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Research article

# Technical study on national mandatory guideline for deriving water quality criteria for the protection of freshwater aquatic organisms in China

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ABSTRACT

Water quality criteria are the basis for formulating environmental water quality standards, and are also an important part of environmental water protection and environmental management programs. The current study focused on a systematic discussion of the current research progress of water quality criteria theories and methodology for aquatic organisms both in China and internationally. This study also successfully pointed out key scientific issues which should be considered in the determination of water quality criteria guidelines from the following perspectives for a national strategy: the selection of pollutants; data collection and screening; species selection; water quality criteria derivation methods, and so on. For the first time, this study systematically introduced technology for the determination of water quality criteria guidelines for protecting aquatic organisms which was suitable for China's regional characteristics and national conditions. Furthermore, this study pointed out the key research directions which should be considered in the future construction of China's environmental criteria and management systems, in order to provide technical support for environmental protection and management projects.

## 1. Introduction

Water quality criteria (WQC) refers to the maximum dosages or levels of pollutants or harmful factors in water environments which do not have harmful effects on human health, aquatic ecosystems, and use functions. Water quality criteria are the foundation and scientific basis for formulating water quality standards. It also forms an important basis for environmental water quality assessments; environmental risk assessments; environmental damage identifications and assessments; and water environmental management and related policies, laws, and regulations. WQC plays an important role in environmental protection and management programs throughout the world (Feng et al., 2012a,b, 2013a). In accordance with different objects of protection, WQC can be roughly divided into the WQC for protecting aquatic organisms, and WQC for protecting human health. WQC for aquatic organisms refers to the WQC which can protect aquatic organisms and their ecological functions, and includes both short-term WQC and long-term WQC. At the present time, China's water environment management policies are mainly made by referring to the "Environmental Quality Standards for Surface Water" (GB3838-2002). Currently, China's "Environmental Quality Standards for Surface Water" are standards which have been divided according to the different use functions of water-body resources, and have referenced the WQC of developed countries (Wu et al., 2010). There currently are five divided categories for convenience of operation and management purposes, and a total of 24 standard values of basic items for environmental quality standard for surface water (Table S1). However, due to the undefined protection objects of the standards, the protection of aquatic ecosystems has been found to be insufficient and does not effectively reflect the targets of protection of aquatic organisms. Therefore, the study of water quality criteria for aquatic organisms can provide scientific and technological support for the revision of China's surface water environmental quality standards, and is more conducive to the comprehensive and systematic management of environmental water quality levels.

Water quality criteria can also provide scientific support for emission standards and provide guidance for water treatment processes

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methods. China Statistical Yearbook 2018 (NAS, 2018) showed that in 2017 China's total water consumption reached 604.34 billion $m^3$, and the total discharge of wastewater was 69.97 billion $m^3$, with the average daily wastewater production volume being of 192 million $m^3$. At present, there are many water treatment methods internationally, such as NAS, NOB (Sepehri and Sarrafzadeh, 2018, 2019). China's wastewater treatment technology mainly includes electrolysis, membrane separation, photocatalytic oxidation and supercritical technology, flocculation, etc. After a series of water treatments, the water quality can be improved, but there are some differences from the water quality criteria threshold. Therefore, water quality criteria research and water treatment processes are also closely related worldwide.

It is known that some variations exist in the aquatic biota within different regions and countries, and there are also differences in the criteria values of the same pollutant for different protection objects (Wu et al., 2013; Feng et al., 2013a; Su et al., 2011). Therefore, due to these factors, some of the developed countries of the world have invested tremendous amounts of human, material, and financial resources in order to achieve major breakthroughs in the field of water quality criteria (Kuriqi et al., 2017, 2019). The study of WQC has also become one of the indicators which reflect the level of environmental science research within a country. Actually, research studies regarding WQC in some of the world's developed countries have been carried out for decades, and a relatively comprehensive system of water quality criteria methodology has been formed (CCME, 2000, 2007; ECB, 2003; WHO, 2006; OECD, 1995; US EPA, 2009). However, systematic research studies regarding WQC in China have been conducted for less than ten years. Also, at the present time, China's WQC research has tended to grope forward on the basis of WQC research methods from developed countries. Therefore, in view of the basic national water environment conditions in China, it is very important to establish a WQC research method system which will be suitable for China's regional characteristics.

