

Article

# Study of Water Environmental Cumulative Risk Assessment Based on Control Unit and Management Platform Application in Plain River Network

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Academic Editors: Elena Cristina Rada and Lucian Ionel Cioca

Received: 8 March 2017; Accepted: 31 May 2017; Published: 7 June 2017

**Abstract:** As the gradual deterioration of the environment, the method of environmental risk assessment has been developed from basing only on a single source to basing on a cumulative risk source. In accordance with the water environment features of the plain river network area, a cumulative risk assessment system of water environment in the plain river network area was established in this paper, the design process for which could be divided into three step: (1) Control unit divided reasonably was chosen as the basic unit for water quality management. (2) On that basis, according to the characteristics of the plain river network area, the cumulative risk indexes were selected. The index weight is calculated using entropy method and analytic hierarchy process (AHP), which could determine the risk grade of each control unit. (3) The cumulative risk assessment method is coupled to the existing water environment management platform. The platform with a dynamic database can realize the dynamic calculation and visualization of the cumulative risk grade. In this paper, the Zhejiang area of Taihu Basin was selected to be the research target as the typical plain river network area. Thirty-five control units were divided with regional water environment and control section. Taking the data in the year 2011 as example, the proposed cumulative risk assessment method was used to identify the control units in different grades and the results demonstrated that the numbers of high-, medium-, low- and extremely low-risk control units are 13, 12, 5 and 5, respectively. It is necessary to give priority to the high-risk control unit. Therefore, the cumulative risk assessment method based on the control unit provides an essential theoretical basis for reducing the probability of water pollution and reducing the degree of water pollution damage.

**Keywords:** control unit; plain river network area; cumulative risk; management platform

## 1. Introduction

Human activities in recent decades have made tremendous impacts on environmental changes [1]. Among them, environmental quality deterioration and pollution incidents are the problems highlighted by most scientists concerned. In order to prevent the occurrence of pollution incidents, scientific and effective risk assessment results can be used to provide both scientific and reasonable technical supports for water environment management, thereby reducing the risk of pollution.

The plain river network area, different from the common water area, has several unique properties such as the complex water system, the low flow rate, and the insufficient pollutant degradation ability, which resulted in water pollution incidents occurring frequently [2,3], especially featured by cumulative pollutions. The cumulative pollutions in the plain river network area always refer to multiple pollutants and pollution sources, which would generate cumulative risks on water environment in temporal and spatial scales. So, the cumulative risk assessment method has become the focus of risk assessment. Due to the above area properties, the range of possible occurrence of cumulative pollution is great in the plain river network area. It is difficult to achieve a comprehensive and accurate risk assessment with the watershed or administrative district scale. Therefore, the reasonable scale unit is the basis of risk assessment. The control unit is the smallest unit of environmental management [4], so the control unit could be selected as the basic unit of the cumulative risk assessment. How to reasonably divide the control unit in the plain river network area becomes the basic work.

Water environment management on the basis of the control unit is mainly the current development tendency in the water environment protection field at home and abroad [5–7]. In recent years, the control unit plays a positive and essential role in basin management and gradually becomes a common unit in the domestic and overseas basin water environment management field. Through taking the control unit as the minimum carrier of water environment management, this paper organically combines the basin management with the administration management. In the field of water environment management, the main purpose of the control unit division is to disassemble the complicated water environment problems into each control unit [8–11], so as to effectively implement both the concrete basin water environment management measures and policies and improve the basin water environment quality [12]. Li et al. [13] regarded the control unit as the management core to put forward some improvement suggestions for the supervisory control of section layout and the effective monitoring technology for water quality supervision objectives in the cross-border section of first-order stream in the Ganjiang basin. Although the control unit has been widely used in water quality planning and management, it is seldom used in the risk assessment.

The cumulative risks refer to the water environment risks caused by the cumulative pollution in the basin [14–17]. It could be divided into spatial cumulative risks and temporal cumulative risks. The former means the cumulative risks caused by the over-discharge pollutant flow from the external basin, in which the spatial cumulative risk value could be analyzed through the measurement results of contaminant flux over standard. The latter means the risks caused by the constant accumulation of regional pollutants, which mainly attribute to some factors such as the regional industry categories, remaining environmental capacity, the assessment of regional water ecology conditions and the response levels of both the government and the public to the environment. At present, the research works concentrating on risk assessment are mainly focused on the research of the sudden risks. Taking the “Danube Emergency Response System” for example, it is the emergency response system for shipping accident pollution. Recently, the cumulative risk assessment has been paid more and more attention as the cumulative pollution happens frequently. Meanwhile, the existing assessment methods have poor applicability, especially the cumulative risk assessment method for the characteristics of the plain river network area. Peng et al. [18] summarized cumulative environmental risk assessment methods at domestic and overseas locations and point out the imperfections of assessment and the insufficiencies of the basic science and the research work. Wang Bingquan et al. [19] pointed out that the basin cumulative environment risk assessments are excessively macroscopic and the exposure methods of health risk assessment proved to be unilateral. Alves et al. [20] used cumulative risk assessment as the basis for developing data in support of environmental decision-making. Teuschler et al. [21] developed the cumulative relative potency factors (CRPF) approach, combining exposure modeling and physiologically. In general, the existing research did not take into account the characteristics of the water environment in the plain river network area. Therefore, it is necessary to set up a complete risk assessment system of the plain river network area in order to fully manage the water environment. The probability of cumulative risks occurrence will be significantly slashed.

Some factors, whether the control unit division is reasonable or not, whether the cumulative risk assessment method is perfect or not, and whether the basic scientific research work is insufficient or not, are essential to provide technical supports for water environment risk warning. Therefore, the key problem is to solve how to divide the control unit reasonably and establish a complete risk assessment method. According to the characteristics of water environment in the plain river network area, control units suitable for the water environment management of the plain river network area were divided and analyzed in order to ensure the rationality in this paper. Taking the control units as the basic management units, the Pressure-State-Response (PSR) framework model is introduced into the cumulative risk assessment system under the influence of various factors. Integrating the risk assessment system with the basic database and the mathematical model [22] established by the Environmental Monitoring Center of Zhejiang Province, the high- and medium-risk control units are calculated through the cumulative risk assessment method and are regarded as the primary basis for water environment management. Control unit division results and cumulative risk assessment technology systems are integrated into the water environment management platform in the Zhejiang area of Taihu Basin established in the *12th Five-Year Plan* in order to realize the cumulative risk grading in different temporal and spatial scales, thus more effectively preventing the real-time water environment risks of each control unit. It symbolizes a beneficial attempt of basin digital environment management.

