Water quota system in China: problems and countermeasures
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ABSTRACT
Water resources are the foundation of economic development, social progress and ecological security, and water shortage is the primary problem facing China. Water quotas have great practical significance for the resolution of water shortages to achieve sustainable use of water resources and sustainable development of the national economy. In this study, to analyse the problems and countermeasures of the water quota system in China, the water quota system progress domestically and abroad, the water quota problem in China, and the countermeasures for the water quota problem are summarized. The data validity test, spatial correlation test and consistency test are used to test the rationality of water use quota. And the specific countermeasures are presented: improving the water quota system, defining its concept, and revising its scheme, etc. This study provides the support to standardize water quotas and implement the effective water conservation policies of China.

Key words | China, countermeasures and suggestions, policy analysis, rationality testing, water quota system

HIGHLIGHTS
- Introduces a method that uses data validity test, spatial correlation test and consistency test of the water quota reasonableness to test the rationality of water quota.
- Presents several specific recommendations: improving the water quota system, defining its concept and revising its scheme
- Provides the support to standardize water quotas and implement the effective water conservation policies.

INTRODUCTION

With the increase of economic and social development, the contradiction between people and water resources in China has become increasingly prominent. And industrial water and domestic water have increased by 10.71% and 52.73% respectively in the past 20 years. Additionally, water problems such as drought, water shortage, soil erosion and water environmental pollution have appeared. Therefore, the issue of water resources is the primary issue facing China. Water resources, together with grain and oil, have become China’s important strategic resources. To solve the contradiction between human and water resources, it is necessary to strengthen the unified management of water resources. Through rational use and effective protection of water resources, promote the sustainable use of water resources. As the important natural resource, water resources have irreplaceable ecological and economic values. Whether it is to maintain ecological balance or develop economic society, the demand for water resources is huge. The harmony between economic development and water consumption is to ensure that water resources will...
not be excessively consumed while realizing total economic growth.

The way to solve the problem of excessive water consumption is to build a water-saving society in an all-round way, and the establishment of water quotas is the prerequisite and key to a water-saving society. Water quota refers to the water consumption per unit product, unit area or per capita in unit time. With the rapid social and economic development of China, the gap between the supply and demand of water resources has become increasingly prominent (Cheng & Hu 2012). To improve the utilization efficiency of water resources, there has been an increasing number of studies conducted by Chinese scholars on water quota explorations. In 1999, the Ministry of Water Resources issued the ‘Notice on The Strengthening of The Establishment and Management of Water Quota’, which was the first time a systematic and comprehensive industrial water quota management plan was carried out on a nationwide level (King & Louw 1998). In 2002, the government passed a new water law known as the ‘Combined System between Water Amount Control and Quota Management’. In 2006, another amendment, ‘Water-Drawing Licenses and Regulations on the Administration of Water Resources Fee Levy’, formally established the legal status of a water quota. In 2007, the Ministry of Water Resources issued the ‘Notice on Further Strengthening the Management of The Water Quota’ to provide a reference for preparing water quotas for specific counties and regions. Specifically, in 2011 a top objective outlined by the central government was to develop a strict water resources management system known as the ‘three red line system’, which has jurisdiction over the total amount of water used, the water usage efficiency, and the pollution limit in water functional areas. The rule highlights new requirements and challenges for water quotas. In 2015, the ‘ten-measure actions’ issued by the Ministry of Environmental Protection was designed to control pollutants and the total quantity of water and to improve the water use efficiency. Water quota management has become a key research focus in current water resources science.

Currently, 30 provinces, autonomous regions and direct-controlled municipalities have established water quotas. However, the current research on water quotas is still mainly at the level of formulation, revision, and management. Related evaluation research is still in the exploratory stage, lacking corresponding theories and methods. In addition, there is insufficient systematic assessment of the existing water quota system, resulting in the current water quota system without a unified standard for measurement. This makes it difficult to compare different water quotas horizontally, and the establishment, revision and implementation of water quotas lag behind. Therefore, a large number of current water quotas have long been unable to adapt to the current situation and have caused more problems for the general application of water quota management. And unreasonably established water quotas reduce the water use efficiency and negatively affect the implementation of water consumption quota management measures. In general, the test of water quota rationality deserves more attention and requires urgent development to improve the water use efficiency.

In summary, this study proposed the problems and countermeasures of water quota system in China by analysing the present situation of the water quota system. The objectives are to conduct the following: (i) progress of water quota systems domestically and abroad; (ii) water quota problems in China; (iii) countermeasures for water quota problems in China. This study can provide theories and methods for the evaluation of water quotas in China, and help the government and water management departments to continuously regulate the efficiency of water quota management.

MATERIALS AND METHODS

Principle of the correlation test

For provincial administrative units, the method of the outlier data test based on the median is usually adopted in rationality verification. Taking samples at the 0.25 fractile (lower quartile) as $Q_1$, 0.5 quantile as $Q_2$, and 0.75 fractile (upper quartile) as $Q_3$, we receive four open intervals $(-\infty, Q_1)$, $(Q_1, Q_2)$, $(Q_2, Q_3)$, and $(Q_3, +\infty)$. Let $Q_d$ denote the separation distance $(Q_3-Q_1)$ between the upper quartile and the lower quartile. The normal values are located in the closed interval $[Q_1 - Q_d, Q_3 + Q_d]$ and to be as the rationality interval ($\alpha$ refers to the coefficient of the rationality interval), while others outside of the interval are outliers signifying abnormal values. According to the actuality of water quotas and case studies, $\alpha = 1.0$ is selected as the coefficient of rationality interval at the present stage. In the future, with the
development of industry, science and technology, as well as the adjustment of water quota values, the coefficient will be modified appropriately according to the actual situation.