Therefore, the present study was undertaken to investigate the ideas, key scientific issues and derivation method of China's water quality criteria guidelines. The determination of China's WQC guidelines will play an important role in the establishment and improvement of China's environmental standard system.

## 2. Material and methods

### 2.1. Overall opinions regarding the establishment of WQC guidelines in China

In China, the establishment of water quality criteria theory and methodology cannot be started from scratch. The technical guidelines for the water quality criteria of aquatic organism which will be suitable for China's regional characteristics and environmental management needs will need to be finally formulated by fully absorbing the latest research progress results of both Chinese and international water quality criteria (Feng et al., 2012a; Zhao et al., 2018). The main international lessons for WQC guidelines have been obtained from the United States and the European Union's technical guidelines for chemical risk assessments. These have been combined with China's regional characteristics and environmental management needs.

The main points which require consideration are as follows: First, the determination of the technical guidelines for WQC should be based on the relevant provisions and requirements stated in the Environmental Protection Law of the People's Republic of China, as well as the Law of the People's Republic of China on the Prevention and Control of Water Pollution, Water Pollution Control Action Plan, and China's existing laws, policies, regulations, and standards for environmental protection. The status quo, laws, regulations, working mechanisms, technical status, and developmental trends of WQC in China and globally should be investigated, compared, and analyzed, in order to ensure that the latest achievements can be fully used for reference during the process of formulating the required guidelines. It is important to ensure that accepted WQC can be effectively adapted to the relevant requirements and developmental trends of China's policies and regulations, as well as being geared to international conventions.

Second, the experiences obtained by the relevant standards and technical guidelines in China and abroad should be fully used for reference purposes, such as the existing technical standards and guidelines of the Environmental Protection Agency, Agricultural Bureaus, and State Oceanic Administrations, and so on, of the United States, European Union, Netherlands, and China. A standard framework can be formed by summarizing the experiences and lessons, and directly introducing or equivalently adopting the relatively mature common technologies, as well as suitably supplementing, validating, and applying the incomplete data.

The third main point which should be considered is focusing on the transformation of environmental management policies which will meet the future needs of China's environmental characteristics and management, and serve as the overall goal of improving water environment quality. It is vital that the working procedures for formulating water quality criteria are clarified in order to improve the working efficiency and guarantee the quality of the management methods. In addition, the formulation of China's WQC for relevant pollutants should be supported by the results of long-term experimental studies and sufficient data, and also has a good preliminary basis to ensure the scientific level, accuracy, and practicability of China's WQC for environmental management.

Finally, China's WQC research should fully absorb the latest results of water quality criteria research. These should include the research results of major national criteria research projects, such as the "973" Program (Lake water environment quality evolution and water environment criteria study), Major Science and Technology Program for Water Pollution Control and Treatment, and Treatment Science and Technology Major Project, along with environmental protection public welfare projects, and other research results which are related to WQC (Feng et al., 2012a; Wu et al., 2010). The guidelines will take science as the criterion, and also give consideration to rationality and feasibility. Meanwhile, the adaptability of China's economic and technological development levels should also be considered, with the bearing capacity of the relevant parties examined in order to establish the most effective technical guidelines for the establishment of water quality criteria for freshwater aquatic organisms in China.

### 2.2. Theoretical methodology research of WQC for aquatic organisms

The research regarding WQC began in the early 20th century. Since the proposing of WQC, it has been continuously improved and developed. With the continuous development of related disciplines, such as environmental geochemistry, toxicology, biology, and ecology, the theories and methodologies of WQC have been constantly updated. At the present time, two representative international WQC research systems exist in the United States and the European Union, respectively (ECB, 2003; Stephan et al., 1985; Feng et al., 2012a). In the aforementioned system, the two main methods of deriving WQC are based on theories of ecological risk assessments. Although the WQC research in China started later than that in other developed countries, it has fully absorbed the research results and experience of various countries. Then, combined with the actual national conditions in China, a series of research results have been achieved in recent years (Lei et al., 2010; Yin et al., 2003; Jin et al., 2011; Wu et al., 2012; Wang et al., 2008, 2015, 2017), which has allowed China to enter the stage of rapid growth and gradual maturity.