## 2. Study Area

The Zhejiang area of Taihu Basin is located in the northern Zhejiang Province, adjacent to Jiangsu Province in the north, and Shanghai City in the east. As for the longitude and latitude, the basin is situated between  $30^{\circ}10'$  and  $31^{\circ}8'N$ ,  $119^{\circ}12'$  and  $121^{\circ}11'E$ . Covering an area of  $12,272\text{ km}^2$ , this basin crosses over thirteen administration districts, as shown in Figure 1. The western part of the study area is Tiaoxi basin and the eastern part is the Hangzhou–Jiaxing–Huzhou plain river network area. The actual river flows of the total research area are 79.2 billion  $\text{m}^3$ . Limited by geographical conditions, the water naturally flows from southwest to northeast into Taihu Lake and Huangpu River. Moreover, influenced by the tide at the junction of the eastern part and Shanghai City, the reciprocating flow happens from time to time. The tide is mainly caused by the tide of the tributaries of the Huangpu River. Due to river bed resistance and runoff blocking, it is an irregular semidiurnal tide. The river flow in the junction of the eastern part and Shanghai City is directly affected by the tide. The annual flood volume is about 69.6 billion  $\text{m}^3$ , and the ebb volume is about 12.4 billion  $\text{m}^3$ . The average annual rainfall in the study area is about 1336 mm. Under the influence of atmospheric circulation, the variation of precipitation in the basin is relatively large, and the annual distribution is uneven. The rainfalls in May and June are affected mainly by the rainy season while the rainfalls in August and September are affected by typhoon rain. Precipitation from May to October accounted for more than 2/3 of the annual precipitation. Due to the high temperature and the evaporation in the plain area, the average annual evaporation of surface water is about 800~900 mm.

The water quality of the study area is much worse. Based on the water quality data (including COD,  $\text{NH}_3\text{-N}$ , TP) in 140 conventional water quality monitoring stations from 2011 to 2012 provided by the Environmental Monitoring Center of Zhejiang Province, the water quality categories of the study area are mainly Grade III and Grade V. According to the “Environmental quality standards for surface water (GB3838-2002)” standard, all the surface water can be divided into five categories deteriorating from Grade I to Grade V. In December 2005, the people’s government of Zhejiang Province approved the “Classification scheme of water functional area and water environment functional area in Zhejiang Province”, in which all important cross-sections in Zhejiang Province were required to achieve the relevant standard. Based on the water monitoring data of all important cross-sections from 2011 to 2012, the water quality exceeding rate has reached 70% or more, as shown in Table 1. The main reason for the decline of the regional water environmental quality is the pollution sources in this area. The types of pollution sources include industry, sewage plant, residential pollution, farmland and livestock. According to Environmental Protection Bureau statistics data of the pollutant discharge, there were

1452 industrial enterprises in the area, with more than 200 types of industry, and the discharge of wastewater was 73.593 million t in 2011. The top five industries discharging wastewater are textile industry, paper making and paper product industry, metal smelting and rolling processing industry, leather, fur and feather products, shoemaking industry, rubber and plastic manufacturing industry. The primary pollutant of concern from those is COD, and the COD discharge constitutes more than 70% of the total industries.

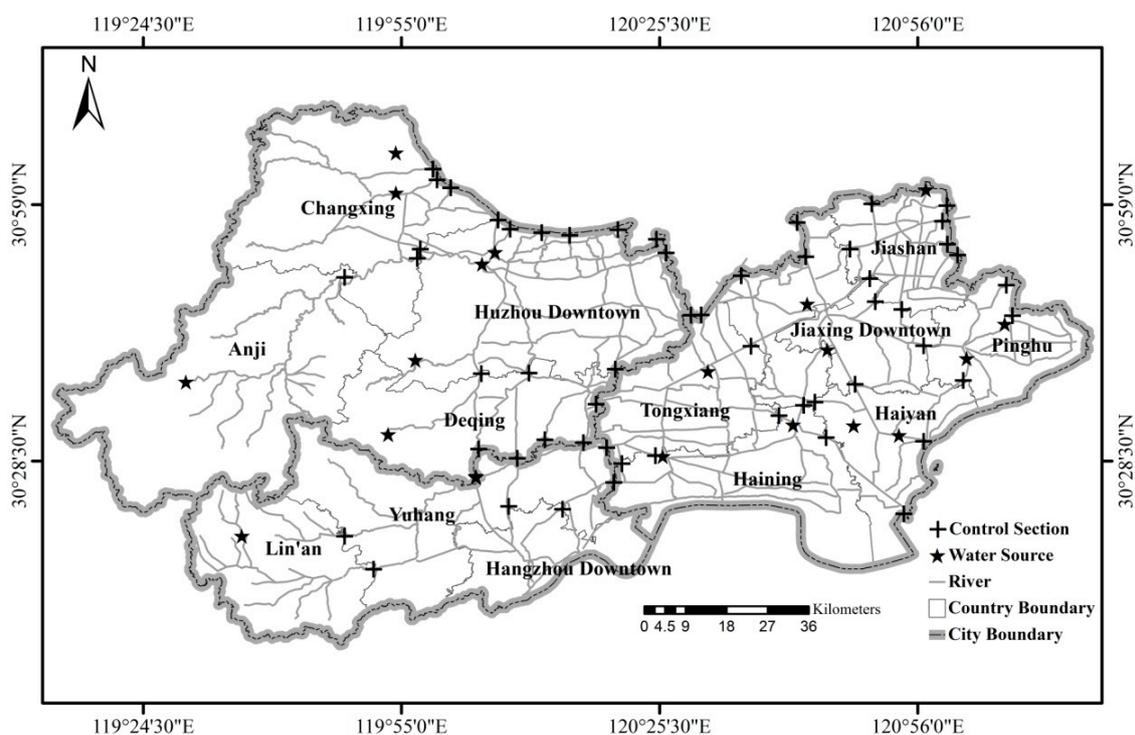


Figure 1. Study area and control section distribution schematic diagram.

