlessly high standards.

In response to the lack of rural sewage standards, the China government has actively promoted the development of rural sewage treatment discharge standards. In early 2018, the Central Office of the Communist Party of China and State Council of China issued a "Three-Year Action Plan for the Rehabilitation of Rural Human Settlements" (General Office of the CPC Central Committee, 2018). This action plan proposed that "drainage methods and discharge destinations should be distinguished among all regions. Also, discharge standards for rural domestic sewage treatment should be classified and formulated". At the same time, a "Notice on Accelerating the Formulation of Local Rural Domestic Sewage Treatment Emission Standards" (MEP, 2018) was issued to clarify the overall requirements, control indicators and discharge limits for rural domestic sewage treatment. These policies have promoted the standardization of rural sewage treatment. So far, 23 provinces have issued their own rural sewage discharge standards as shown in Table 2.

This study collects the data of the 31 provinces and cities in China. Among them, 23 provinces and cities have promulgated rural sewage discharge standards. These standards are analyzed in terms of grade division and indicator determination. It is found that most of these standards are made with reference to the national urban sewage discharge standards. This is essentially tantamount to continuing to use national urban discharge standards, and will also lead to out of limits of rural sewage discharge. Therefore, this paper presents an approach to reformulate the rural sewage discharge standards per the local conditions in rural areas of China. New standards should take into account the treated water utilization and regional characteristics, which will be reflected in the paper's end-use and environmental capacity, respectively. Also, methods for setting grades and indicators for standards according to end-use (e.g. fishery, irrigation, etc.) and thresholds according to the environmental capacity are elucidated. The finding is expected to help guide the design of applicable discharge standards for rural wastewater treatment in China and other developing countries as well.

The problem of China by 2019 will be conducted to illustrate the availability of a new standard formulation method. The following parts of this paper will be organized as follows: Section 2 states the way to research and the data source; Section 3 states the status quo of existing rural sewage discharge standard in China; Section 4 discusses the defect of the existing standard and the recommendation for new standard formulation methods; Section 5 draws the conclusions.

2. Methodology

The paper uses the data of rural sewage discharge standards in 31 provinces and cities in China, and proposes a new standard formulation method based on end-use and environmental capacity. This study considered that the formulation of standards could be derived from two parts, which are grades and indicators. A mathematical model is proposed to judge the relative environmental capacity of different regions. Finally, this study obtained a more reasonable formulation of rural sewage discharge standard method system for reference.

2.1. Data collection

2.1.1. Data sources

Two forms of data were used in this research, namely, statistical data and some national or local standards.

National or local standards: these data were used to analyze the situation of China's rural sewage discharge standards and are needed for reference in the formulation of new standards. Firstly, by 2019, 23 provinces and municipalities in China had introduced rural sewage discharge standards (Table 2). Secondly, some related discharge standards are used in the paper, just like "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant" (GB 18918-2002) (MEP, 2002a), "The reuse of urban recycling water-Standards for irrigation water quality (GB20922-2007)" (General Administration of Quality Supervision, 2007), "Water quality standards for fisheries (GB11607-89)" (MEP, 1989) and some other Chinese standards mentioned in the paper. The data source used for this purpose was the website of the Ministry of Environmental Protection of the People's Republic of China (MEP) (http://www.mee.gov.cn/). The website publishes new local standards in a timely manner, making it a reliable source.

Statistical data: The data on population density, Gross Domestic Product (GDP), area and total surface water were collected through China Urban Construction Statistics Yearbook (National Bureau of Statistics of the People's Republic of China, 2019). Data on annual pollution conditions in rivers, lakes and air are published in the Bulletin of China's State of Environmental Ecology by Ministry of Ecology and Environment of the People's Republic of China.

Table 2
List of local rural sewage discharge standards by 2019.

Province	Number	Release date	Organization
Beijing (Beijing Municipal Ecological Environment Bureau, 2019)	DB11/1612-2019	2019-01-07	Beijing Municipal Ecological Environment Bureau
Chongqing (Chongqing Environmental Protection Bureau, 2018)	DB50/848-2018	2018-04-08	Chongqing Environmental Protection Bureau
Gansu (Gansu Ecology and Environmental Department, 2019)	DB62/4014-2019	2019-08-14	Gansu Ecology and Environmental Department
Guizhou (Guizhou Ecology and Environmental Department, 2019)	DB52/1424-2019	2019-09-01	Guizhou Ecology and Environment Bureau
Guangdong (Guangdong Ecology and Environmental Department, 2019)	DB44/2208-2019	2019-11-22	Guangdong Ecology and Environmental Department
Hebei (Hebei Environmental Protection Bureau, 2015)	DB13/2171-2015	2015-02-15	Hebei Environmental Protection Bureau
Henan (Henan Ecology and Environmental Department, 2019)	DB41/1820-2019	2019-06-06	Henan Ecology and Environmental Department
Heilongjiang (Heilongjiang Ecology and Environmental Department, 2019)	DB 23/2456-2019	2019-08-27	Heilongjiang Ecology and Environment Bureau
Hainan (Hainan Ecology and Environmental Department, 2019)	DB46/483-2019	2019-11-04	Hainan Ecology and Environment Bureau
Jiangsu (Jiangsu Ecology and Environmental Department, 2018)	DB32/T 3462-2018	2018-11-09	Jiangsu Ecology and Environmental Department
Ningxia (Ningxia hui autonomous region environmental protection department, 2011)	DB 64/T700-2011	2011-09-05	Ningxia Hui autonomous region environmental protection department
Shaanxi (Shaanxi Ecology and Environmental Department, 2018)	DB61/1227-2018	2018-12-29	Shaanxi Ecology and Environmental Department
Shanghai (Shanghai Ecology and Environmental Department, 2019)	DB31/T1163-2019	2019-06-14	Shanghai Ecology and Environmental Department
Shandong (Shandong Ecology and Environmental Department, 2019)	DB37/3693-2019	2019-09-27	Shandong Ecology and Environmental Department
Shanxi (Shanxi Ecology and Environmental Department, 2019)	DB14/726-2019	2019-11-01	Shanxi Ecology and Environmental Department
Tianjin (Tianjin Ecology and Environmental Bureau, 2018)	DB12/889-2019	2019-07-09	Tianjin Ecology and Environmental Bureau
Fujian (Fujian Ecology and Environmental Department, 2019)	Draft discharge standard	–	Fujian Ecology and Environmental Department
Hunan (Hunan Administration for Market Regulation, 2019)	Draft discharge standard	–	Hunan Administration for Market Regulation
Hubei (Hubei Ecology and Environmental Department, 2019)	Draft discharge standard	–	Hubei Ecology and Environmental Bureau
Jiangxi (Jiangxi Ecology and Environment Bureau, 2019)	Draft discharge standard	–	Jiangxi Ecology and Environment Bureau
Liaoning (Liaoning Ecology and Environmental Department, 2019)	Draft discharge standard	–	Liaoning Ecology and Environment Bureau
Zhejiang (Zhejiang Ecology and Environmental Bureau, 2019)	Draft discharge standard	–	The People's Government of Zhejiang province
Sichuan (Sichuan Ecology and Environmental Department, 2019)	Draft discharge standard	–	Sichuan Ecology and Environmental Department