#### 2.2.1. Technical study of water quality criteria in developed countries

Many international countries and institutions have systematically studied the WQC of aquatic organisms. As a result, some countries have established relatively complete WQC systems. For example, the United

States was the first country to start research into WQC systems, and currently is a leader in the development of an international WQC field. The research regarding WQC has been carried out in the United States much longer than in other developed countries. Since the 1960s, the United States has published several water environmental criteria documents, such as the Green Book (US, 1968), Blue Book (NAS, 1972), Red Book (US EPA, 1976), and Gold Book (US EPA, 1986), which form a complete system of water environmental criteria which focuses on the protection of aquatic organisms and human health. These have been supplemented by nutrient criteria, sediment criteria, bacterial criteria, biological criteria, wildlife criteria, physical criteria, and so on. At the present time, there are three main methods for deriving WQC in the world: assessment factor methods; toxicity percentage ranking methods; and species sensitivity distribution (SSD) methods.

The assessment factor methods are currently used to study WQC and the main representative country of these methods is Canada. In 1999, the Canadian Environment Cabinet revised the Draft Guidelines for the Derivation of Water Quality Criteria for the Protection of Aquatic Organisms (CCME, 1999), in which the derivation of the criteria requires both toxicological and environmental fate data, and evaluations of toxicity data and criteria derivation methods are also specified. In order to ensure the validity and scientific accuracy of the WQC, and to protect aquatic organisms and ecosystems as comprehensively as possible, the data which are required to derive WQC must meet the minimum data requirements in the draft. However, if the data are insufficient, but can meet the relatively loose minimum data set requirements, transitional guidance values may be temporarily derived. The complete criteria can only be derived when the minimum data requirements of the toxicological and environmental data are successfully met. In order to ensure the unified and scientific evaluation of each pollutant, the toxicity data require evaluation. The evaluation mainly considers the experimental conditions, experimental concentrations, temperature, hardness, pH, co-solvent, experimental design, and statistical descriptions of the toxicity data estimations. There are no fixed requirements for the toxicological data assessments. However, there are certain reference standards in place. Following the assessments, the toxicity data can be divided into three categories: primary data; secondary data; and unavailable data. The majority of the data which are used to derive the complete criteria must be Level 1 data. Level 1 and Level 2 data are also available for the transitional guidance values. If sufficient data are available, the most sensitive and minimum observable effect concentrations in the study of the chronic exposure of native species in Canada is then multiplied by the safety factor (0.1), in order to be used as the final guiding concentration of the WQC. Otherwise, the most sensitive $LC_{50}/EC_{50}$ in the study of the acute exposure will be divided by an appropriate acute-chronic toxicity ratio or assessment factor for the purpose of implementation in the final guiding concentration criteria.

The United States is the top representative country in the study of WQC derivation based on toxicity percentage ranking methods. In 1985 (Stephan et al., 1985), the United States developed guidelines for WQC. The guidelines required the collection of large amounts of toxicity experimental data in order the formulate the criteria, which included the following: (1) The acute and chronic toxicity data of animals, which involved the acceptable acute and chronic experimental results in at least three phyla and eight families, as well as acute-chronic ratios calculated from at least three different families; (2) The toxicity data of aquatic plants, which required at least one acceptable experimental result from a freshwater (or sea-water) algae or vascular plant species; (3) Biological enrichment data which included at least one freshwater (or sea-water) species to determine the biological concentration factor. Second, using the obtained data, a series of values should be calculated using a toxicity percentage ranking method, such as the final acute value, final chronic value, final plant value, and final residual value. Finally, the maximum concentration and continuous concentrations of the criteria can be obtained. The aforementioned derivation method is still widely used. The current WQC in the United States has updated some of the WQC values for protecting aquatic organisms based on the results of previous studies. Also, WQC for protecting aquatic organisms and protecting human health are now listed separately.

The countries in the world which use SSD methods for the study of WQC are represented by the European Union, and also include Australia, New Zealand, the Netherlands, and so on (ECB, 2003; ANZECC and ARMCANZ, 2000). The method of SSD was first proposed by Kooijman (1987), and was later improved on by many researchers (Klimisch et al., 1997; Mu et al., 2014; Wu et al., 2013; Kwok et al., 2008). The methods use all of the toxicity data of known pollutants to fit the sensitivity distribution curves of various species, and then extrapolate the data to obtain the accurate criteria. In 2003, the Scientific Advisory Committee on Chemical Toxicity and Ecotoxicity of the Council of Europe issued a guideline document on risk assessment techniques, which had mainly used SSD as the method of deriving WQC. It has been found that this method can reflect the maximum concentration of pollutants in an environment without impacting the functions of the ecological communities. Therefore, the unacceptable harmful effects on ecosystems, along with damage to organisms caused by accumulations of pollutants through food or other means, can be effectively assessed. For the calculations of the criteria, species sensitivity distribution methods are recommended. It has been determined that through the applications of SSD methods, a long-term criterion for the protection of more than 95% of species, namely $HC_5$ (concentrations making 5% of the species at risk), could be finally obtained.