**Principle of the consistency test**

The set of water quotas in a time series can be denoted as \{(x, y)\} = \{(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)\} using the least squares estimation method to set up linear regression equation as follows:

\[ y = \beta_0 + \beta_1 x + \varepsilon \]  

where \( \beta_0 \) denotes the constant, \( \beta_1 \) is the regression coefficient and \( \varepsilon \) is the random error.

In a given area for many years, \( x(n) \) denotes the water use of the \( n \)th year, so \( x(n+1) \sim y \), \( (n+1) \sim y \), \( x(n) \sim x \); let \( x(n) \) and \( x(n+1) \) represent the independent and dependent variables, respectively. The linear autoregressive model is:

\[ x(n+1) = \beta_0 + \beta_1 x(n) + \varepsilon \]  

where \( \beta_1 \) can be calculated as:

\[ \beta_1 = \frac{(n-1) \sum_{i=2}^{n} x_{i-1}x_i - \sum_{i=2}^{n} x_{i-1} \sum_{i=2}^{n} x_i}{(n-1) \sum_{i=2}^{n} x_{i-1}^2 - \left( \sum_{i=2}^{n} x_{i-1} \right)^2} \]  

and \( \beta_0 \) can be calculated as:

\[ \beta_0 = \frac{\sum_{i=2}^{n} x_{i-1} x_i - \beta_1 \sum_{i=2}^{n} x_{i-1}}{n-1} \]  

The standard error can be calculated as follows:

\[ S_{xix_{-1}} = \sqrt{\frac{\sum_{i=2}^{n} x_{i}^2 - \beta_0 \sum_{i=2}^{n} x_i - \beta_1 \sum_{i=2}^{n} x_{i-1} x_i}{n-3}} \]  

The t-test is then applied to the autoregressive model to assess whether it has a linear relationship under the \( \alpha \) significance level. The statistic of the t-test is presented as:

\[ t = \left( \frac{\beta_1}{S_{xix_{-1}}} \right) \sqrt{ \frac{\sum_{i=2}^{n} x_{i}^2 - \left( \frac{\sum_{i=2}^{n} x_{i-1} x_i}{n-3} \right) (n-2)/(n-1)}{\sum_{i=2}^{n} x_{i}^2 - \left( \frac{\sum_{i=2}^{n} x_{i-1} x_i}{n-3} \right) (n-2)/(n-1)}} \]  

If the quota value passes the significance test, it indicates that the quotas have a regression relationship in the corresponding time series with good consistency. If not, the residual error (\( r \)) and standardized residuals (\( e_i \)) should be used to identify abnormal points which are defined by the relations:

\[ r_i = y_i - \bar{y}_i \quad (i = 1, 2, \ldots, n) \]  

\[ e_i = \frac{r_i}{\sqrt{\text{Var}(r_i)}} \]  

\[ \text{Var}(r_i) = \frac{1}{n} \sum_{i=1}^{n} (r_i - \bar{r})^2 \]  

where \( y_i \) is the observed value, \( \bar{y}_i \) is the predicted value, and \( \text{Var}(r_i) \) denotes the variance of the sample. In general, the abnormal points are identified by the characteristic that their standardized residual absolute values are greater than 2.

**Technology roadmap**

The roadmap of the countermeasures to improve China's water quotas are presented in Figure 1.

[Image: Technology roadmap of the countermeasures to China's water quota problems.]
PROGRESS OF WATER QUOTA SYSTEMS DOMESTICALLY AND ABROAD

Worldwide water quota system

Most countries use water quotas as reference standards of water consumption assessment (King & Louw 1998; Amir & Fisher 1999, 2000), taking water-saving as a guideline for setting water quotas (Qiang & Lianhai 2007). These guidelines govern industrial water allocations and control sewage water management (Cheng 2002).

Starting in the 1960s, Israel began to implement a water resources development license system and a water quota system that included water permits, quotas, and non-gratuitous water distributions (Friedler 2001). In Egypt, a water quota system was gradually perfected through enhancing the efficiency of economic configurations that combined methods such as tax collection, subsidy, regulation implementation and water-saving technology improvement (Mohamed & Savenije 2000). Water rights system management, governing laws and regulations, policy systems, and the general market are the primary factors in perfecting industrial water management. For instance, the United States, Britain, Japan, and many other countries optimized the allocation of water resources by promoting water saving through improving the efficiency of industrial water through the water rights market, non-gratuitous use and transferring systems of water resources (McCuen 2010). In recent years, to deal with water shortages, many countries have used different measures of water resources utilization and management. These methods include allocating water resources by water rights, in accordance with the priority principles of water use to allocate water rights; establishing water rights trading markets; and formulating relevant laws and regulations (Table 1).

| Country | Measure |
|---------|---------|
| USA     | The states established water right systems; the federal government focuses on water rights in water management; the water distribution and supply are primarily adjusted by the market and non-governmental organizations spontaneously. |
| Russia  | To combine the ecological benefits and economic benefits reasonably in water resources development, utilization and protection; priority should be given to ecology protection and human health. |
| Israel  | To encourage water conservation; to increase water price; the water right quota was presented to distribute water resources, and users whose quantity is over the quota should be levied with a higher price according to the grade rates. |
| Singapore | To carry out the water management law and regulation specifically and operably; to install water saving facility; to encourage water recycling in industry. |

For water resource management, the United Nations Economic Commission for Europe (ECE), including the United States, Canada, Russia, Germany and France, has passed legislation regarding the economic and technological aspects of water resource management. The organization established the following characteristics in its water management guidelines (Bosnjakovic 2000): (1) reflecting the country’s judicial, administrative and water management system reform, emphasizing public management of water resources; (2) changing water rights to promote the rational use of water resources; (3) emphasizing water conservation; (4) restricting water use and wastewater discharge to promote reasonable water use; (5) coordinating the management of water resources; and (6) adopting flexible legislation in case of emergencies, among others. Many members of the ECE formulated the various water quotas by analysing the different types of water need, drainage and use habits, as well as assessing the water decrease due to consumptive water-using. The countries primarily focused on the raw material, the production method, the usage of a water management facility, the water cycle and the use of wastes and by-products. The current trend makes the quota standard more flexible with the use of economic stimuli. Simultaneously, quotas need timely corrections to adapt to environmental and technological developments.