Table 1. Water Quality Information in the Zhejiang Area of Taihu Basin (Unit: %).

Year	I	II	III	IV	V	Worse Than V	Single Factor Exceeding Rate			Exceeding Rate
							COD	NH <sub>3</sub> -N	TP	
2011	1.1	14.1	34.1	13.1	10.5	27.1	51.3	75.0	67.2	75.0
2012	0.8	14.2	30.0	12.2	9.0	33.9	44.3	70.9	66.2	70.9

### 3. Method

#### 3.1. Outline

The main research methods of this paper are as follows (Outline is as shown in Figure 2): (1) The division of the control unit. The control unit is regarded as the basic management unit; (2) The cumulative risk assessment system, with the determination of the assessment index and the calculation of the index weight, is established; (3) Construction management platform. Through the coupling technology, the database/control unit division and the cumulative risk assessment technology system are integrated into the water environment management platform so as to achieve the cumulative risk grading in different temporal and spatial scales.

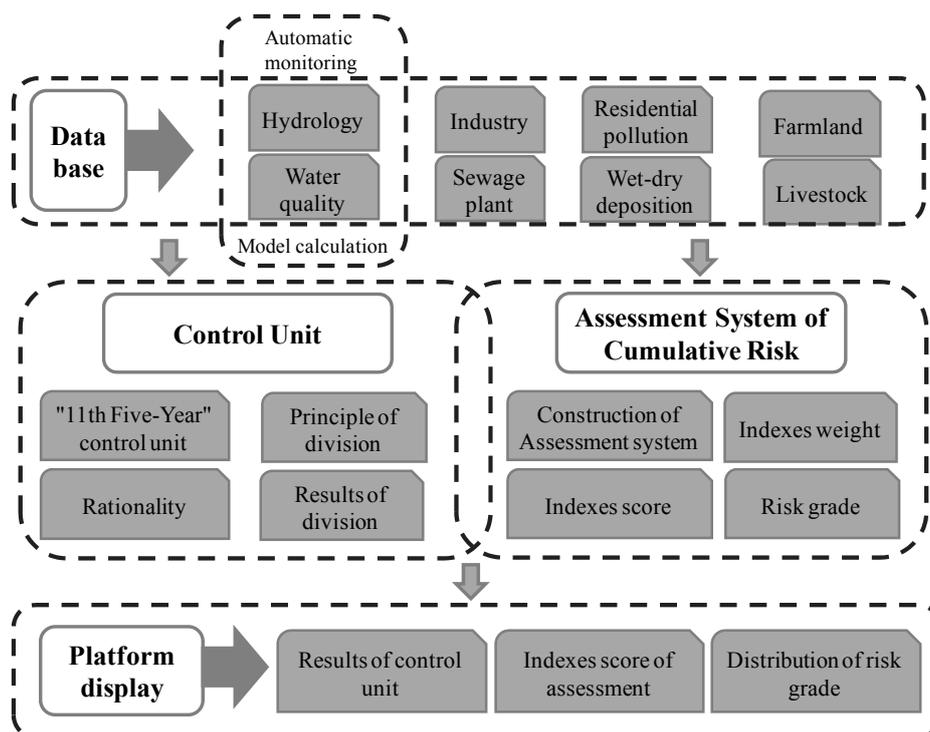


Figure 2. Technology outline.

### 3.2. Division of Control Unit

#### 3.2.1. Control Unit Division Method

The control unit is the area where the main pollution has the prominent influences on the water quality of the control section [6,23,24]. During the *11th Five-Year Plan* period, Gao Junfeng et al. [25,26] divided the Zhejiang area of Taihu Basin into 35 control units. Given that the location of assessment sections in Zhejiang Province is not clear during the *11th Five-Year Plan* period, the division of the control unit has little relation with the assessment section, which resulted in the fact that there was no corresponding control section to achieve supervision and management after the control unit division. Beginning in 2012, the sections were built and operated. Therefore, the division results of the control unit during the *11th Five-Year Plan* did not combine with the section.

The control section consists of 55 sections and 20 drinking water sources. During the *12th Five-Year Plan* period, 55 automatic monitoring stations were set up to be used as the assessment section by the Environmental Monitoring Center of Zhejiang Province. The improvement of the monitoring system offers strong supports for water environment management and simultaneously provides an important referential basis for the modification of the control unit. Drinking water source is the origin of both the domestic water and the industrial water. Especially in recent years, the water quality in drinking water source has severely deteriorated. As a consequence, one of the important objectives of control unit management is to ensure high water quality in drinking water source. Taking into account the location of the control section, this paper develops a method on the basis of the results of the control unit division during the *11th Five-Year Plan* period. The basic principles of the control unit division methods adopted in this paper are described as follows (The flow is shown in Figure 3). (1) The first principle is to regard the location of the control section in the study area during the *12th Five-Year Plan* as a reference. During the implementation period of the *12th Five-Year Plan*, the Environmental Monitoring Center of Zhejiang Province establishes a total of 55 automatic monitoring stations as assessment sections. There are 20 drinking water sources in the study area. On the premise of having clarified the location of assessment sections and drinking water sources, this paper makes

adjustments and improvements on the existing division results of the control unit in the study area. Moreover, it is significant to make sure that each control unit has at least one control section. (2) The second principle is to consider the basin and water conditions. There are many rivers and lakes in the study area. Influenced by the tides, most rivers at downstream boundary are bi-directional rivers. Therefore, the impacts of water quality in the control section are rather complicated and changeable. The division of the control unit has to consider the basin and main hydrological conditions. (3) The third principle is to properly take the county or district administration boundary into consideration. To make the administration management easier, the regulated control unit boundary should primarily consider the administration boundary. As for those administration boundaries devoid of regulations, further improvements should be made in accordance with the river system distribution.

