Application of Projection Pursuit Model to Water Resources Carrying Capacity Assessment in Longitudinal Ridge-gorge Region of Yunnan

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Abstract: Water resources carrying capacity (WRCC) assessment is an effective way to evaluate the coordinated development of water resources, economic society and ecological environment, thus, it is significant to study WRCC to realize the harmony among water resources, economy and society in region. In this paper, an index system for evaluating WRCC was constructed from the perspective of water quantity and water quality. Moreover, the projection pursuit technique was applied to evaluate WRCC. Based on the grade division standard of WRCC, the projection function which could reflect the variability of the WRCC was constructed, and genetic algorithm was introduced to optimize the function and seek the optimum projection vector, while the projection pursuit model to evaluation of WRCC was built by the data of the vector. WRCC of the 80 counties in Longitudinal Ridge-gorge Region of Yunnan was evaluated by this model, and the results which accord with the fact were gained. The result showed that WRCC is dynamic with evaluation index value was presented as the logistic curve. The WRCC in research region was good overall, but that in three counties and four counties was already in overload and nearly overload, respectively. Potential of WRCC in mid and western of research region was higher than the other area. The evaluation results were given with continuous real number, which could reveal the temporal-spatial change characteristics of WRCC accurately. Evaluation model of WRCC based on projection pursuit model was practical and feasible for dynamic evaluation of regional WRCC.

1. Introduction

The Longitudinal Ridge-gorge Region (LRGR)¹,² in Southwestern China is an extremely important ecological corridor in the local area and Southeast Asia and is also the China-ASEAN Economic Corridor. Due to its regional feature of "channel-block" and related human activities, the environment in LRGR is complex, and its changes can directly affect the sustainable development of downstream countries with a land totaling 200×104 km² and a population of more than 200 million³. The present research on LRGR mainly focuses on the cross-border ecological security⁴, water vapor⁵, temperature⁶, precipitation⁷, runoff⁸, agriculture⁹, ecology¹⁰, vegetation cover¹¹,¹², land use¹³.
among other spatial and temporal differentiation characteristics of environmental, geographical and human factors and their corresponding causes, but rarely touches upon the regional water resources carrying capacity. Water resources carrying capacity is a comprehensive indicator for evaluating the coordinated development between the water resource, the socio-economic development and ecological environment. An important prerequisite for achieving regional sustainable development is to keep the need for water resource in regional socio-economic development within the scope of its carrying capacity. Therefore, it is of great significance to evaluate the water resources carrying capacity of LGRG in order to safeguard China's cross-border ecological security and promote regional sustainable development.

Since the introduction of concept of water resources carrying capacity by Academician Shi Yafeng in the 1980s, it has been the focus and hotspot of water resources research[15-25]. The empirical formula method, the indicator system evaluation method and the systematic analysis method are the three major methods for studying this topic[17], which are used in research in different regions. Among the above three methods, the indicator evaluation method is the most widely used one. This method conducts comprehensive evaluation of the carrying capacity of water resources by establishing an indicator system and then applying mathematical models. It mainly includes fuzzy comprehensive evaluation method[26], principal component analysis method[27], independent component analysis method[29], gray correlation analysis method[30], and neural network method[31] and so on. The results obtained using the above methods are mostly discrete and semi-quantitative water carrying capacity grades with lower precision[32]. However, the evaluation indicators of the actual carrying capacity are generally continuous real values. The evaluation indicators of capacity values of the same level can differ greatly. Therefore, the discrete grading result of water resources carrying capacity seems inconvenient when it is used in the dynamic monitoring and early warning of water resources carrying capacity, the optimization of regional socio-economic development layout, and the formulation of differentiated control measures of water resources.