In addition, the management models of some developed industrial countries have gradually turned from water-saving technology services to the integrated audit supervision aimed at water saving (Gagnon 1984; Özelkan & Duckstein 1996), and they put forward higher requirements on quota management. A water audit means checking and calculating water use (domestic, commercial and industrial), which is used to confirm the potential field of water saving and efficiency improving. A system water audit refers to validation.
and calculation for production, delivery and allocation in a water system. The integrated water audit presents detailed instructions for water distribution systems to promote the efficiency of water resources management and the reliability of the water supply. Overall, these countries focus more on the management of quotas.

International studies on water quotas are also numerous, for example, Raju demonstrated the implementation of multi-criterion decision making in a case study of Flumen Monegros irrigation area in Spain (Raju et al. 2000); Molle reviewed market quotas for agricultural irrigation water – the problem is to use the price mechanism to solve the water resource allocation (Molle 2009); Oulmane explored the impact of different water prices and quotas on farmers in Algeria – their results show that reducing quotas may lead to a reduction in irrigated areas and changes in planting patterns (Oulmane et al. 2019). Most studies on water quotas in the world focus on agricultural irrigation, but there are few studies on water quotas in other industries.

### Water quotas in China

The water quota research started relatively late in China, but with continuous research progression, there are preliminary research studies on the formulation, management, and revision of water quotas (Table 2). Studies on quota formulation and management are the most developed. Amendment research is still in its infancy. Revision directions, methods and procedures of quotas in research currently lack depth (Yan et al. 2005; Wang et al. 2013).

In addition, there are studies that are focused on analysing the defects of water quota calculation methods and management mechanisms in current systems (Qiang & Lianhai 2007), describing the basic conceptual and standardized problems existing in urban water quotas (Qishun & Xiao 1995), and proposing the application of the experience method, statistical analysis, the analogy method, and the theoretical method to the calculation of water quotas (Wang et al. 2002). Nevertheless, most of these research studies were still in the qualitative stage of theoretical analysis. To understand and explain the concept of the water quota, the studies also had different focuses. Rational analysis of water quotas needs further extensions.

### Analysis of the development of water quota system in China

Since the 1990s, China has been introducing a series of water quota policies. The Ministry of Water Resources issued the ‘Letter Reference Outline of Compilation in Industry and Urban Domestic Water Quota’ and the ‘Notice on Strengthening The Compilation and Management of the Water Quota’ in 1999. This was the first time that a comprehensive industrial water quota management plan was carried out nationwide, which put forward the procedure and method to guide regional water quotas. In 2012,

| Table 2 | Water quota research progression in China |
|---------|------------------------------------------|
| Research aspect | Research progress |
| The quota formulation | To explain the selection principle of a typical product and how to eliminate abnormal values in the quota formulation (Liao et al. 2016). |
| The quota formulation | To present the method to eliminate various influence factors in the industrial water quota formulation (Jiang et al. 2010). |
| The quota formulation | To establish the mathematical model of ‘Dynamic industrial water quota’ to analyse the influence attributed to the productive scale (Zhou et al. 2016). |
| The quota management | To investigate the method of industrial water quota formulation (Yiming et al. 2006). |
| The quota revision | The quota management of a hotel in Beijing should be carried out periodically to realize a smooth transition on the urban water management mode (Jianbing & Yuansheng 2005). |
| The quota revision | The water quota system of Beijing colleges was discussed systematically (Qiang & Lianhai 2007). |
| The quota revision | The security technology system was built combining the total amount of control in concert with the quota management (Yuansheng et al. 2009). |
| The quota revision | To present the principle of water quota revision (Shi et al. 2014). |
| The quota revision | The revision should be divided into regular and irregular. The revision concept and time interval were defined (Yiming et al. 2006). |
| The quota revision | To complete the concept and the principle of water quota revision, and the revision method of industrial water quotas was proposed (Junwu 2002). |
China’s state council issued the ‘Strict Water Management System Doctrine’, which required the acceleration of technical reconstruction to conserve water resources. To strengthen management and application of water quotas, China’s Ministry of Water Resources issued the ‘notice of being strict on water quota management’ in 2013, which standardized the formulation and revision of water quotas and reinforced the supervision. Currently, 30 provinces, autonomous regions and direct-controlled municipalities in China have released their local water quota standards (Table 3), effectively promoting water resources management and the construction of water-saving infrastructures. Developed areas such as Shanghai, Chongqing, and Beijing are the first that have issued water quota standards, as shown in Figure 2. Due to the special monsoon climate, Heilongjiang province, which suffers from spring droughts nine out of 10 years, issued the first industry water quota in 2000. Inner Mongolia, Shanxi, Gansu, Ningxia and other arid regions also issued quota standards following Heilongjiang. With the continuous improvement of water quota standards in various areas, the control and quota management of water resources continue to mature.

WATER QUOTA PROBLEMS IN CHINA

Outline of water quota issues

By studying the progress of water quota systems domestically and abroad, we can see that the water quota is an important index for water management and a reasonable measurement in the industry for water use. For the concept of the water quota, there is currently no unified definition, which results in confusion during implementation. The overall meanings expressed by different scholars are similar in concepts, but have varying focuses (Table 4). It is necessary to clearly define the encompassing concept of the water quota in the analysis and research.