In 2000, Australia and New Zealand issued the Guidelines for Freshwater and Marine Water Quality (ANZECC and ARMCANZ, 2000). It was pointed out in the guidelines that SSD methods are generally used to derive water quality criteria, and evaluation factor methods can also be used when the data are insufficient. Then, in accordance with the quantity and quality of the toxicological data and levels of protection, the data can be divided into high reliable trigger values, medium reliable trigger values, and low reliable trigger values. Since the quantity and quality of the data required for the derivation require the highest reliability, many uncertainties in extrapolation process can be avoided, and the accuracy will be at the highest level. Therefore, the obtained results will best reflect the actual needs of an environment. In 2001, the Netherlands promulgated the Guidelines on the Derivation of Environmental Risk Limits (RIVM, 2001), with the aim of protecting all organisms in aquatic ecosystems from the adverse effects of pollutants. The environmental criteria values were obtained from the environmental risk limits. The environmental criteria included three different levels for ecosystems: Serious hazard concentrations; maximum allowable concentrations; and negligible concentrations. The corresponding environmental quality standards were also divided into three levels: Intervention value (in which the pollution has reached a level in which recovery cannot be realized naturally, and manual interventions are required); maximum allowable concentration value; and target value.

*2.2.2. Technical study of water quality criteria in China*

In recent years, China has carried out a series of studies regarding WQC. Many recent WQC projects have been carried out, such as the aforementioned National 973 Program Project, along with Major Science and Technology Program for Water Pollution Control and Treatment. These have included the Major Project of the Environmental Protection of Public Welfare, preliminary studies of the frameworks and typical cases of environmental criteria technology in China, and so on. However, when compared with other developed countries, the research on WQC in China still remains relatively weak. The fundamental reason for this is that the research on WQC in China started later than other developed countries and lacked operable methodologies for WQC which were appropriate for China's environmental needs. Therefore, the existing water quality standards for surface water could only be formulated according to the environmental quality criteria and standards of other developed countries, which has tended to result in an inadequate scientific basis, and potential “over-protection” or “under-protection” phenomena in the current protection policies of the whole ecosystems.

The WQC of aquatic organisms have been found to have obvious regional requirements. The regional environmental differences include the physical and chemical properties of the water (temperature, dissolved oxygen, pH value, hardness, organic matter, and so on); community structures of the aquatic organisms; water pollution degrees; environmental geochemical characteristics of the pollutants, and so on (Jin et al., 2015; Li et al., 2019; Wang et al., 2017; Welsh et al., 2000). Therefore, the WQC for protecting aquatic organisms throughout the world are established on the basis of the environmental characteristics and natural background of each country or region, especially for regional native species (Maltby et al., 2005; Su et al., 2011). The difference in regional species sensitivity is the most important factor, which could ultimately lead to the difference in water quality criteria. The WQC tend to be limited to certain environmental conditions when protecting specific water functions or organisms. The physical and chemical properties, biodiversity, and climatic factors of water bodies will vary with different water environment conditions, which will subsequently affect the protection effects of the water quality criteria on various ecosystems (Mu et al., 2018; Jin et al., 2015; Feng et al., 2012a). Therefore, while drawing lessons from other countries' research methods of water criteria for the protection of aquatic organism, it is recommended that attention should be paid to the differences in ecological environment characteristics, pollution characteristics, and biological fauna among different countries. For example, Salmonidae is a representative fish in the United States, while half of the freshwater fish in China belong to Cyprinidae (Su et al., 2011). Therefore, in order to more accurately reflect the regional differences of different countries, and effectively protect their water functions, it will be necessary to further expand the basic research regarding the regional differences in ecological environments in combination with the regional characteristics of different countries and the need for pollution control measures.