Projection Pursuit[33] is a multi-indicator comprehensive problem analysis and evaluation method driven directly by sample data. It has the advantages of high consistency rate between evaluation result and actual situation, presentation of evaluation result using continuous real number, and refined division of the evaluation grades. It has been widely used in the evaluation of resources[34, 35], environment[36, 37], ecology[38] and disaster[39-41]. Therefore, this paper, on the basis of the indicator system and grading standards for water resources carrying capacity evaluation, establishes the Projection Pursuit evaluation model based on the genetic algorithm, in order to make more accurate and intuitive evaluation of the water carrying capacity of LGRG in Yunnan Province. In this way, we can provide more guidance for regional strategic development and planning, and implement the harmonious development concept of “regulate the city, the land, the people, and the production by water”.

2. Materials and Methods

2.1. Materials
The selected materials include: (1) 2015 Water Resources Bulletin of 14 states (cities) in Yunnan Province, including Diqing, Nujiang, Lijiang, Dali, Chuxiong, Kunming, Baoshan, Dehong, Lincang, Pu'er, Yuxi, Honghe, Wenshan and Xishuangbanna; (2) total water use control indicators, target water qualification rate of water function area, COD discharge limit, and NH$_3$-N discharge limit in 2015 in Yunnan Province announced in Opinions of the Yunnan Provincial People's Government on the Implementation of the Strictest Water Resources Management System (Yunnan Provincial People's Government [2012] No. 126); (3) monitoring data of 374 river discharge outlets and 222 water functional areas measured and reorganized by Yunnan Hydrology and Water Resources Bureau in 2015. Among them, a total of 197 water function areas (non-repeated statistics) and 520 water quality monitoring sections are involved in the evaluation.
2.2. Calculation theory of Projection Pursuit Model

Projection Pursuit means to find the optimal reflection of features of the data structure by projecting high-dimensional data into low-dimensional (generally 1~3 dimensional) space, and exploring the characteristics of high-dimensional data by analyzing the projection features of low-dimensional space. In this way, it can effectively deal with complex problems with multiple indicators. The core idea is to analyze the multi-factor indicators related to the problem using Projection Pursuit to obtain the optimal projection eigenvalues reflecting the characteristics of the comprehensive indicator, and then establish the one-to-one correspondence between the projected eigenvalue and the dependent variable, and finally analyze the one-dimensional projection value so as to make a more reasonable classification and evaluation of the sample. The principle is as follows:

Assume there are m indicators k levels for the evaluation of water resources carrying capacity, that is, \( y_i (i = 1, 2, \ldots, k) \). The worse the water resources carrying capacity is, the higher the evaluation level (set the lowest level as 1, and the highest level as k). The evaluation matrix of water resources carrying capacity is \( X_B \). Based on \( X_B \), the generated sample set is \( X_{n\times m} \), \( i = 1, 2, \ldots, m \), \( j = 1, 2, \ldots, n \). In the sample set, \( m \) means the number of indicators in the sample; \( n \) refers to the number of samples, and \( x_{ij} \) means the \( i \)-th indicator value of the \( j \)-th sample. The Establishment of the Projection Pursuit Model for water resources carrying capacity evaluation is to establish a mathematical relationship between \( X_{n\times m} \) and \( y_i \). The specific steps are as follows:

2.2.1. Standardization of sample indicators. The evaluation indicators may be of different types and dimensions. Therefore, it is necessary to normalize the indicator data so as to eliminate the dimensions of each indicator. The evaluation indicators are divided into two types: positive indicators (the larger, the better) and negative indicators (the smaller, the better). The standardization treatment of the two types of indicators is as follows:

Positive indicator (the larger, the better):
\[
x'_i = \left( x_i - \min \{ x_i \} \right) \left( \max \{ x_i \} - \min \{ x_i \} \right)^{-1}
\]

(1)

Negative indicator (the smaller, the better):
\[
x'_i = \left( \max \{ x_i \} - x_i \right) \left( \max \{ x_i \} - \min \{ x_i \} \right)^{-1}
\]

(2)

In the formula, \( x_i \) refers to the data sample value before standardization and \( x'_i \) is the data sample value after standardization.