The idea of a ‘limited quota’, which is referenced more in the academic journals, emphasizing that a water quota is the water consumption limited quota under a certain condition. From the perspective of government management, a water quota is a defined standard water quantity usage enforced to be followed by all users. An established water quota is straightforward and is the essence of ‘water management service’ for the government. In China, there are three main concepts of water quotas, namely, design, statistics and management quotas (He et al. 2015). Design norms often appear in a variety of design specifications and documents to satisfy the design of buildings or facilities that meet the user’s water demand. A design norm refers to a ‘loose’ water quota that focuses on the ‘supply side’. Statistical quotas are often used in statistics or water demand predictions that reflect the current or future situation of water usage. Management quotas, which are the common water quotas, are set by the government of water management to plan for water usage, focusing on the management of water resources.

Formulation and management problems of water quotas

Water quota is not only a measure to evaluate the level of regional water-using and water-saving but also a type of appraisal index. According to the regional and industrial analysis of the latest water quota regime, there are still problems concerning quota formulation and management in China.

The water quota formulation and standard system are incomplete

Although most of the provinces, autonomous regions and direct-controlled municipalities have established water quotas, several regions, with the exception of Tibet, have revised the original quotas that were incomplete in recent years. The established quota standards are imperfect. Most of the existing standards are for some particular industries. These standards are primarily aimed at specific products rather than an industry or enterprise as a whole. Although specific product quotas are scattered, they are divided meticulously, covered widely, and referenced. The comprehensive water quotas for industries is the key to understanding the integrative water quotas.

Determining the statistical scale of water quotas

The basic determined method of water quotas in China is a statistical method rather than use of the demand method that is recognized internationally. Therefore, the scale
| No. | Province/autonomous region/direct-controlled municipality | Trial quota (issue date) | Current quota (issue date) | Department oversight |
|-----|---------------------------------------------------------|--------------------------|---------------------------|---------------------|
| 1   | Heilongjiang                                           | Industrial water quota (trial) of Heilongjiang (2000) | DB23/T727-2003 Water quota of Heilongjiang (2003) | The Quality and Technology Supervision Bureau of Heilongjiang |
| 2   | Shanghai                                               | Water quota (trial) of Shanghai (2001) | Water quota revision of Shanghai 1. school, hospital, hotel (2007) | The Water Supply Management Office of Shanghai |
|     |                                                        |                          | Water quota revision of Shanghai 2. thermal power, electronic, drink industry (2008) |                      |
|     |                                                        |                          | Water quota revision of Shanghai 3. iron and steel, automobile manufacturing, oil refining, papermaking, cotton dyeing and printing industry (2009) |                      |
|     |                                                        |                          | Water quota revision of Shanghai 4. chemical industry, food, electrical industry, building materials, commercial office building (2010) |                      |
| 3   | Chongqing                                              | Part of industrial products water quota (trial) of Chongqing (2001) | Part of industrial products water quota (trial) of Chongqing (2001) | The Water Resources Bureau of Chongqing |
|     |                                                        |                          | Part of industrial products water quota (2) of Chongqing (2006) |                      |
|     |                                                        |                          | Agriculture water quota of Chongqing (2006) |                      |
|     |                                                        |                          | Non-production water quota standard of Chongqing (2006) |                      |
| 4   | Beijing                                                | Main industrial water quota of Beijing (2002) | Main industrial water quota of Beijing (2002) | The Water Conservation Office of Beijing |
| 5   | Hebei                                                  | Water quota (trial) of Hebei (2002) | DB15/T1161-2016 Water quota (revised) of Hebei (2016) | The Quality and Technology Supervision Bureau of Hebei, The Water Resources Department |
| 6   | Sichuan                                                | Water quota (trial) of Sichuan (2002) | Water quota (revised) of Sichuan (2010) | The Water Resources Department of Sichuan, The Quality and Technology Supervision Bureau of Sichuan, The Economic Commission of Sichuan, The Construction Department of Sichuan |
| 7   | Tianjin                                                | DB12/T158-2003 Urban domestic water quota (2003) | DB12/T158-2003 Urban domestic water quota (2003) | The Quality and Technology Supervision Bureau of Tianjin |
|     |                                                        | DB12/T159-2003 Agricultural water quota (2003) | DB12/T159-2003 Agricultural water quota (2003) |                      |
|     |                                                        | DB12/T101-2003 Industrial products water quota (2003) | DB12/T101-2003 Industrial products water quota (2003) |                      |