## 3. Results and discussion

The WQC for aquatic organisms are mainly obtained through scientific judgments based on the exposure data of specific objects in environmental media and dose-effect relationships. The criteria involve the latest research results in such frontier disciplines as environmental chemistry, toxicology, ecology, epidemiology, biology, and risk assessment. At the present time, there are many sections involved in the study of WQC guidelines for aquatic organisms. Generally speaking, the main factors which affect the WQC guidelines include the determination of the pollutants, collection and screening of the toxicity data, selection of the species, and the determination of WQC derivation methods. These factors play key roles in the determination of the WQC, of which “the determination of WQC derivation methods” has the greatest impact on WQC value. The flow chart of water quality criteria research is shown in Fig. 1.

### 3.1. Determination of the pollutants in the WQC

The selection of the pollutants is the first factor which must be considered in the determination of their WQC. There are many types of pollutants with greatly different properties in water environments, including toxic organic pollutants, heavy metals, nutrients, and so on. Not all of the substances are suitable for the study of WQC for aquatic organisms. For example, there are known to be some substances which cannot stably exist in water environments, and these substances are not suitable for criteria research. Also, there are now some new pollutants for which the previous analytical methods are not mature enough to accurately determine their content levels or specific toxicity end-points in water environments. Furthermore, different types of pollutants have varying environmental concentrations, harmfulness levels, and pollution degrees, and their action sites and mechanisms are also known to be different. Therefore, in the selection of pollutants, the types of pollutants and their toxicity degrees should be comprehensively considered. Also, the pollution situation of water pollutants in basin environments should be taken into account. At the same time, the pollutants should be selected by referring to the official list of pollutants. Therefore, in the technical guidelines for the formulation of WQC, it is necessary to apply some limiting conditions for the suitable pollutants which will be used for deriving WQC using unified standards. These conditions mainly include the following: (1) the substance can be detected in most natural water environments and presents potential ecological hazards or risks; (2) the chemical properties of the substance and its environmental behavior parameters are known and available; (3) there are effective analytical methods available for the substance.

### 3.2. Collection and screening of the toxicity data

The core content of the WQC derivations is the screening of the toxicity data. The accuracy and reliability of the toxicity data are the premise of deriving the most effective WQC. Therefore, during the determination of the WQC guidelines, it is necessary to have specific requirements for the sources of the data, as well as the data screening. Data sources mainly include mainstream online toxicity databases both in China and internationally (such as ECOTOX database https://cfpub.epa.gov/ecotox/); publicly published literature or reports; and the actual measured data of local species. If the above data collection sources cannot meet the requirements of the WQC formulation, then toxicological experiments should be carried out in order to collect relevant experimental data. In terms of the data screening principles, it will be necessary to specify the toxicity data to be obtained, which would mainly include the design of the experimental conditions; experimental control measures; toxicity endpoint selections; abnormal value eliminations; data selection principles; and some special substance criteria which would need to be formulated separately (Dyer et al., 2008; Feng et al., 2012a; Liu et al., 2016).

### 3.3. Selection of the species

It has been determined that, from the perspective of biodiversity protection, aquatic organisms of different flora and trophic levels must be considered in the formulations of WQC. For example, Salmonidae is prominent in the WQC of the United States, and is related to the widespread distribution of Salmonidae fish in North America (Stephan et al., 1985). Similarly, when Australia uses SSD methods to derive water ecological criteria, it is also recommended to use Australian native species or regional aquatic toxicological data (ANZECC and ARMCANZ, 2000). Therefore, the native aquatic species of a country play very important roles in the deduction of WQC.

In addition, in order to improve the accuracy and reduce the uncertainties of model fitting, the minimum data needed are generally limited in the statistical data during the deduction of water quality criteria using model fitting methods, as well as when considering the regional distributions of species. That is to say, the least amount of data can be used to fit the model, and the WQC value can then be extrapolated relatively accurately. For example, the United States WQC require the toxicity values of aquatic animals from a minimum of three phylum and eight families, and at least one plant species (Stephan et al., 1985). The European Union requires at least ten chronic NOEC values for eight different species of organisms (ECB, 2003). Other countries also have requirements regarding the minimum data for deriving WQC. Therefore, on a global scale, the minimum requirements for the number of species may vary from country to country, as detailed in Table 1.