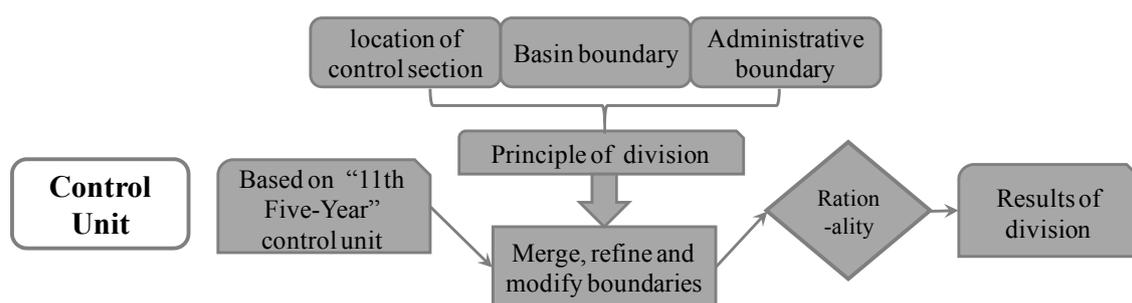


Figure 3. Flow of control unit division.

### 3.2.2. Rationality Analysis Method

The control unit is the area where the main pollution has the prominent influences on the water quality of the control section. Through calculating the influential weight of the control unit internal pollution load against control section water quality, the rationality of the control unit division could be determined. The influential weight of control unit internal pollution load against control section water quality can be expressed as follows:

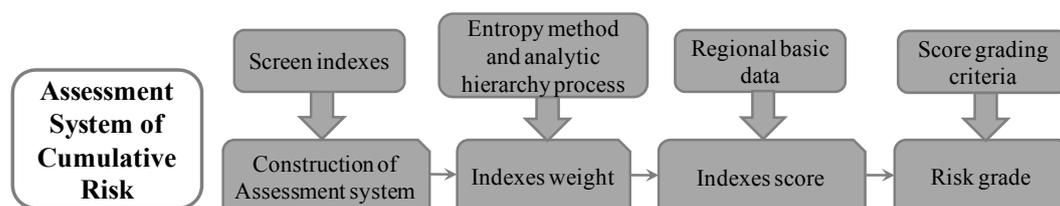
$$\alpha_i = \frac{c_i/W_i}{c_i/W_i + c_0/W_0} \quad (1)$$

In the above formula,  $\alpha_i$  means the influential weight of control unit internal pollution load against control section water quality (%),  $W_i$  means the internal pollution load of control unit,  $c_i$  means the influential water concentration value of control unit internal pollution source against control section water quality,  $W_0$  means external pollution load of control unit and  $c_0$  means the influential water concentration value of control unit external pollution source against control section water quality.

### 3.3. Constructing Cumulative Risk Assessment System

Pressure-State-Response (PSR) framework model [27] is mainly adopted to observe the relationships among environment pressures, state and response. At present, many governments and organizations consider PSR model as the most effective framework applied in environment index organization and environment state reports [28]. Water environment cumulative risks refer to multiple pollutants and pollution sources discharged in different ways, which would generate water environment cumulative risks in temporal and spatial scales. Taking the water environment characteristics within the study area into consideration, this paper screens out the typical risk index, which stands for the study area, and utilizes the PSR model to build a water environment cumulative risk assessment technology system in the Zhejiang area of Taihu Basin. According to the basic data of the study area, it is helpful to determine the comprehensive risk score of each index while it is also beneficial to calculate the weight of each cumulative risk index through entropy method and analytic hierarchy process (AHP). The comprehensive risk score and risk grade based on the control unit is calculated through

the comprehensive risk grading method. Furthermore, the effective environmental management is implemented for the control units with different risk grades. The flow is shown in Figure 4.



**Figure 4.** Flow of assessment system of cumulative risk.

### 3.3.1. Screening Index

For the determination of the assessment index, it is necessary to consider not only the water quality of the basin, but also the pressure index, the state index and the response index.

#### (1) Pressure index

The pressure index, including internal pollution pressure and external pollution pressure, refers to the pollution pressure that can lead to the cumulative pollution of the water environment in the control unit. The internal pollution pressure is mainly caused by the leading industrial type of the pollution sources and is brought by influence of the pollutant discharged to water environment. The external pollution pressure refers to the pollution pressure of all incoming pollutants to the control unit. Due to the obvious tidal impacts on the eastern part of the study area, this paper introduces the pollutant flux index to calculate the amount of pollutants in each control unit. The pollutant flux is positive while the exit is negative, so as to solve the pollution load caused by tide.

#### (2) State index

State index refers to the risk characterization after pressure. Water quality is the direct characterization of the water environment in the control unit. Therefore, the water quality of the specific control section and the basic ecological quantity in the river can be evaluated.

#### (3) Response index

Risk response refers to the reaction mechanism of the rapid establishment of the water environment in the control unit after the occurrence of the risk pressure. Indexes reflect the awareness of the government and the public. According to the actual situation, some typical representative indexes, including the emergency response ability, the implementation of policies and regulations, and public awareness of environmental protection, were selected.

Based on the regional environmental characteristics, refer to “the classification of national economic industries”(GB/T4754-2011), “fertilizer technical guidelines for environmental safety” and international fertilizer, “surface water environment quality guideline”, “water pollutant capacity calculation procedures”(SL348-2006), “surface water environmental quality standard”(GB3838-2002) and other related documents and references [29];all of them together determine the risk grade of each single index classification. The water environment cumulative risk assessment system in the Zhejiang area of Taihu Basin was established, as shown in Table 2.