(continued)
| No. | Province/autonomous region/direct-controlled municipality | Trial quota (issue date) | Current quota (issue date) | Department oversight |
|-----|-----------------------------------------------------------|--------------------------|---------------------------|---------------------|
| 8   | Shanxi                                                    | Water quota (Revised) of Shanxi (2003) | DB14/T1049.1-2015 Agricultural water quota of Shanxi (2015) | The government of Shanxi |
|     |                                                           |                          | DB14/T1049.2-2015 Industrial water quota of Shanxi (2015)   |                     |
|     |                                                           |                          | DB14/T1049.3-2015 Urban domestic water quota of Shanxi (2015) |                     |
| 9   | Inner Mongolia                                           | DB15/T385-2003 Industrial water quota standard of Inner Mongolia (2003) | Industrial water quota standard (revised) of Inner Mongolia (2009) | The Quality and Technology Supervision Bureau of Inner Mongolia |
| 10  | Liaoning                                                 | DB21/T1237-2003 Industrial water quota of Liaoning (2003) | DB21/T1237-2015 Industrial water quota of Liaoning (2015) | The Quality and Technology Supervision Bureau of Liaoning |
| 11  | Hubei                                                    | Water quota (trial) of Hubei (2003) | Water quota (trial) of Hubei (2003) | The Water Resources Department of Hubei, The Construction Department of Hubei |
| 12  | Guangxi                                                  | Water quota (trial) of Guangxi (2003) | Main industrial products water quota (2010) | The Water Resources Department of Guangxi, The Quality and Technology Supervision Bureau of Guangxi |
|     |                                                           |                          | Urban domestic water quota (2010) |                     |
| 13  | Jiangxi                                                  | DB36/T419-2003 Urban domestic water quota of Jiangxi (2003) | DB36/T419-2011 Urban domestic water quota of Jiangxi (2011) | The Quality and Technology Supervision Bureau of Jiangxi |
|     |                                                           |                          | DB36/T420-2003 Main industrial products water quota of Jiangxi (2003) |                     |
|     |                                                           |                          | DB36/T420-2011 Main industrial products water quota of Jiangxi (2011) |                     |
|     |                                                           |                          | DB36/T619-2011 Agricultural irrigation water quota of Jiangxi (2011) |                     |
| 14  | Jilin                                                    | DB22/T389-2004 Water quota of Jilin (2004) | DB22/T389-2010 Water quota of Jilin (2010) | The Quality and Technology Supervision Bureau of Jilin |
| 15  | Shandong                                                 | Agricultural irrigation water quota (trial) of Shandong (2004) | Agricultural irrigation water quota (trial) of Shandong (2004) | The Quality and Technology Supervision Bureau of Shandong |
|     |                                                           | Industrial water quota of Shandong (2004) | DB37/1639-2010 Main industrial products water quota of Shandong (2010) |                     |
|     |                                                           | Urban domestic water quota of Shandong (2004) |                     |                     |
| 16  | Henan                                                    | Water quota (trial) of Henan (2004) | DB41/T385-2014 Industrial and urban domestic water quota of Henan (2014) | The Water Resources Department of Henan |
| 17  | Zhejiang                                                 | Water quota (trial) of Zhejiang (2004) | Water quota of Zhejiang (2015) | The Water Resources Department of Zhejiang, The Economic and Trade Commission of Zhejiang, The Construction Department of Zhejiang |
| 18  | Qinghai                                                  | Water quota (trial) of Qinghai (2004) | DB63/T1429-2015 Water quota of Qinghai (2015) | The Water Resources Department of Qinghai |
| Province | Description                                                                 | Code                          | Relevant Department/Authority                                      |
|----------|------------------------------------------------------------------------------|-------------------------------|---------------------------------------------------------------------|
| Shanxi   | Industrial water quota (trial) of Shanxi (2004)                              | DB61/T943-2014 Industrial water quota of Shanxi (2014) | The Bureau of Hydrology and Water Resources Survey of Shanxi        |
| Gansu    | Industrial water quota of Gansu (2004)                                      | Industrial water quota (revised) of Gansu (2011) | The Water Resources Department of Gansu                             |
| Ningxia  | Industrial products water quota of Ningxia (2005) Urban domestic water quota (trial) of Ningxia (2008) | Industrial products water quota of Ningxia (2005) Urban domestic water quota (trial) of Ningxia (2008) | The Water Resources Department of Ningxia, The Construction Department of Ningxia |
| Yunnan   | DB53/T168-2006 Water quota of Yunnan (2006)                                  | DB53/T168-2013 Water quota of Yunnan (2013) | The Water Resources Department of Yunnan, The Water Authority of Yunnan |
| Jiangsu  | Urban and public domestic water quota of Jiangsu (2006) Industrial water quota of Jiangsu (2011) | Industrial, service industry and domestic water quota (revision) of Jiangsu (2014) | The Quality and Technology Supervision Bureau of Jiangsu            |
| Guangdong| Water quota (trial) of Guangdong (2007)                                      | DB44/T1461-2014 Water quota of Guangdong (2014) | The Formulation Group of Industry Water Quota of Guangdong         |
| Anhui    | DB34/T679-2007 Industrial water quota of Anhui (2007)                       | DB34/T679-2014 Industrial water quota of Anhui (2014) | The Quality and Technology Supervision Bureau of Anhui             |
| Fujian   | DB35/T772-2007 Industrial water quota of Fujian (2007)                      | DB35/T772-2013 Industrial water quota of Fujian (2013) | The Quality and Technology Supervision Bureau of Fujian            |
| Xinjiang | Domestic and industrial water quota of Xinjiang (2007) Agricultural irrigation water quota standard (trial) of Xinjiang (2012) | Domestic and industrial water quota of Xinjiang (2007) Agricultural irrigation water quota standard (trial) of Xinjiang (2012) | The Water Resources Department of Xinjiang                         |
| Hunan    | DB43/T388-2008 Water quota of Hunan (2008)                                   | DB43/T388-2014 Water quota of Hunan (2014) | The Quality and Technology Supervision Bureau of Hunan              |
| Hainan   | Industrial and urban domestic water quota (trial) of Hainan (2008)           | Industrial and urban domestic water quota (trial) of Hainan (2008) | The Water Authority of Hainan, The Development and Reform Department of Hainan |
| Guizhou  | DB52/T725-2011 Industrial water quota of Guizhou (2011)                     | DB52/T725-2011 Industrial water quota of Guizhou (2011) | The Quality and Technology Supervision Bureau of Guizhou           |
range of the statistical analysis has a strong influence on water quotas. In general, the larger the statistical scale, the smaller the water quota, and vice versa, mainly because the larger the statistical scale, the higher the degree of water reusage, which decreases the water quota relatively. Overall, the water quota based on the basin scale is generally lower than the water quota that is based on a regional or urban scale of the basin.