2.1.2. Watershed data

When setting a standard indicator threshold, the population size, economy, water volume and environmental capacity of the receiving rivers should be considered comprehensively. For environmental capacity of a river, "The Bulletin of China's State of Environmental Ecology" (MEP, 2019a) divides China's watershed into ten major river basins, namely the Yangtze River Basin, the Yellow River Basin, the Pearl River Basin, the Songhua River Basin, the Huai he River Basin, the Hai he River Basin, the Liao River Basin, the Zhejiang-Fujian River Basin, the Northwest Rivers and Southwest rivers. Different watersheds can accept different amounts of pollutants. Table 3 shows 31 province administrative regions (excluding Taiwan, Macao and Hong Kong) in China according to river basins.

2.2. Analytical methods

2.2.1. Integrated standards formulation framework

In this paper, all provinces in China are classified according to river basins, and the classification methods of grades and indicators of all rural sewage discharge standards are gathered, analyzed and compared. In order to analyze conveniently, each standard is classified in terms of grade I, grade II, and grade III categories. In principle, indicators, like pH, chroma, chemical oxygen demand (COD), biological oxygen demand (BOD), suspended solids (SS), NH_4-N, total nitrogen (TN), total phosphorus (TP), animal and vegetable oil and fecal coliform are classified into physical, organic, nutrient and other indicators.

It is found that the grade of the standard and the type of the indicators are affected by the end-use, and the threshold of the indicators are related to the local environmental carrying capacity. Meanwhile similar standards should be adopted in similar areas. What's more, the effluent is not only used for discharge in the standard, but should be reused as reuse water to save water resources. Therefore, in the classification of grades and the selection of indicator types of standards, the end-use of effluent needs to be considered and combined with other current reuse water standards to increase utilization. Simultaneously, due to the differences in population size, economic development and water resources in different regions resulting in the difference of environmental capacity, so it should be fully considered when determining the threshold of standard indicators. Based on these factors, we put forward relevant grades' classification, indicators selection and threshold determination suggestions according to different end-use of effluent.

A framework of rural sewage discharge standard formulation is provided in Fig. 1.

2.2.2. The mathematical model of environment capacity

Environmental capacity initially describes the carrying capacity of an area's environment for population growth and economic development. The carrying capacity determines the size of the standard indicator

Table 3
River conditions and distribution. Due to geographical location, some provinces are located in 2–3 river basins. Meanwhile, a little part province located in one basin is neglected.

River area	Pollution status	The proportion of water below IV (%)	provinces
The Yangtze River Basin	Good	12.6	Qinghai, Sichuan, Yunnan, Guizhou, Chongqing, Hubei, Hunan, Jiangxi, Anhui, Jiangsu, Shanghai
The Yellow River Basin	Mild pollution	33.5	Qinghai, Gansu, Ningxia, Inner Mongolia, Shanxi, Shaanxi, Henan, Shandong
The Pearl River Basin	Good	15.2	Yunnan, Guangxi, Hainan, Guangdong
The Songhua River Basin	Mild pollution	42	Heilongjiang, Jilin, Inner Mongolia
The Liao River Basin	Moderately polluted	50.9	Liaoning, Inner Mongolia
The Huai River Basin	Mild pollution	42.8	Henan, Anhui, Jiangsu, Shandong
The Hai he River Basin	Moderately polluted	53.8	Beijing, Tianjin, Hebei
The Zhejiang-Fujian River Basin	Good	11.2	Zhejiang, Fujian
The Northwest Rivers	Excellent	3.2	Xinjiang
The Southwest rivers	Excellent	4.8	Tibet