**Table 2.** Water environment cumulative risk assessment technology system.

Criteria Layer	Sub-Criteria Layer	Index Layer	Grading			
			High-Risk	Medium-Risk	Low-Risk	Extremely Low-Risk
Pressure	Internal pressure of the control unit	Leading industry <sup>1</sup>	Petroleum refinement, coke making, nuclear fuel processing industry, chemical raw material and chemical product manufacturing industry, medicine industry.	Textile industry, paper making and paper product industry, metal smelting and rolling processing industry, metal surface processing and heated processing, leather, fur and feather products, shoemaking industry, rubber and plastic manufacturing industry, chemical fiber manufacturing industry.	Equipment manufacturing industry, transportation industry, storage and postal industry, architecture industry, mining industry.	Other
		Inflow amount/environment capacity ratio	>2	≤2	≤1.5	<1
	External pressure of the control unit	Flux/threshold value ratio	>2	≤2	≤1.5	<1
State	Water environment of the control section	Section control category	State control	Provincial control	Municipal control	County control and below
		COD (mg/L)	≤50%	50~70%	70~90%	≥90%
		NH <sub>3</sub> -N (mg/L)	≤50%	50~70%	70~90%	≥90%
		TN (mg/L)	≤50%	50~70%	70~90%	≥90%
		TP (mg/L)	≤50%	50~70%	70~90%	≥90%
		Water quality objective regulated by water functional regionalization	I; II	III	IV	V
	Water ecology	Ecological landscape	Poor	Medium	Favorable	Excellent
Response	Government	Execution force of policy and regulation	Extremely low	Low	Medium	High
		Emergency response ability	Extremely low	Low	Medium	High
	Public	Public environmental protection consciousness	Extremely low	Low	Medium	High

<sup>1</sup> Provided agriculture is the leading industry, then high-risk, medium-risk, low-risk and extremely low-risk, respectively, represent nitrogen fertilizer utilization intensity (kg/hm<sup>2</sup>) >364, >225, >120, ≤120, phosphate fertilizer utilization intensity (kg/hm<sup>2</sup>) >104, >46, >10, ≤10, and life sewage fitting rate (%) ≤70, ≤80, ≤90, ≤100).

### 3.3.2. Index Weight

As for the multi-index assessment problem, the determination of weight is the key point and a severe problem. At present, there are two common weight methods, namely subjective weighting method and objective weighting method [30]. This paper combines entropy method and AHP. The entropy method is adopted as for the selection of the objective judgment threshold value of each sub-index so as to conduct the weight calculation. As for the index category without threshold value reference, it is useful to make use of the AHP method to conduct weight calculation. The index layer of weight coefficient corresponds to 13 indexes. Pressure layer and state layer both are quantitative indexes. In order to assure the fair weight among indexes, this paper adopts the entropy method to determine the weight coefficient of quantitative indexes. The ecological landscape and response layer are qualitative indexes, calculated by AHP. Based on the comparison of the two indexes, the judgment matrix composed of the importance coefficient is obtained, and the weight analysis is applied to the qualitative index [31].

### 3.3.3. Comprehensive Risk Assessment Method

Comprehensive risk assessment method is adopted on the basis of the cumulative risk assessment technology system, using the mathematical methods to calculate the weight coefficient of each index separately. Each single index of the control units is divided into four levels, namely extremely low-risk, low-risk, medium-risk and high-risk, scoring 1~4 respectively. The index score is multiplied by the corresponding weight coefficient, and is weighted by the sum of all indexes to get the comprehensive risk score. Furthermore, the range of comprehensive risk score of all control units ( $x_{\min}$ ,  $x_{\max}$ ) can be divided into four equal parts (Table 3), and corresponding to different risk grades. The formula is shown as follows:

$$ESI = \sum r_j \times \omega_{3j} \times \omega_{2j} \times \omega_{1j} \quad (2)$$

In the above formula:  $ESI$  means the comprehensive risk score;  $r_j$  means the risk score of single index  $j$ ;  $\omega_{3j}$  means the third index weight of the index  $j$ ;  $\omega_{2j}$  means the secondary index weight of the index  $j$ ;  $\omega_{1j}$  means the primary index weight of the index  $j$ .

**Table 3.** Criteria for the comprehensive risk score grade.

Range	$x_{\min} < ESI \leq x_{\min} + 0.25\Delta$	$x_{\min} + 0.25\Delta < ESI \leq x_{\min} + 0.5\Delta$	$x_{\min} + 0.5\Delta < ESI \leq x_{\min} + 0.75\Delta$	$x_{\min} + 0.75\Delta < ESI \leq x_{\max}$
Risk grade	Extremely low-risk	Low-risk	Medium-risk	High-risk

Remarks:  $\Delta = x_{\max} - x_{\min}$ .

## 4. Results and Discussion

### 4.1. Control Unit Division Results

Based on the divided results of the control units in Taihu Basin during the 11th Five-Year Plan, this paper adopts the division method to further improve control unit division in the study area, which takes the country and district administration boundary, automatic monitoring system, drinking water source, basin and water conditions into consideration. After combination, refinement and modification of the boundary, this paper derives 35 control units in the study area. The results of control unit division are shown in Figure 5.

On the premise of having clarified the location of assessment sections and drinking water sources, this paper makes adjustments and improvements on the existing division results of the control unit in the study area. Moreover, it is significant to make sure that each control unit has one control section. Compared with the control unit division results during the 11th Five-Year Plan, the result in this paper is more convenient to the environmental management.

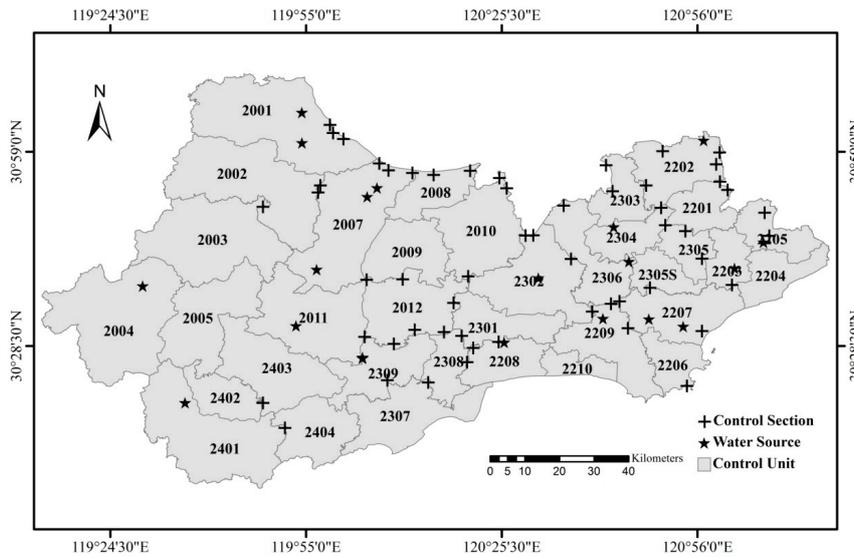


Figure 5. Control unit division results diagram in the study area.