**Unclear relationships among water quotas**

Currently, the commonly used water quotas include industrial quotas, agricultural irrigation quotas, domestic quotas, ecological quotas, among others. The water quotas are further divided into the ‘water-using quota’, the ‘water-taking quota’, the ‘new water quota’, among others. However, the relationship among the various quotas is unclear, which causes confusion in the formulation and management of water resources.

| Table 4 | Water consumption quota definitions |
| --- | --- |
| **Definition** | **Emphasis** |
| With a certain production technology and management, the reasonable water-using standard of unit production creating a per unit of output or providing a per unit of service. | Units of measurement |
| Within a certain period and range, the stipulated water consumption quota in an accounting unit under a constraint condition (Taolu et al. 2010). | Limited quota |
| In a certain period, the standard of water quantity complied by water units or people engaged in an activity and expressed as a limit of quantity (Junwu 2002). | Government regulations |
| In a certain period, the water quota approved by the reasonable water consumption of the city industries according to the corresponding accounting unit (Jiang et al. 2010). | Time range |
| Under a certain technological condition and management level, the water consumption (or occupation) standards for the verification of the rational utilization of water resources (Cai et al. 2007). | Technological condition and management level of water resource systems |
| The certain standard of water amount in the process of water-using (Xiugui et al. 2005). | Water-using process |

**Limited flexibility in water quotas**

Without considering the differences in water resource conditions and the economic status quo between different areas in one certain province, some areas are used to directly reference others’ quotas. Most measuring units of quotas are product based, which also limits their flexibility.

**Varying formulation methods of water quotas**

There are various types of formulation methods and principles of water quotas in China. The formulation is not in conformity with basic requirements of standardization, simplification, coordination and optimization. Taking agricultural water...
quotas for example, the values could be largely different due to the diversity among soil conditions, crop varieties, water-using scopes, and terrains in various areas, which are also attributed to the different calculation methods and data sources.

The formulation method does not comprehensively reflect the changing structure of water-use and the actual water demand

The water quota is a dynamic index that is subject to revisions every 3~5 years according to changes in water degree, adjustments of product structures and quota implementation. Currently, the formulation is based on a statistical method, a kind of analysis ex post, requiring a long time series of statistical data. This method may not be suitable to the rapidly changing situation of water-using structures and water demand in China.

Outline of water quota issues

According to the present study, three aspects of the water quota irrationality are summarized as follows (Qiang & Lianhai 2007; Jiang et al. 2008; Zhao et al. 2013). First, the data have poor integrity and validity. Second, there are spatial differences in the measurements for water quotas. Third, there are time sequence differences within water quotas. The water quota rationality test is a reasonable evaluation of water-use on a national scale, and the general industry scales are used to assess whether the water quota values are consistent with the water quotas of the national industry.

Validity test

Data validity ensures that each index has the correct data type, format, and effective data range. The data validity test of water quotas requires that the values are of the numeric type, and the industry quota units must be unified to analyse data between different regions. Quota validation is the basis of data space analysis and consistency analysis.

The water quota integrity should be considered as well, including referential planning quotas, instructive design quotas and mandatory management quotas. The index system should comprise agricultural, industrial, service industrial and domestic water quotas (and even to consider the ecological environment water quotas).

In consideration of the differences in water resources and economic and social situations among different provinces, the given product generally does not only have a fixed standard. The water quota interval is based on the characteristics of local water conditions to examine if the quotas are in reasonable intervals (Yong-Min 2008).

Spatial correlation test

The spatial correlation of data, within the same scale of the study area, should distribute smoothly in space, and significant abnormal values should not exist. Otherwise, abnormal values indicate that the quota does not meet the requirements of rationality. The purpose of the spatial correlation test is to identify abnormal points of water quota values in all study areas. The formulation of water quotas needs to consider regional differences because of economic diversity.

Given the unevenly spatial distribution of water resources, Northern China is water deficient, while southern China is rich in water resources, and the Qin Mountains – Huai River is regarded as the main line dividing China into north and south areas (as shown in Figure 3). Agricultural water usage has a close relationship with the local climate. To eliminate the influence of the climate factor on the rationality test, the case study is conducted in both south and north areas.

We take agricultural water quotas as examples to analyse its rationality. Agricultural water has a close relationship to the category of local crops. For the purpose of avoiding such interference factors on the rationality test, we test the irrigation water quota of summer corn with a 75% confidence probability of irrigation water in northern China and test the irrigation water quota of rice with a 75% confidence probability of irrigation water in southern China, as shown in Figure 4.

The rationality intervals in both regions are calculated by the method of outlier data test based on the median, and the results are presented in Table 5.

The rational interval of the irrigation water quota of summer corn is approximately [46.8, 126.6] in northern provinces. Apparently, the outliers are 140 m³/mu for Liaoning province, 235 m³/mu for Qinghai province and 320 m³/mu
for the Xinjiang Autonomous Region. The water quota of rice is approximately $[194, 615.5]$ in southern provinces, and the abnormal value is $670 \, \text{m}^3/\text{mu}$ in Shanghai. However, further analysis is still needed on whether the quotas are reasonable on the basis of local conditions. The crop irrigation quota is strongly influenced by the local climate environment. The northern regions are drier, in general, and the crop irrigation water demand is higher, while the southern regions are rainy so that water usage is lower. There is potential for irrigation quota reductions, depending on the use of advanced water-saving irrigation technology and reasonable management methods.

### Consistency test

Consistency means that a set of data shows a certain trend over time and should not be significantly different than adjacent data. The abnormal values of a given year indicate that the quota does not meet the requirement of rationality (Wei et al. 1990). The consistency tests aim to identify the quota outliers in the study time series. The effective regression analysis method is applied in this test due to the large quantity of data of national water quotas.