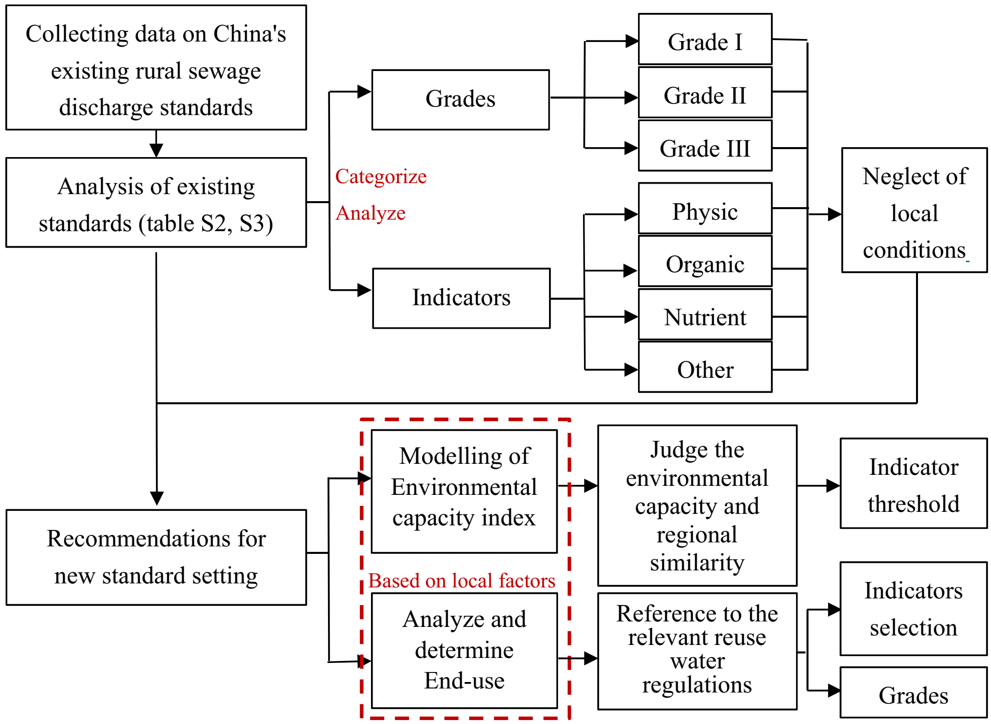

Fig. 1. framework of rural sewage discharge standards formulation.

threshold in a certain area(Zhou et al., 2017). Therefore, we used population density, GDP and water pollution to express the carrying capacity of a region's water environment, and proposed a mathematical model which can suggest the water environmental capacity in a region.

$$\text{environmental capacity index(ECI)} = \frac{\text{SW} \times \text{WP(IV)}}{\text{GDP}} \times \frac{1}{\frac{P}{A}}$$

SW—total surface water,100 million m^3;

WP(IV)—the proportion of water below four categories, %;

A—area, 10,000 km^2;

P—population, 100 million people;

GDP—gross domestic product of each province, 100 million yuan.

This model integrates population density, GDP and water pollution of a certain region, which can well reflect the environmental capacity of different regions in water environment. The ECI represents the ability of pollutants to be assimilated by the local environment and can be applicable to provinces with a population density >100 p/km^2 in China. The ECI can reflect the size of the environmental capacity in a region and the similarity of environmental capacity in different regions. By calculating the environmental capacity index of different regions in China, the results reflect the similarity of ECI in similar regions, and also show the regularity in different regions in line with China's current situation.

In fact, the trends of ECI variation can not only clearly exhibit the correlation of environmental capacity among regions, but also guide the government to formulate more precise and effective standards and policies, so it is incorporated for thorough exploration.

3. Results

3.1. Standard grades

3.1.1. Classification by functional zoning of water body

In the Grade-I standard classification, Ningxia, Shaanxi, Zhejiang, and Jiangsu are classified by the environmental functions of the receiving water and basically refer to the classification method of "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant" (GB 18918-2002) (MEP, 2002a) (Table A.2 in supplementary). Nonetheless, there are still several provinces and cities that have proposed their own classification systems. For example, Shaanxi added a special discharge limit requirement for the effluents discharged to the 2 km extensions of the bank of lakes serving as drinking water sources. The grades adopted in the Jiangsu Province is relatively meticulous, and the classification requirements are determined by the local water functional zoning. Tianjin divides the third-grade standards into three levels in a scale-oriented manner, whereas Ningxia raised the requirements for crop irrigation in the third-grade standard (Table A.2).

The classification according to functional zoning of the receiving water is the most basic method in the standard grading. The method takes into account the environmental capacity of the water functional zoning.

3.1.2. Classification by functional zoning of water body and treatment facilities scale

Beijing, Tianjin, Shanxi, Chongqing, Shandong, Hunan, Gansu, Guangdong, Jiangxi, Hubei, Sichuan, Heilongjiang, Liaoning, Guizhou and Henan added scale requirements based on the control of the quality of the receiving water bodies and considered the impact of treatment facilities scale on pollutant discharge (Table A.2 in supplementary). In general, the scale of treatment facilities for rural sewage is under 500 m^3/d. Yet, each province chooses a different scale as its dividing line. For instance, Hunan uses 5 m^3/d as the boundary. Heilongjiang added 30 m^3/d, and Beijing, Jiangxi and Shandong added 50 m^3/d as their limit. By contrast, Chongqing, Hubei, and Guangdong used 100, 100, and 20 m^3/d as their respective criteria. Sichuan divided its standard grades both at 20 m^3/d and 100 m^3/d, whereas Guizhou and Gansu chose 10 m^3/d and 55 m^3/d respectively (Table A.2 in supplementary).

When the standards are graded according to the functional zoning of water bodies and the treatment scale, consideration to the scale of the treatment facilities is given by reference to the "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002)" (MEP, 2002a). The scale of the treatment mainly reflects the population size and the total amount of pollutants. This classification method is also based on environmental capacity, and at the same time, it increases the population factor.

3.1.3. Classification by functional zoning of water body and economic classification

Hebei and Fujian used the rural area economy as an auxiliary condition for controlling the receiving water body, whereby different economic conditions refer to different levels. Generally, the entire province is divided into developed, less developed and underdeveloped economic regions (Table A.2 in supplementary).

The economic factors affect the influent quality of the treatment facilities, treatment technology selection and post-operation and maintenance, all of which impacts on the quality of the effluent.

3.2. Standard indicators

All the indicators in the standards include two factors, namely, the type of indicator and threshold.

3.2.1. Indicator selection

Generally, indicators of effluents include physical (pH, chroma, suspended solids), organic (COD, BOD_5), nutrient (ammonia nitrogen, TN, TP) and other indicators (animal and vegetable oils, fecal coliforms). However, not all provinces choose to use all these indicators.