In order to protect China's aquatic ecosystems more scientifically and rationally during the process of determining the most effective WQC, it is necessary to make provisions for species selection not only in terms of their sources and regional distributions, but also in terms of the

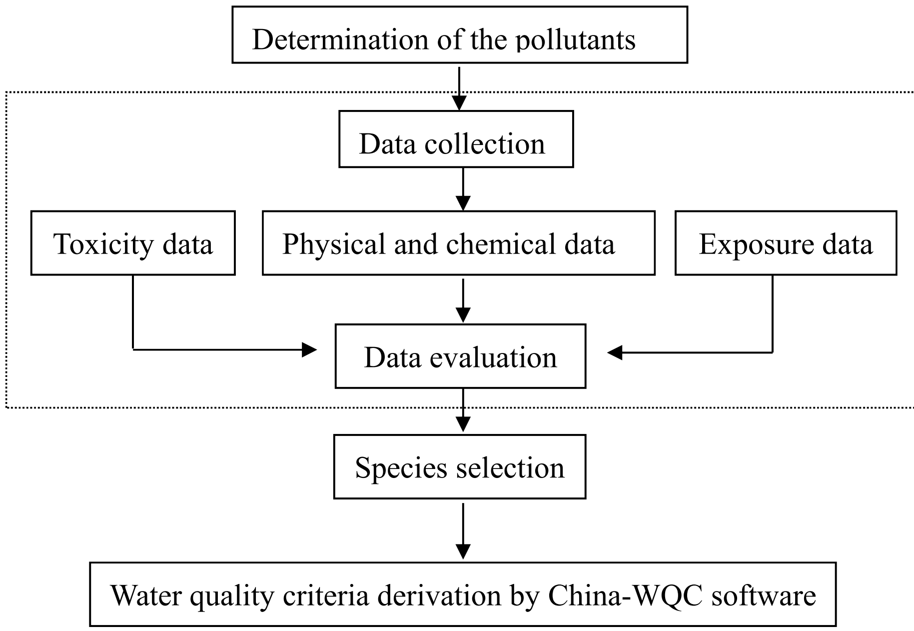


**Fig. 1.** Process for deriving water quality criteria.

minimum data requirements. Therefore, based on drawing lessons from the biological categories adopted by developed countries in formulating WQC, and in accordance with the floristic characteristics of aquatic organisms in China, the most appropriate WQC can be determined. The selected species for experimental study should include different nutrition levels and biological categories. The main three categories should include international common species, which are widely distributed in China's natural waters, as well as native species and introduced species. During the process of determining China's WQC, related data should be theoretically collected as much as possible for the selection of species data. However, when the data are insufficient, it is suggested that the minimum data requirements should be defined as five species, in view of the species needs of other developed countries and previous research findings. In addition, the categories of these five species will be limited. In other words, the species should cover at least three nutrition levels as follows: aquatic plants and primary producers; invertebrates and primary consumers; vertebrates and secondary consumers. Also, the five species should include at least one species of bony cyprinidae fish; one species of bony non-cyprinidae fish; one species of zooplankton; one species of benthic animals; and one species of aquatic plants. Based on previous research (MEE, 2017),a list of native species used to derive WQC for aquatic organisms in China was listed (Table 2), which could provide reference for WQC research.

### 3.4. Derivation method for water quality criteria

When compared with other derivation methods of WQC, it has been found that the SSD method is currently one of the most internationally recognized methods. It has the advantages of making full use of the toxicity data of all species, and assumes that the limited species are randomly sampled from the ecosystems and can effectively represent the entire ecosystem. In terms of the application scope, when the toxicity data of the pollutants are sufficient, SSD methods can be used to fit the model and extrapolate the criteria, which will reduce the uncertainty of the statistical results. Therefore, SSD methods are also recommended in the determination of China's water quality criteria guidelines for aquatic organisms (MEE, 2017). It has been determined that when using this type of method to derive the WQC, the following main steps should be included: toxicity data distribution tests; cumulative probability calculations; model fitting and evaluations; and water quality criteria extrapolation (Fig. 2). During the extrapolation processes of the WQC, the selections of the models also play key roles in the research of the WQC, and will be directly related to the determination of the criteria values. The results which are obtained by different fitting models may also display significant differences. Therefore, choosing which model to fit, and the subsequent judging of the advantages and disadvantages of the fitness are the key steps in deriving WQC. Consequently, on the basis of a large number of WQC case studies (Newman et al., 2000; Liu et al., 2014; Versteeg et al., 1999; Feng et al., 2013b; Wheeler et al., 2002), the three types of models which are most suitable for SSD fitting can be summarized as logistic models, normal models, and extreme value models. These three types of models have been found to have the strongest universality and best fitting effects. At the same time, during the evaluations of the goodness of fit of the models,