### Table 5 | Rationality intervals of quotas in northern and southern China

| Regions  | $Q_1$ | $Q_2$ | $Q_3$ | $Q_4 = Q_3 - Q_1$ | Left interval | Right interval | Max | Min |
|----------|-------|-------|-------|-------------------|---------------|---------------|-----|-----|
| North    | 73.4  | 85    | 100   | 26.6              | 46.8          | 126.6         | 320 | 50  |
| South    | 334.5 | 410   | 475   | 140.5             | 194           | 615.5         | 670 | 250 |
Due to the duration of the time series of existing water quotas and the quantity of collectable data, domestic water is used as an example for a case analysis. The life water consumption (L/d) of resident students in one college during 2001–2010 is shown in Table 6, taking the water consumption from 2001 to 2009 as the independent variable \( X(n) \) and taking that of 2002–2010 as the dependent variable \( X(n + 1) \).

Using the least squares estimation method to set up a linear regression equation (Figure 5):

\[
X(n + 1) = 3.75 + 0.94X(n)
\]

Several parameters can be calculated, such as \( R^2 = 0.67 \), \( S = 4.3 \), and \( t = 2.440 \). Under the significance level \( \alpha = 0.05 \), \( t < t(6, 0.025) = 2.447 \), which indicates the regression model is not significant. Furthermore, the residual error and standardized residual should be used to identify abnormal points.

The standardized residual in the point of (2002, 2003) is more than 2; therefore, it is theoretically an abnormal point. After field research, due to an enrolment expansion in 2003, the resident students’ water consumption increased differently compared to the usual period. While the water consumption was steadily within a normal range over the next few years, this trend was attributed to the continuously advancing water-saving facilities.

The outliers in the correlation test and the consistency test may not be unreasonable. There are many reasons for abnormal values, such as the formulation by the relevant department, local economic levels, water-saving technologies, water-using habits, climate changes, and so on. Therefore, the theoretical outliers may be reasonable. If the reason for the abnormal value can be determined, for example, the agricultural water quota is low because of advanced agricultural technology, undoubtedly, the quota of this region should not be adjusted. If the case is invalid, the reason for the abnormal value should be analysed as soon as possible and revised in time.

**COUNTERMEASURES FOR WATER QUOTA PROBLEMS IN CHINA**

**Clarifying the concept of a water quota**

Currently, there are two kinds of water quotas in water resource management in China. The ‘water-intake quota’

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**Table 6** | Water consumption (L/d) and relevant statistics in one college during 2001–2010

|       | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|-------|------|------|------|------|------|------|------|------|------|------|
| \( X(n) \) | 100  | 99   | 104  | 97   | 95   | 94   | 95   | 90   | 87   | 85   |
| \( X(n + 1) \) | 99   | 104  | 97   | 95   | 94   | 95   | 90   | 87   | 85   |      |
| Residual error | 0.728 | 6.714 | −5.218 | −0.313 | 0.66  | 2.646 | −3.34 | −1.408 | −0.449 |
| Standardized residuals | 0.257 | 2.375 | −1.845 | −0.111 | 0.233 | 0.936 | −1.181 | −0.498 | −0.159 |

**Figure 5** | Scatter diagram and trend line of the domestic water consumption (L/person-day) in one college during 2001–2010.
refers to the actual water from all kinds of sources extracted by water consumption units. The ‘water-using quota’ refers to the comprehensive water demand to guarantee normal operation, which is the sum of the intake water and the recycle water (Handan et al. 2017). The water-intake quota is often used in industries in which water reuse is common, and the water-using quota is adopted in industries in which water reuse is sparse. It is necessary to clarify the concept of water quota in analyses and research.

**Improving the water quota establishment method and standard**

Due to the vast and diverse regions in China, the large time and space differences in water resource distributions and the gaps of economic and social development, different regions should research water quota management, establishment principles, techniques and approaches as well as revisions according to various industries and regional characteristics in time. ‘The technical guidance (trial) of water quota formulation’ has been followed in these works.

Currently, Tibet has not introduced a local water quota and the standard is not comprehensive. The water conservancy department should carry out research to refine the water quota of industry as soon as possible. Agricultural water quotas cover farm irrigation, fruit and grass field irrigation, and fishery and animal husbandry. Industrial water quotas cover professional production water, auxiliary production water (such as boiler water, air conditioning water, cooling water, etc.) and accessory production water. The water quotas of various parts in each product need to be classified explicitly. Domestic water quotas cover a variety of aspects such as office, hotel, school, hospital, restaurant, sport, bath, landscaping, car wash, and transportation hub. Similarly, it should ensure that the adjustment and classification measures have followed the local conditions.

**Using the data rationality tests to evaluate water quotas**

The validity test, correlation test, and consistency test mentioned above are suggested for evaluating the water-using rationality of industry, agriculture, life, and other industry quotas. In this way, the relevant department could determine whether the water quotas are consistent with general levels, improving the system of water resource allocation.

As part of the spatial correlation test used in this paper, abnormal values of the corn irrigation water quota are found in Liaoning Province, Qinghai Province, and Xinjiang Autonomous Region in the northern area of China; abnormal values of the rice irrigation water quota are found in Shanghai Province in the southern area. The room for irrigation quota reduction depends on whether use is made of advanced water-saving irrigation technology and reasonable management methods.

**Analysing the cause of water quota irrationality**

There are varying causes of abnormal values, such as the formulation by relevant department, local economic levels, water-saving technologies, water-using habits, and climate changes. If the reasons for the abnormal value are determined, for example, the agricultural water quota is low with advanced agricultural technology, reasonable structure of crop production, and optimization of planting, the quota of this region should not be adjusted. On the other hand, considering the case in an economic developing area where the development of industry is slow without advanced water-saving facilities, if its water quota standard is low, an abnormal value is unreasonable. The reason for the abnormal value should be determined as soon as possible to provide the basis for a revision.