By inductive analysis of the existing standards, pH, SS, COD, ammonia-nitrogen, TN, TP and animal and vegetable oils as the main indicators are selected by all provinces. Simultaneously, chroma (Hebei, Fujian), BOD_5(Beijing, Hebei, Fujian, Ningxia), fecal coliform (Hebei, Ningxia, Shanxi, Zhejiang, Jiangsu and Hainan et al.) as supplementary indicators are chosen by provinces in brackets. Conversely, Chongqing and Guangdong directly cancel out the TN indicator (Table A.3).

3.2.2. Indicator thresholds

3.2.2.1. Physical indicators. Physical indicators refer to the properties that can be expressed without chemical changes. Temperature, pH, chroma and suspended solids (SS) are regarded as the main indicators in urban sewage treatment. Nonetheless, Table 2 shows that, in rural sewage treatment, pH and suspended solids (SS) are selected as the main physical indicators of the discharge standards in most areas.

All provinces proposing or drafting discharge standards require the value of pH to fall between 6–9 (Wang et al., 2017). These represent consistency (Table A.3 in supplementary).

In the grade I standard of the “Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant” (GB 18918-2002) (MEP, 2002a), the value of SS requires Grade I-A to be 10 mg/L and Grade I-B to be 20 mg/L. But in rural sewage discharge standards, except for the limit of 30 mg/L in Chongqing, the limits set by the most provinces fall between 10–20 mg/L. Hebei, Fujian and Jiangsu have divided grade I into two levels, which are I-A and I-B, with the same limits as the “Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant” (GB 18918-2002). Beijing also adopts grade I-A and grade I-B, but with the limit same of 15 mg/L. The remaining provinces require a limit of 20 mg/L, which is consistent with the Grade I-B standard of the “Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002)” (MEP, 2002a) (Table A.3 in supplementary).

However, Chongqing was formally established as a municipality in 1997. Compared with other municipalities (Beijing, Shanghai, Tianjin), it developed relatively late. Therefore, the standards formulated are more relaxed than the “Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002)” (MEP, 2002a).

3.2.2.2. Organic indicators. The conventional organic matter indicators usually refer to biochemical oxygen demand (BOD) and chemical oxygen demand (COD) (Morgane et al., 2019). COD is mainly used as the organic matter indicator in existing rural sewage discharge standards.

In the grade I standard of the “Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant” (GB 18918-2002) (MEP, 2002a), the limit value of COD required for Grade I-A is 50 mg/L and that for Grade I-B is 60 mg/L. However, in the rural standards, Beijing still proposes a higher threshold of 30 mg/L due to the characteristics of urban development. Also, Shanxi and Tianjin are consistent with Grade I-A standard. In addition, Ningxia, Zhejiang, Shandong, Hunan, Gansu, Hainan, Jiangxi, Hubei, Sichuan, Liaoning, Heilongjiang, Guizhou et al. following the requirements of the “Guidelines for the Preparation of Water Pollutant Discharge Control Regulations for Rural Domestic Sewage Treatment Facilities (Trial)” (MEP, 2019b), are basically consistent with the “Discharge Standards for Pollutants in Urban Sewage Treatment Plants”, which is set at 60 mg/L. Hebei, Shanghai, Jiangsu and Fujian have divided grade I into two levels, which are I-A and I-B, with the same limits as the “Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant” (GB 18918-2002) (MEP, 2002a). Overall, Chongqing adheres to a more relaxed standard (Table A.3 in supplementary).

3.2.2.3. Nutrient indicators. Elevated nutrient concentration (e.g., TN and TP) in water reservoirs trigger blooms of cyanobacteria such as Anabaena sp., Planktothrix or Microcystis sp. caused by eutrophication (Vincent and Richard, 2018). Eutrophication stresses aquatic ecosystems and threatens drinking water supplies (Vincent et al., 2014). Unreasonable standard values of nitrogen and phosphorus will have a detrimental impact on closed water bodies such as lakes and reservoirs. Ammonia-nitrogen, as a source of N, is also classified as a nutrient indicator (Williams et al., 1998).

Basically, all provinces have regulations on ammonia-nitrogen, TN, and TP in the grade I. The requirements for TN in all provinces are not very strict. Beijing, Shanghai, Hebei and Fujian have two divisions of grades A and B, with TN indicators similar to the Pollutant Discharge Standards for Urban Sewage Treatment Plants. The most provinces basically chose 20 mg/L as the grade I limit. However, the difference in requirements for ammonia-nitrogen is relatively large. The limits of ammonia-nitrogen in Beijing as the central area of China, set at 1.5 mg/L, which is basically only one-third of the limit of that of the pollutant discharge standards for urban sewage treatment plants. In addition, these provinces have relatively high indicators threshold, such as Chongqing, Shaanxi, whose population density and economic development are moderate, are relatively high at 20, 15 mg/L respectively. As for TP, it is shown that the provinces with loose ammonia-nitrogen requirements have lower requirements for TP, such as Shanxi, Shaanxi, Zhejiang, and Chongqing (Table A.3 in supplementary).

3.2.2.4. Other indicators. Animal and vegetable oils, anionic surfactants and fecal coliforms are classified under other indicators that are not mandatory in rural sewage treatment.

All provinces have requirements for animal and vegetable oils in the grade I, and the threshold ranges from 0.5 to 5 mg/L. The difference in thresholds for animal and vegetable oils may be due to the different development levels in the catering industry in rural areas. Only Shandong, Ningxia, Shanxi, Fujian, and Jiangsu have established anionic surfactant limits, which are basically consistent with the “Discharge Standards for Pollutants in Municipal Wastewater Treatment Plants.” Shandong, Hebei, Ningxia, Hainan, Zhejiang and Jiangsu provinces have requirements for fecal coliforms, and the limits are basically set at 10,000/L. There is a correlation between the number of fecal coliform bacteria and the number of intestinal pathogenic bacteria. To ensure that the water body is not contaminated by intestinal pathogenic bacteria, the threshold of fecal coliforms is set to 10,000/L under the conditions of economic and technical permission (Hays, 1977) (Table A.3 in supplementary).