**Table 1**
Minimum species data requirements for deriving WQC in different countries.

| Countries/organization | Toxicological endpoints | Derivation method | Minimum number data |
|---|---|---|---|
| US EPA | $LC_{50}$ and NOEC | Toxicity percentage ranking method | 9 |
| European Union (EU) | NOEC | SSD | 10 |
| OECD | NOEC | SSD | 5 |
| Canada | $LC_{50}$ and NOEC | Assessment factor method | 6 |
| Australia and New Zealand | $LC_{50}$ and NOEC | SSD | 3/5[a] |
| The Netherlands | $LC_{50}$ and NOEC | SSD | 5 |
| China | $LC_{50}$ and NOEC | SSD | 5 |

[a] The amount of toxicity data required varies according to the different trigger values derived. High reliability trigger values require at least NOEC values of more than three species, or NOEC values of five or more different species; moderate reliability trigger values require acute toxicity values of at least five species.

**Table 2**
Recommended sensitive native aquatic organisms in China (MEE, 2017).

| Kingdom | Phylum | Family | Species |
|---|---|---|---|
| Animal kingdom | Chordata | Cyprinidae, Cobitidae, Bagridae, Synbranchidae, Percichthyidae, Ranidae. | *Cyprinus carpio*, *Ctenopharyngodon idellus*, *Hypophthalmichthys molitrix*, *Aristichthys nobilis*, *Carassius auratus*, *Pseudorasbora parva, Misgurnus anguillicaudatus*, *Pelteobagrus fulvidraco*, *Monopterus albus*, *Siniperca chuatsi*, *Quasipaa spinosa* |
| | Arthropoda | Daphnia, Gammaridae, Palaemonidae, Varunidae. | *Daphnia magna*, *Daphnia pulex*, *Daphnia cucullata*, *Daphnia hyaline*, *Simocephalus serrulatus*, *Ceriodaphnia dubia*, *Gammarus pulex*, *Gammarus lacustrid*, *Macrobrachium nipponnense*, *Eriocheir sinensis*, *Brachythemis contaminate*, *Baetis rhodani*, *Heptagenia sulphurea* |
| | Rotifera | Brachionida, Lecanidae. | *Brachionus calyciflorus*, *Lecane quadridentata*, *Keratella cochlearis* |
| | Mollusca | thiaridae, Lymnaeidae, Corbiculidae. | *Semisulcospira libertine*, *Lymnaea stagnalis*, *Corbicula fluminea* |
| | Annelida | Naididae, Tubificidae. | *Tubifex tubifex*, *Branchiura sowerbyi*, *Dero* sp.,*Nais* sp. |
| | Cnidaria | Hydroida. | *Hydra oligactis*, *Hydra viridis*, *Hydra vulgaris* |
| | Platyhelminthes | Dugesiidae. | *Dugesia japonica* |
| Plant kingdom | Angiospermae | Lemnaceae, Potamogetonaceae, Hydrocharitaceae, Ceratophyllaceae. | *Lemna minor*, *Spirodela polyrrhiza*, *Potamogeton crispus*, *Hydrilla verticillata*, *Ceratophyllum demersum* |
| | Chlorophyta | Chlamydomonadaceae, Chlorellaceae, Scenedesmaceae. | *Chlamydomona sreinhardtii*, *Pseudokirchneriella subcapitata*, *Scenedesmus acutus* |
| | Bacillariophyta | Naviculaceae. | *Navicula pelliculosa* |
| | Pteridophyta | Salviniaceae. | *Salvinia natans.* |