The hotel water quotas in southern China are generally higher than those of the northern region. This difference is primarily influenced by local habits and the weather difference. In the southern area, the water consumption of residents is higher than that of residents in the northern area. In addition, there are gaps between the provincial quota values. The three-star hotel water quotas are more than 1,000 L/bed in Fujian, Jiangxi, Hubei, and Guangdong Province. The value is approximately 10 times higher than that of Gansu Province, which has the national minimum value of 120 L/bed. These water quota outliers are reasonable. However, before 2007, the hotel water quota in Jiangsu Province was 2,300 L/bed, and it was ascertained that the outlier was unreasonable. This result provided the theoretical basis for data analysis. Finally, it was later revised as 600 L/bed.
Regular and nonscheduled revisions of water quotas

The water quota is a dynamic index that requires constant regular and nonscheduled revisions according to the new situation. The period of regular revisions can be every five years. A nonscheduled revision is implemented when renovated water-saving production processes or equipment are used, which contributes to a decrease in water consumption so that the original quota can no longer adapt to the actual situation which should be revised in time.

The improvement in people’s living standards has caused the domestic water proportion use each year to increase. The rapid growth of industrial water usage has made water-saving a more pressing issue. Specifically, the five high water consumption industries of thermal power, textiles, petrochemical industry, papermaking, and metallurgy account for approximately 50% of the total industrial water. With the improvement of industrial production technology, the above five industries have used far less than the original quota standards. The original quotas no longer have an effect on water saving, and it is necessary to revise water quotas in a timely manner.

To study the relationship between water quotas and water use efficiency

An exploration of the relationship between water quotas and water use efficiency could help implement the strictest water resources management through the strict control of water quotas and also help to examine the efficiency of the restriction line of water use. Through the continuous feedback and adjustment of quotas, the dynamic balance between total water use and quota management can be achieved.

There are still large potentials of water efficiency existing in several provinces (mainly in south and northwest China), including Qinghai, Guizhou, Hainan, Guangxi, Jiangxi provinces, Xinjiang, Ningxia and Tibet autonomous regions. Northwestern areas have an underdeveloped economy and fragile ecological environments that cause the larger water consumption proportion. The agricultural irrigation method is flood irrigation, and the manufacturing focus is on primary products processing. The economic growth of these areas requires high investments of resources, and their development patterns are more extensive than those in prosperous regions. Their higher water quotas also limit the further improvement of the water use efficiency. In conclusion, based on an efficient water-saving facility and low consumption production process, the water quotas should be gradually reduced in these areas through rationally dealing with the relationship between water quotas and water use efficiency.

Building an information platform of water quota management to manage water-intake and water-use

The formulation, management, and revision of water quotas are related to data collection, analysis, the processing process, and a large number of mathematical statistics. With the rapid changing situation of water-using structures and amounts in China, an information management platform can allow data analysis automation and improve the intelligence of quota management.

Houma City in Shanxi province was established as the third batch of a national pilot water-saving society construction by the Ministry of Water Resources in 2008. The Ministry of Water Resources strived to build a water resources information management system through 2008–2012 to achieve water management. In 2012, the city’s total water consumption was $3.4 \times 10^7$ m$^3$, which dropped by 58.5% compared with that at the beginning of the pilot. The water consumption of 10,000 yuan (1 US dollar $\approx 6.30$ Chinese yuan in 2012) GDP was 55.75 m$^3$, falling by 58.1%. The water consumption of 10,000 yuan in industry was 16.47 m$^3$, which fell by 49.9%. The farmland irrigation water use coefficient was 0.63, which increased by 5.0%. Meanwhile, the reuse rate of industrial water increased from 65% to 89%. Houma has built control centers for a water-saving society by installing intelligent telemetry equipment that can carry out water real-time data monitoring and dynamic management, providing a construction reference for regions of water shortage.

CONCLUSIONS

This study analyses the problems in the Chinese water quota system, the irrationality of the integrity and availability of data and the temporal-spatial aspect. The consistency and
rationality tests are presented, further clarifying the index and numerical attributes and time and spatial characteristics of water quotas. Finally, to address the existing problems, the aim of the national water department is to improve and refine the establishment method of regional industrial water quotas using the data rationality test methods to evaluate irrationality and analysing the reasons for the irrationality to revise the quotas in a timely manner. The above points provide support to further standardize China’s water quotas, to enhance the efficiency of water-using and to favourably carry out the water-saving policy.

However, along with the severe shortage of water resources, there is still a long way to go regarding how to reasonably and continuously develop the revision of water resources, there is still a long way to go regarding how to reasonably and continuously develop the revision of water resources. This issue requires a deep and comprehensive study on water-saving management measures, the implementation of total amount controls, the promotion of a standards system and the innovation of science and technology.

**AUTHOR CONTRIBUTIONS**

Z.Z. contributed substantially to the conceptualization, methodology, validation, data curation, data interpretation, and writing. Z.Z., H.W., S.G., and C.W. participated in drafting the article or revising it critically, and gave final approval of the version to be submitted. All authors have read and agreed to the published version of the manuscript.

**FUNDING**

This research was supported by the National Key Research and Development Program of China (2019YFC0408902), the National Natural Science Foundation of China (Grant Nos.51879010 and 51479003), the Graduate Innovation Fund in Beijing Key Laboratory of Urban Hydrological Cycle and Sponge City Technology (HYD2020IFDC03) and the 111 Project (Grant No. B18006).

**CONFLICTS OF INTEREST**

The authors declare no conflict of interest.

**DATA AVAILABILITY STATEMENT**

All relevant data are included in the paper or its Supplementary Information.

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