4. Discussion

4.1. Recommendations for standard formulation

4.1.1. Standard grades

There are three classification methods for existing rural discharge standards: functional zoning of the receiving water, the treatment scale and economics. Regardless of any of these, the existing classification methods only consider a single factor and the effluent for discharge. But discharge is not the only way to end-use.

Also, China is a country that anticipate water scarcity. The water reclamation is the best way of preserving water resources (Panda, 2019; Clémence et al., 2020). A report shows that only gray water (GW) reclamation can decreases potable water consumption by 29% to 47% (Jawaduddin et al., 2019). Yet, the existing standard grading methods only considers effluent discharges and woefully neglects effluent recycling (Michael-Kordatou et al., 2015). The key element involved in wastewater recycling is water quality security. But now, China's system for recycling water is still far from meeting the safety needs of reclaimed water (Zhang et al., 2016). Therefore, the first step in promoting the reuse of sewage is to clarify the end-use of sewage when formulating standards (Gansu has begun to pay attention to the end-use in the latest standards). Areas facing water shortage can be considered above all water reuse. Sewage is recycled for end-uses of the toilet flushing, dishwashing, and indoor taps in some areas of developed countries (Ajmal and Manish, 2020). However, rural domestic sewage effluent reuse involves farmland irrigation, fisheries and landscape replenishment, and thus can follow "The reuse of urban recycling water-Standards for irrigation water quality (GB20922-2007)" (General Administration of Quality Supervision, 2007), "Water quality standards for fisheries (GB11607-89)" (MEP, 1989) and "The reuse of urban recycling water—Water quality standard for scenic environment use (GB/T18921-2002)" (China, State Administration for Market Regulation, 2002). In other words, the end-use of treated sewage may fall into several classes as described in Table 4 in the formulation of rural sewage discharge standards.

When effluent is used as irrigation water for farmlands, three grades can be classified according to the type of crop being irrigated. On the other hand, for fisheries, a single standard of only the Grade I may be required. For effluents directly discharged, it is first clear that the scale of rural sewage should be less than 500 m^3/d. Then a classification based on the water quality of the receiving water and the scale of the treatment facilities may be included, which follows the "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002)" (MEP, 2002a).

4.1.2. Indicator selection

Due to the weak rural economic and technological strength, it does not have some pollution object detection capability. Therefore, the selection of rural sewage pollutant control indicators needs to be discussed.

Chroma is an indicator of the aesthetic quality of water. Commonly, the influent color of rural domestic sewage is low, and conventional precipitation methods can easily meet the requirements, so the color can be not mandatory.

Both BOD_5 and COD are the part of organic indicators. There is no doubt that excess of organics will lead to deterioration of water quality, even black-odorous (Cao et al., 2019). The two indicators reflect the pollution of water bodies by reducing substances. However, BOD_5 takes a long time to measure, while COD is a national key pollutant control indicator and easy to detect. Therefore, COD is used as the main organic matter measurement indicator in rural domestic sewage discharge standards.

Total Nitrogen (TN) is the sum of inorganic nitrogen and organic nitrogen in a water body, including the nitrogen content in soluble and suspended particles, which can reflect the nutrients level of lakes and reservoirs. According to Huang et al. (2017), nitrate-nitrogen accounts for a large proportion of the total nitrogen content in lakes and reservoirs. Therefore, if the domestic sewage treatment effluent is directly discharged, it is necessary to set a limit for TN. Moreover, when the effluent is used as farmland irrigation water, the TN may not be mandatory.

Fecal coliforms are generally controlled as important biological indicator. It is necessary to include a disinfection step during the treatment process. However, due to the high operating cost of the disinfection equipment, it is not suitable for rural areas. Therefore, fecal coliforms may not be used as a control indicator.

With reference to the experience of foreign developed countries, for example, Japan's "Purge Tank Law" (Ministry of Land and Infrastructure and Transport and Tourism of Japan, 2005) selects only a few pollutant control indicators such as COD, BOD_5, TN, and TP for rural sewage. But in China, in the formulation of rural domestic sewage discharge standards, indicator selection should be based on different sewage end-uses. Different end-uses directly affect the types of indicators. It may follow the criteria presented in Table 5. Table 5 shows some existing standard for different end-use in China, especially for recycled water. The indicators for recycled water can be selected according to the requirements for farmland irrigation, fisheries and landscape water issued by the state. When the effluent is directly discharged, it can be selected with reference to "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plants (GB18918-2002)" (MEP, 2002a). But the peculiarity of rural domestic sewage should be considered.

4.1.3. Indicator thresholds

Analysis of the existing standard shows that the thresholds are disordered. Furthermore, existing standards are set for discharge and a single factor, not for the end-use and environmental capacity index of treated sewage. Also, many problems arise, such as too strict standard indicator thresholds, reference to urban standards, and even a contradiction between limits for TN and ammonia-nitrogen in Hunan. Overly strict standards have not yet been met in urban areas, let alone in rural areas where economic and technological development is lagging behind. Like establishing the ammonia water quality criteria in the US (USEPA, 2013), an empirical formula for adjusting ammonia was proposed, which considered the different pH and temperature influence on ammonia. Also, the methods guide other similar country, just like

Table 4
Reference of the grade of new standards.

	Standard	Grade I	Grade II	Grade III
Resource utilization	Standards for irrigation water quality (GB20922-2007)	Vegetables	Paddy crop irrigation	Dryland crop irrigation
	Water quality standard for scenic environment use (GB/T18921 2002)	Recreational landscape environment water (non-systemic contact)	Ornamental landscape environment water (not indirect contact)	–
	Water quality standard for fisheries (GB11607-89)	Fishery standard	–	–
Discharge	Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002)	Grade I	Grade II	Grade III

Table 5
Reference of the indicator selection of new standards.