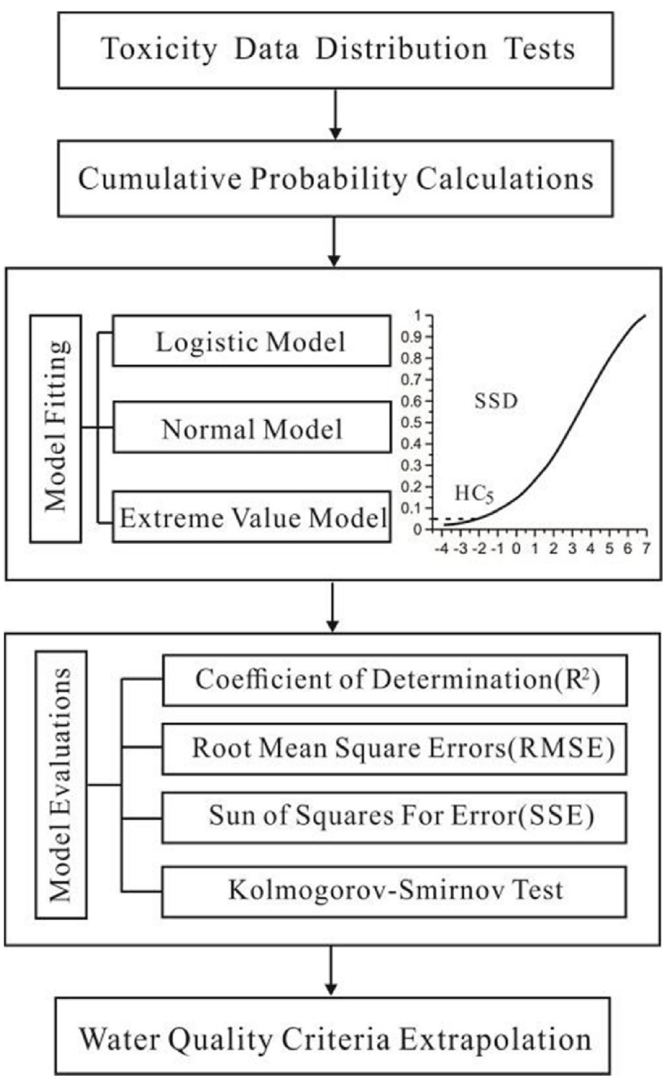


**Fig. 2.** Derivation steps of water quality criteria for the protection of freshwater aquatic organisms.

this study also proposed the use of the four most important evaluation indicators as follows: The coefficient of determination ($R^2$); root mean square errors (RMSE); sum of squares for error (SSE); and K-S test (Kolmogorov-Smirnov test), in order to comprehensively judge the fitting effects of the different models. Meanwhile, in order to better realize the convenience and specificity of the WQC derivations, this study specially developed the "Freshwater Aquatic Organism Model Prediction Software" (China-WQC) program, which will be specially suitable for WQC derivations in China, and a shared software platform was successfully formed (http://www.sklecra.cn/). This software is developed by Microsoft. Net technology, which supports data entry and Excel data pasting. The software integrated normal distribution model, logarithmic normal distribution, logistic distribution, logarithmic logistic distribution, extreme value distribution and KS normality test, etc. At the present time, the SSD model software which had been specially used for the extrapolation of WQC in China was applied to the derivation of WQC for typical pollutants in China, and the accuracy of the results were successfully verified.

## 4. Conclusions

During the last ten years, environmental criteria research studies in China have been rapidly developed. However, the majority of those studies have involved scattered exploratory research which lacked unified management in terms of output and application of criteria. The present study first comprehensively and systematically elaborated the principles, basic flow, key scientific issues and specific derivation method of water quality criteria guideline. In addition, a shared software platform was also established for the scholars of water quality criteria in China, which would provide technical guidance for the scientific and standardized formulations of water quality criteria. Moreover, it has further standardized and improved the basic system construction of environmental criteria management in China. Therefore, the future criteria management can be thoroughly documented and legally based. The research results have provided core scientific and technological support for relevant major national action plans, policies, laws, and regulations. These have become the national will and government actions, which will provide decision support and policy recommendations for future national environmental protection and management policies. Overall, the development of a national environmental protection standard has been successfully promoted.

In the future, under the guidance of national action, environmental criteria research will continue to advance. Also, criteria research and development capacities will continue to be strengthened, and research teams will continue to grow. With the continuous improvements and updating of a series of technical guidelines for environmental criteria, as well as the continuous availability of case results regarding relevant pollutant criteria, the management systems for environmental criteria will be continuously improved. Therefore, from this perspective, we can confidently say that a set of environmental criteria management and technological systems which will be suitable for China's national conditions will eventually be established.

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