4.2. Rationality Analysis of Control Unit Division Results

The control unit is the area where the main pollution has the prominent influences on the water quality of the control section. Through calculating the influential weight of control unit internal pollution load against control section water quality, the rationality of control unit division could be determined. According to the pollution load materials, the water condition materials, control section information in the study area, the influential weight of control unit internal pollution against control section water quality could be calculated. The calculation results are as shown in Figure 6. Based on the maximizing integrity of the water system, the scale of the divided control unit can be used to reflect the pollution status in the area. According to the calculation results, the influential weight of each control unit internal pollution against control section water quality ranges between 65% and 89%. This implies that the internal pollution source in the control unit is the main influential source of control section water quality. Besides, the control of internal pollution sources could effectively guarantee the improvement of water quality. Among others, the internal rivers of the four control units, with codes as 2004, 2005, 2401 and 2402, all belong to river sources. There does not exist any pollution load outside of the control unit.

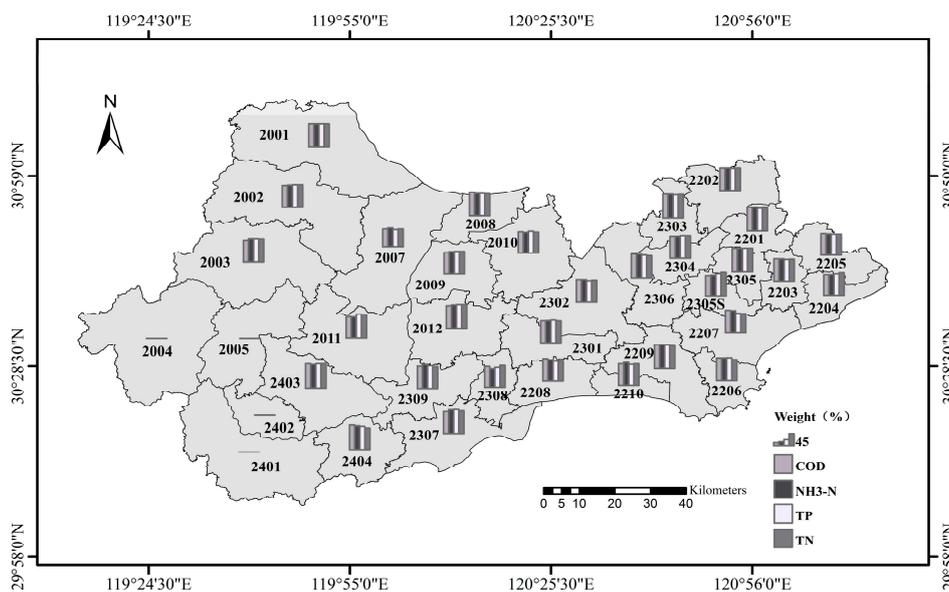


Figure 6. Weight of control unit internal pollution against control section water quality.

The area of control unit after being improved ranges between 112 km<sup>2</sup> and 770 km<sup>2</sup>. Due to the consistency with five-class hydrological unit basin size (163~1013 km<sup>2</sup>), the complete drainage and the pollutant impact weight with in the allowable range, the division of each control unit is basically rational.

#### 4.3. Index Weight Calculation Results

There are no objective index thresholds for the secondary and the primary index weight, and the weight coefficient is determined through AHP. The tertiary indexes of the pressure and state layers are quantitative indexes, and the weight is determined by entropy method. The ecological landscape index and the tertiary indexes of the response layer are qualitative indexes, and the weight is determined relying on the experts. Fifteen questionnaires were collected and all regained, and then validated by consistency test. The questionnaire mainly involved experts in the field of water environment as well as the relevant personnel of the management agency in the study area. The experts need to determine its priorities between every two indexes in the primary index, secondary index and tertiary index, so as to establish the matrix to determine the weight coefficient of each index. The calculation result is shown in Table 4.

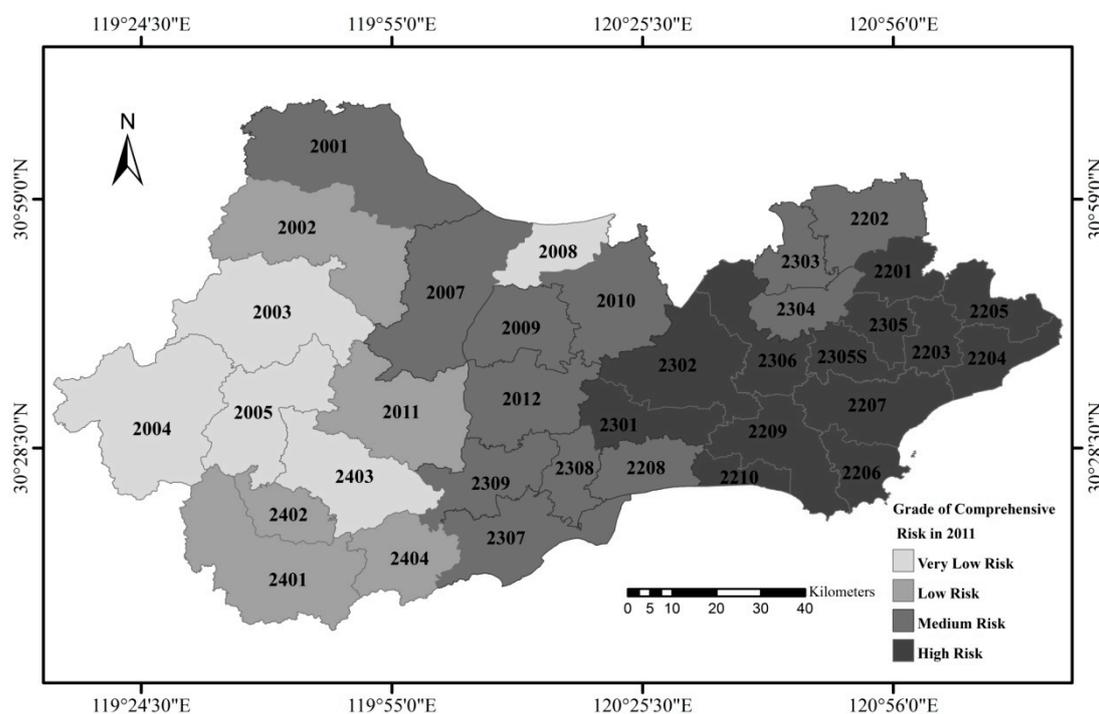
**Table 4.** Index weight coefficient of PSR risk assessment.