	Physical indicators[a]			Organic indicators		Nutrient indicators			Other indicators		
	pH	SS	Chroma	BOD_5	COD	Ammonia nitrogen	TN	TP	Animal and vegetable oil	Anionic surfactant	fecal coliforms
Standards for irrigation water quality (GB20922-2007)[a]	•	•		•	•					•	•
Water quality standard for scenic environment use (GB/T18921 2002)	•	•	•	•		•	•	•		•	•
Water quality standard for fisheries (GB11607-89)[a]	•	•		•							•
Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002)	•	•	•	•	•	•	•	•	•	•	•
Discharge Standard of Pollutants for Rural Wastewater Treatment Plant	•	•			•	•	•	•	•		

[a] Farmland irrigation water and fishery water should also pay attention to heavy metals such as mercury, cadmium and arsenic, so as to avoid the accumulation of heavy metals in crops and organisms. The fishery water needs to pay attention to pesticides such as DDT and 666.

Canada (Canadian Council of Ministers of the Environment, 2010; Yan et al., 2020).

Standards are determined by a combination of many factors, such as population density, economic conditions, river pollution, instead of determination by a single factor. But now, the indicator thresholds of many provinces and cities basically refer to the urban standards without much consideration of the local environmental capacity and the possible similarities within the same river basin. For example, due to locating in the downstream of the Pearl River, rapid urbanization and industrialization, the area of the "V+" category water in Guangdong has been increasing since 2000 (He et al., 2020). Thus, each province formulated the indicator thresholds that suit them. Meanwhile, a macroscopic index that reflects the environmental capacity and regional similarity of different regions in China is proposed, which is discussed in detail in the Section 4.2.

4.2. Environmental capacity index

4.2.1. The calculation of environmental capacity index

Table 6 is obtained by calculating the ECI of the declared area.

Beijing, Hebei, and Tianjin lie in the Hai River. They are located in the Bohai Sea area of North China. The very small ECI shown for this area indicates that the three provinces need relatively strict standards than the other Chinese provinces. When the end-use has been determined as discharge, Beijing and Tianjin, as the central provinces of China, can directly comply with the requirement in the "Guidelines for the Preparation of Water Pollutant Discharge Control Regulations for Rural Domestic Sewage Treatment Facilities (Trial)" (MEP, 2019b)—the standards of urban sewage treatment (special areas can be slightly stricter).

In the Huai river basin, Shandong and Jiangsu have ECI of only 1.5837 and 1.4727 respectively. These ECI are relatively small. Thus, the grade I

Table 6
the summary of ECI calculations of various provinces.

Provinces	Population (100 million people)	Area (10,000 km^2)	Population density (p/km^2)	GDP (100 million yuan)	Basins	The proportion of water below four categories (%)	Total surface water (100 million m^3)	ECI
Beijing	0.2171	1.68	1292	28,015	The Hai River Basin	42.8	12.0	0.1418
Hebei	0.7520	18.77	401	34,016			60.0	1.8843
Tianjin	0.1557	1.13	1378	18,549			8.8	0.1474
Shandong	1.0006	15.38	651	72,634	The Huai River Basin	53.8	139.1	1.5837
Henan	0.9559	16.70	572	44,553			311.2	6.5652
Jiangsu	0.8029	10.26	783	85,870			295.4	1.4727
Anhui	0.6255	13.97	448	27,018			717.8	31.9228
Gansu	0.2626	45.44	58	7460	The Yellow River Basin	33.5	231.8	180.1229
Ningxia	0.0682	6.64	103	3444			8.7	8.2402
Shanxi	0.3702	15.63	237	15,528			87.8	7.9971
Shaanxi	0.3835	20.56	187	21,899			422.6	34.6586
Inner Mongolia	0.2529	118.3	21	16,096			194.1	188.9680
Qinghai	0.0598	72.23	8	2625			764.3	11,781.3698
Sichuan	0.8302	48.14	172	36,980	The Yangtze River Basin	12.6	2466.0	48.7211
Chongqing	0.3075	8.23	374	19,425			656.1	11.3904
Guizhou	0.3580	17.60	203	13,541			1051.5	48.1021
Hubei	0.5902	18.59	317	35,478			1219.3	13.6396
Hunan	0.6860	21.18	324	33,903			1905.7	21.8670
Jiangxi	0.4622	16.70	277	20,006			1637.2	37.2556
Shanghai	0.2418	0.63	3838	30,633			27.8	0.0298
Yunnan	0.4801	38.33	125	16,376			2202.6	135.3024
Qinghai	0.0598	72.23	8	2625			764.3	4431.2018
Zhejiang	0.5657	10.20	555	51,768	The Zhejiang-Fujian River Basin	11.2	881.9	3.4402
Fujian	0.3911	12.13	322	32,182			1054.2	11.3789
Liaoning	0.4369	14.59	299	23,409	The Liao River Basin	50.9	161.0	11.6904
Inner Mongolia	0.2529	118.3	21	16,096			194.1	287.1186
Heilongjiang	0.3789	47.30	80	15,903	The Songhua River Basin	42	626.5	206.5554
Jilin	0.2717	18.74	145	14,945			339.8	65.8653
Inner Mongolia	0.2529	118.3	21	16,096			194.1	236.9151
Guangdong	1.1169	18.00	621	89,705	The Pearl River Basin	15.2	1777.0	4.8526
Hainan	0.0926	3.40	272	4463			380.5	47.5865
Guangxi	0.4885	23.6	207	18,523			2386	94.5911
Xinjiang	0.2445	166	15	10,882	The Northwest Rivers	3.2	969.5	193.5612
Tibet	0.0337	122.8	3	1311	The Southwest Rivers	4.8	4749.9	63,371.1339

Table 7
Different ECI reference standard threshold.