Criteria Layer	Primary Weight	Sub-Criteria Layer	Secondary Weight	Index Layer	Tertiary Weight
Pressure	0.35	Internal pressure of the control unit	0.55	Leading industry	0.183
				Inflow amount/environment capacity ratio	0.817
		External pressure of the control unit	0.45	Flux/threshold value ratio	1
State	0.4	Water environment condition of control section	0.6	Section control category	0.166
				COD	0.167
				NH <sub>3</sub> -N	0.167
				TN	0.167
				TP	0.167
Water quality objective regulated by water functional regionalization	0.166				
		Water ecology	0.4	Ecological landscape	1
Response	0.25	Government	1	Execution force of policy and regulation	0.283
				Emergency response ability	0.483
				Public environmental protection consciousness	0.234

#### 4.4. Cumulative Risk Assessment Results

Based on the results of the control unit division, this paper adopts pollution source and the hydrology data of Zhejiang Province environmental statistics in 2011, pollution source data of the Zhejiang Province Yearbook in 2012 (2011 statistics) [32], the water quality data of water environment normal monitoring in 2011, hydrology and water quality statistics data from 55 automatic stations in the study area and the hydrology and water quality data from the water environment mathematical model of the Zhejiang area of Taihu Basin to assess the water environment cumulative risks in the study area. The data of the environment capacity, pollutant flux and threshold value are adopted from the results of the National Water Pollution Control and Treatment Science and Technology Major Project in the Zhejiang area of Taihu Basin during the 12th Five-Year Plan. Pursuant to the above materials, the tertiary indexes of the pressure and response layer in each control unit were scored, and 15 relevant experts give the score to the indexes of ecological landscape index and tertiary indexes of the responding layer. The cumulative risk grading comprehensive score in 35 control units in the study area could be calculated through comprehensive risk assessment method. The range of grading score is varied between 1.277~3.185. Accordingly, there will be 13 high-risk control units, 12 medium-risk

control units, 5 low-risk control units, and 5 extremely low-risk control units. The distribution of control unit cumulative risk grading is as shown in Figure 7.



**Figure 7.** Control unit cumulative risk grading diagram in the Zhejiang area of Taihu Basin in 2011.

According to the cumulative risk grading division results of the control unit, there are 13 high-risk control units mainly distributed in the downstream area of the study area. Besides local pollution discharge, this area also bears the cumulative pollution from the upstream area. As a consequence, the prior control status of this area needs to be concerned. There are 12 medium-risk control units. For most control units, there exist potential pollution risks with various degrees. Therefore, it is necessary to enhance risk monitoring and prevention warning management and effectively prevent the transition to high-risk layer.

#### 4.5. System Integration

With the help of the water environment management platform in the Zhejiang area of Taihu Basin established by DHI Shanghai company Limited during the *12th Five-Year Plan* period, this paper adopted B/S and C/S deployment method [33] and system interconnection technology to insert the results of control units division and the cumulative risk assessment technology system into the existing management platform. The risk grade threshold and the cumulative risk grading scoring method were integrated into this management platform. Making use of the platform function of dynamically updating basic database, the new integrated platform could not only judge but also manifest the real-time cumulative risk grading in the control unit.

According to the risk grading judgment index system, the risk grading judgment function module could demonstrate the assessment area, the index system and index weight. In the front part of the interface, users could select the time period and realize risk assessment results inquiry, presentation and derivation functions. The presentation function takes the control unit as the presentation unit and presents statistics with different colors according to different risk grades. The export function could assess different time steps with identical assessment unit (year, month, day) and identical time steps with different units to export results. The platform structure is shown in Figure 8.

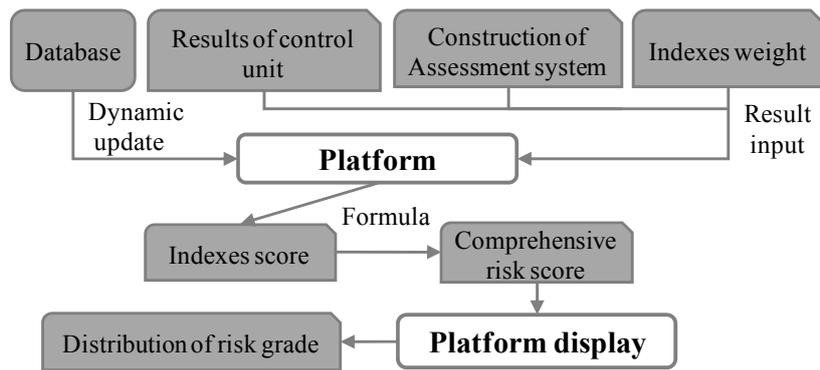


Figure 8. Platform structure.

The cumulative risk assessment technology module of the management platform in the Zhejiang area of Taihu Basin combines the exiting hydrology and water quality statistics from 55 automatic monitoring stations in Zhejiang Province and takes the existing water environment mathematics model in the Zhejiang area of Taihu Basin as a reference, so as to realize the dynamic calculation of cumulative risk assessment. Each type of data is connected with the interface established by the exiting platform. The management platform could satisfy the management requirements of users to exert real-time calculation and presentation functions in the study area and offer policy supports for cumulative risk monitoring warning in the study area. It is also a beneficial attempt in basin digital environmental management.