Density of population	ECI range	Reference standard grade and threshold[a]
≥100 p/km^2	≤1	Superior to grade I-B
	1–10	Grade I-B
	10–50	Inferior to grade I-B
	>50	Superior to grade II
<100 p/km^2		Grade II

[a] Grade I-B and grade II are both from Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002).

can refer to the "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002)" (MEP, 2002a). However, the ECI of Henan is 6.5652. When setting standards, they can be relaxed a little than Shandong and Jiangsu.

Ningxia, Gansu, Shanxi and Shaanxi belong to the Yellow River Basin. The calculation of environmental capacity is quite different. The ECI for Ningxia and Shanxi are relatively small. Ningxia covers a small area and has less water resources, so it can use treated effluent for water reuse. The population density of Gansu is small, resulting in a larger ECI. Therefore, when the population density < 100 p/km^2, ECI can be replaced by population density to judge environmental capacity. However, due to its small population density, the standard can be relaxed or even referred to Grade II of the "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002)" (MEP, 2002a). Inner Mongolia and Qinghai have not yet set standards, but they are two special provinces. These two provinces cover a large area and belong to 2–3 river basins at the same time. Therefore, such a province can be divided into several parts in the formulation of standards, or the smallest ECI in several river basins can be selected as the standard formulation method for that province.

The remaining basins could use ECI in this way when formulating standards. The specific usage of the method of ECI is shown in Table 7.

4.2.2. Similarity of environmental capacity in different areas of China

ECI is an index that comprehensively reflects the environmental capacity of different regions by the factors such as population, area, GDP, water volume and extent of river basin pollution. ECI cannot only guide the determination of standard values, but also reflect the similarity of standard values in different provinces of the same basin.

ECI can work when the population density is greater than 100 p/km^2. Table 6 shows that in the published standards, the provinces with similar ECI in the same watershed are also relatively similar in geographical area, which means that these regions have similar characteristics. Therefore, these provinces, in the formulation of standards requirements, should be basically same, such as Guizhou, Jiangxi and Sichuan, Tianjin and Beijing. But the existing standards ignore such regional similarities (Fig. 2). Of the 31 Chinese provinces, Anhui and Guangxi are the most densely populated but have not yet proposed standards. Anhui can refer to the closest ECI provinces in the same basin—Henan. Guangxi can follow the same principle. ECI cannot only provide a basis for the reformulation of standards that have been promulgated, but also provides a reference for provinces that have not promulgated standards yet.

Conversely, ECI may be large when population density is small. Because the area is large and sparsely populated, the amount of sewage is relatively small, which will reduce the impact on the environment. At this time, the area can adopt the most similar population density within the same basin or the population density of the basin with similar pollution status (Fig. 3). For example, Xinjiang and Tibet can refer to Qinghai or Gansu's standard requirements.

5. Conclusions

An analysis of the current state of rural sewage discharge standards in 31 provinces of China demonstrate that most areas depend on the "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002)" (MEP, 2002a). Also, the local conditions are not well considered. Even some areas still have no relevant rural sewage discharge standards. This paper mainly provides reference on the establishment of rural sewage standards in China. The provinces and cities that have promulgated the standards may revise the standards according to the suggestions. And it can also be used as a reference to formulate new standards for the area without standards.

In conclusion, appropriate discharge standards for rural sewage may be (re)formulated by considering the local conditions from two aspects:

(1) End-use of treated water

When new standards are (re)formulated, the purpose of treating effluent should be determined first. In addition to effluent discharge, recycling water is seen as a more promising approach. The water quality used in different drainage ways must vary greatly. Meanwhile, end-use will require different grades and indicators. Thus, end-use should play an important role in the grade and indicator selection of the rural sewage standard. For example, fishery water, irrigation water and discharge water shall refer to the fishery water standards, irrigation water, and discharge standards, respectively, in the grade classification and indicators selection.

(2) Environmental capacity index

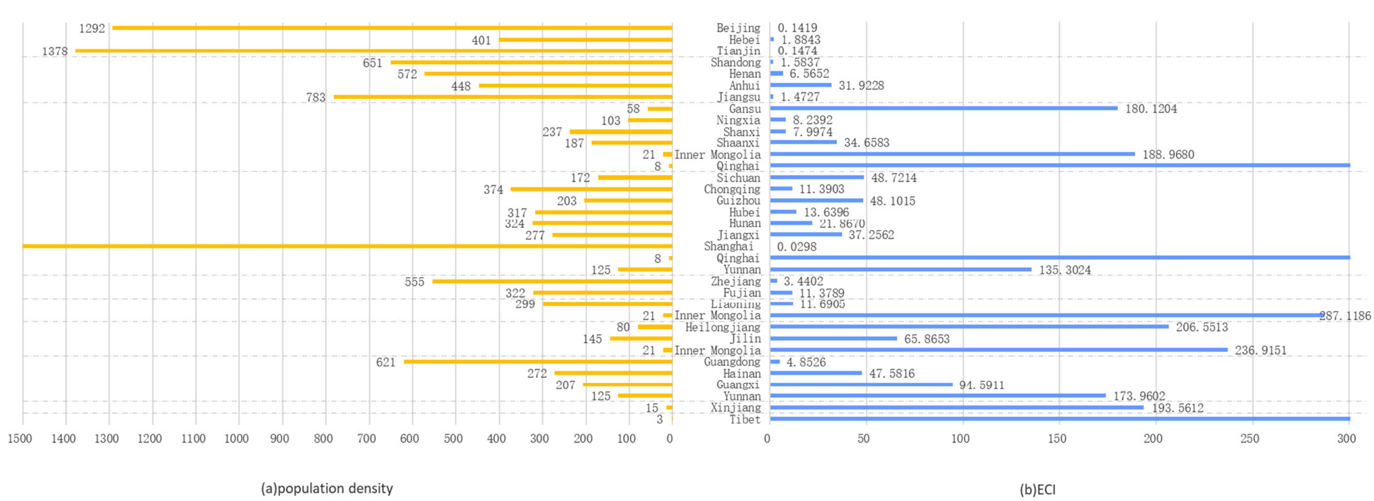

Fig. 2. Watershed boundaries and standard requirement of grade I in China. I-A, I-B stand for the grade I-A and I-B of "Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002)". Gray areas represent provinces and cities that have not proposed standards.