By way of the dynamic calculation function in the management platform, this paper selects the statistics in 2012 to make cumulative risk assessment. The system automatic calculation and the presentation results are as shown in Figure 9. In comparison with the cumulative risk assessment results in 2011, the number of high-risk control units decreases to nine, which proves that the water environment pollution conditions in 2012 have achieved prominent progress. The high-risk control unit requires a further rational control so as to completely improve the water environmental conditions.

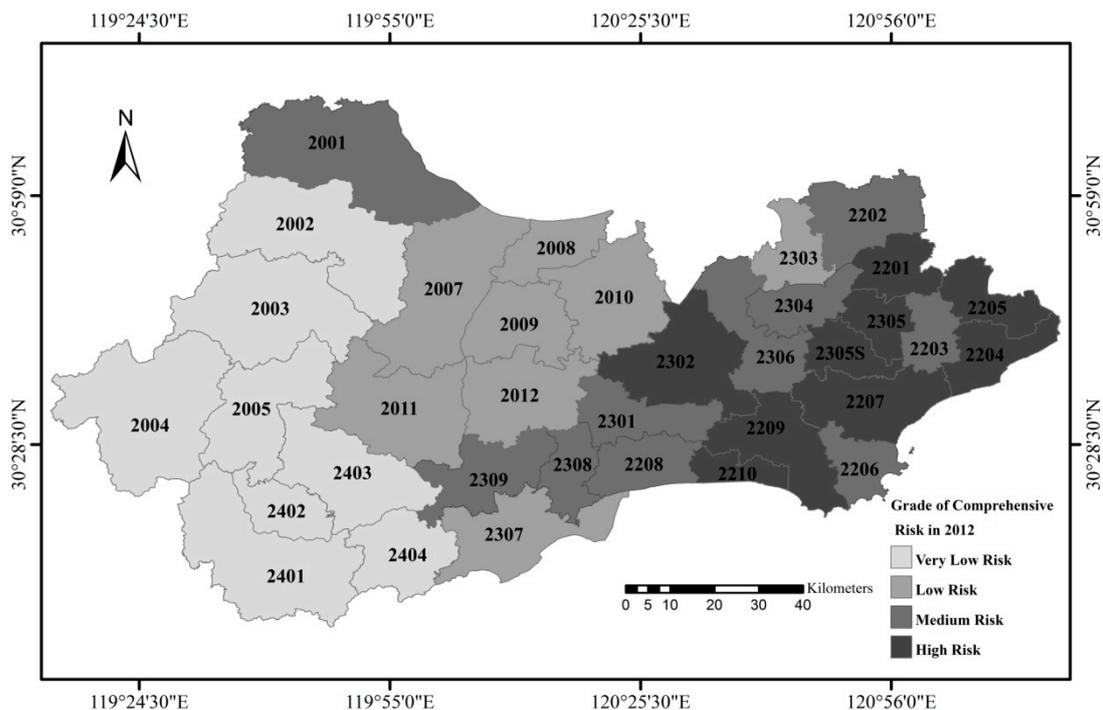


Figure 9. Control unit cumulative risk grading diagram in the Zhejiang Area of Taihubasin in 2012.

## 5. Conclusions

Firstly, the division of control unit regarded as the basic unit of water pollution control has to fully take the river direction and water system integrity characteristics of water systems in the plain river network area into consideration. Based on control unit division methods, this paper divided 35 control units in the Zhejiang area of Taihu Basin with a coverage of 112~770 km<sup>2</sup>. The divided control unit is basically consistent with five-degree division scale in America. The influential weight of control unit internal pollution load against control section water quality ranges between 65% and 89%. Thus, the division results of control units are basically rational.

Secondly, according to the water environmental characteristics in the study area, this paper established a water environment cumulative risk assessment technology system in the Zhejiang area of Taihu Basin. Cumulative risk grading judgment is conducted on 35 control units on the basis of the automatic monitoring data, the model assessment data and the pollution source database in 2011 in the study area, reaching a conclusion that there are 13 high-risk control units, 12 medium-risk control units, 5 low-risk control units and 5 extremely low-risk control units.

There are 13 high-risk control units mainly distributed in the downstream area of the study area. Besides local pollution discharge, this area also bears the cumulative pollution from the upstream area. As a consequence, the prior control units of this area need to be concerned. There are 12 medium-risk control units. For most control units, there exist potential pollution risks with various degrees. Therefore, it is necessary to enhance the risk monitoring and prevention warning management so as to effectively prevent the transition to high-risk control unit.

Thirdly, combine the divided control unit results and water environment cumulative risk assessment technology system with the management platform. By using the database, geographical information system and the visual programming technologies, this platform simplified the binding conditions, the calculation methods and the results analysis into the visual interface, and realized the real-time display of the dynamic calculation results.

In the future when the automatic monitoring system could be applied comprehensively, and the water environment risk grading could be judged according to the retrieval of water environment materials, it is available to effectively prevent the real-time water environment risks in each control unit. This method could be improved as for the cumulative risk assessment in random scope range. It is a beneficial attempt of basin digital environment management.

**Acknowledgments:** This paper is funded by the Natural Science Foundation of Fujian (2016J05096), Educational Scientific Research Projects for Young and Middle-aged Teachers of Fujian (JA15141), National Water Pollution Control and Treatment Science and Technology Major Project (Grant No. 2014ZX07405-002), the National Water Pollution Control and Treatment Science and Technology Major Project (Grant No. 2012ZX07506-006), the Priority Academic Program Development of Jiangsu Higher Education Institutions and the Natural Science Foundation of the Anhui Higher Education Institutions of China (Grant No. KJ2017A465).

**Author Contributions:** Xue Wang carried out the analysis and drafted the manuscript. Xiao Wang, Qi Zhou and Rongrong Xie participated in the manuscript modification. Yong Pang carried out the design of the outline. All authors have read and approved the final manuscript.

**Conflicts of Interest:** The authors declare no conflict of interest.

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