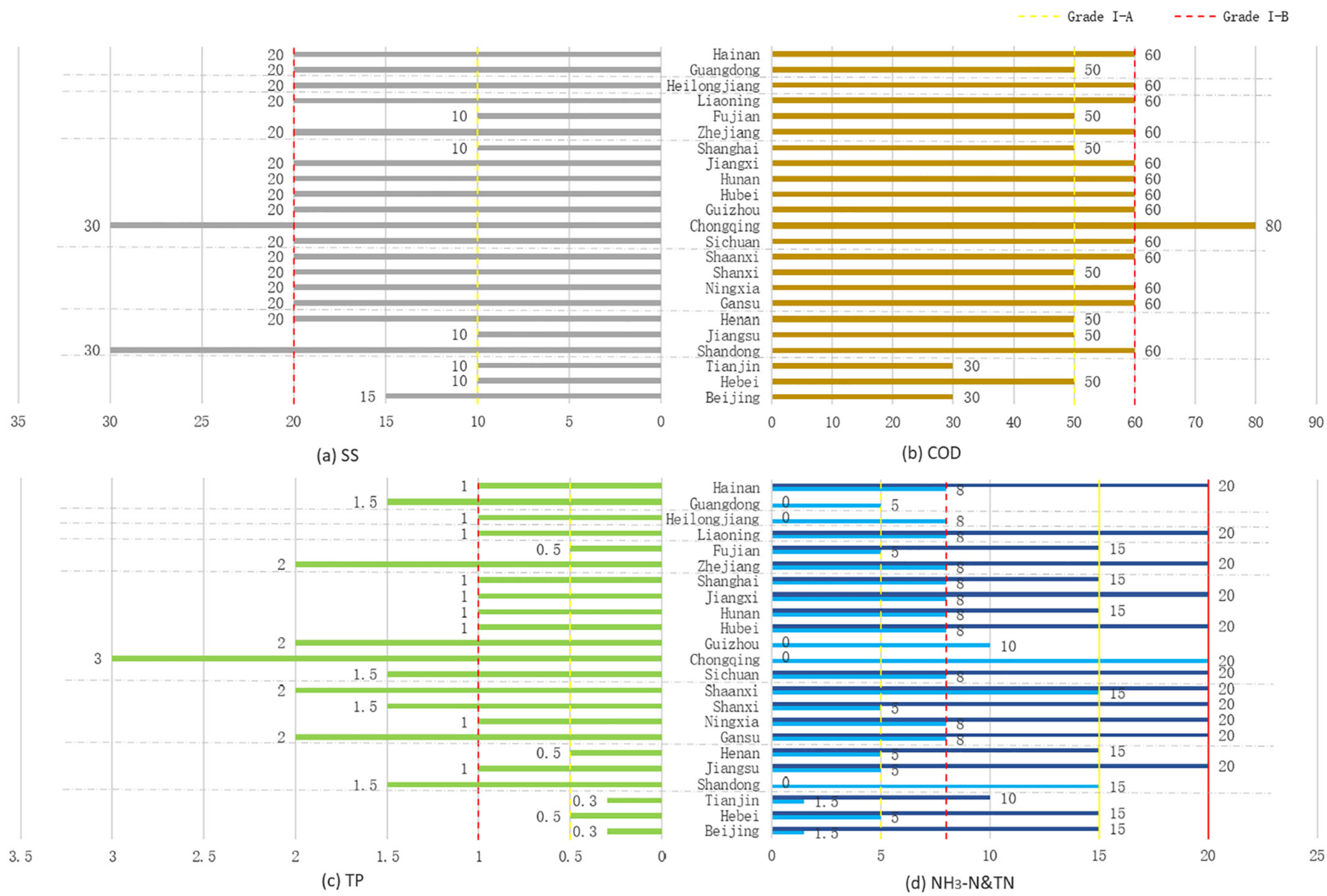

Fig. 3. Sum the population density and ECI of all provinces in China. ECI is larger in areas with smaller population density, so population density is taken as the first consideration.

Regional environmental capacity is particularly important for standard setting. It is not necessary to adopt the same threshold for all regions in an indicator. The concept of environmental capacity index (ECI), which is calculated by regional population size, economy, and quality of the receiving water etc., is proposed to reflect both the regional environmental capacity and the similarity between different provinces. The ECI can play an important role in determining the threshold of an indicator. Within the effective range, regions with large ECI can choose a relatively loose threshold, just as Beijing choosing a slightly stricter threshold and Ningxia choosing a looser one. Furthermore, provinces located in the same river basin can refer to others with a similar ECI (e.g. Beijing and Tianjin). It can well reflect the relation of relative environmental capacity between different regions and serve as the mutual reference for determining the threshold of rural sewage discharge standard indicators between regions.

CRediT authorship contribution statement

Y.D. Xie: Conceptualization, Methodology, Writing - original draft. **Q.H. Zhang:** Methodology, Writing - review & editing. **M. Dzakpasu:** Writing - review & editing. **Y.C. Zheng:** Investigation, Writing - review & editing. **Y. Tian:** Investigation. **P.K. Jin:** Supervision. **S.J. Yang:** Formal analysis. **X.C. Wang:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This study is supported by the Shaanxi Key Research and Development Program (Grant No. 2019ZDLNY01-08), The New Style Think Tank of Shaanxi Universities: Research institute of water pollution control and water environment construction in ecological fragile areas in north-west China.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.143533.

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