2.2.2. Construction of projection indicator function. Projection Pursuit means to synthesize the \( m \)-dimensional data \( x'_i \) into one-dimensional projection value \( z_j \) in the direction of \( \bar{a} = (a_1, a_2, \ldots, a_m) \):
\[
z_j = \bar{a} \cdot x'_i = \sum_{i=1}^{m} a_ix'_i
\]

(3)

According to the principle of Projection Pursuit, the projection value \( z_j \) should extract the variation information of \( x'_i \) as much as possible. The dispersion feature of \( z_j \) should have the following two characteristics: (i) the local projection point should be as dense as possible, preferably condensed into several clusters (ii) viewing from a general view, the projection point clusters should scatter as much as possible. The local density function of the projection value \( D_z(\bar{a}) \) and the standard deviation function \( S_z(\bar{a}) \) can be used to respectively represent the two features of \( z_j \). The projection indicator function can be expressed as:
\[
Q_z(\bar{a}) = S_z(\bar{a})D_z(\bar{a})
\]

(4)

In the formula, \( S_z(\bar{a}) \) and \( D_z(\bar{a}) \) only changes with the projection direction \( \bar{a} \), the formula is as
follows:

\[
S_c(a) = \left( \frac{1}{n-1} \sum_{j=1}^{n} (z_j - E(z))^2 \right)^{1/2}
\]

(5)

\[
D_c(a) = \sum_{j=1}^{n} \sum_{k=1}^{n} (R - r_k)f(R - r_k)
\]

(6)

\( E(z) \) is the average value of the projection value \( z_j \); \( r_k = |z_j - z_k| \); \( R \) refers to the window radius of the local density, which can be taken as \( r_{max} + \frac{m}{2} \leq R \leq 2m \); the function \( f(R - r_k) \) is a unit step function:

\[
f(R - r_k) = \begin{cases} 
1 & R - r_k \geq 0 \\
0 & R - r_k < 0 
\end{cases}
\]

(7)

2.2.3. Estimation of optimal projection direction. The \( Q(a) \) value changes with the change of \( \bar{a} \). When the maximum value of \( Q(a) \) is taken, \( \bar{a} \) is the direction that can best reflect the characteristics of the sample data structure, or the optimal projection direction \( \bar{a}_{opt} \). Therefore, the estimation of optimal projection direction is to solve the maximum value of the projection indicator function \( Q(a) \):

\[
\max Q(a) = S_c(a)D_c(a) \quad \text{s.t.} \quad ||\bar{a}|| = 1
\]

(8)

The solution of the maximum value of \( Q(a) \) is a complex nonlinear optimization problem, which is difficult to solve using a conventional method. But the genetic algorithm [42] is proved to be a very simple and effective method.

2.2.4. Evaluation of water resources carrying capacity. After obtaining the optimal projection direction \( \bar{a}_{opt} \), the corresponding projection vector \( \bar{z}_i \) is calculated according to the evaluation grade standard matrix of water resource carrying capacity indicator \( XB \).

\[
\bar{z}_i = \bar{a}_{opt} \cdot XB
\]

(9)

Assume the sample to be evaluated is \( X_y \), the corresponding projection value is \( z_y = \bar{a}_{opt} \cdot X_y \). By analyzing the interval of \( z_y \) in \( \bar{z}_i \), the grade to which the evaluation sample belongs can be obtained.

3. Evaluation indicator and distribution characteristics of water resources carrying capacity

3.1. Construction of evaluation index system

The key to the evaluating water resources carrying capacity is to establish a scientific and reasonable evaluation index system [43], which, however, has not yet been accomplished by the academic community. Considering the importance of the impact on water resources carrying capacity, and following the principles of objectivity, systematicness and accessibility, this paper selects indexes from the perspective of water quantity and water quality. Two water quantity indexes include total water consumption utilization rate (TWCUR) and water resources utilization rate (WRUR). Three water quality indicators include water qualification rate of water function area (WQR), COD over-discharge rate (CODR), and NH3-N over-discharge rate (NH3-N-R). The five indicators are shown in Table 1.
Table 1. The index system for evaluation of water resource carrying capacity

| Index | Equations |
|-------|-----------|
| TWCUR | Comparable water consumption/total water consumption |
| WRUR  | Actually total water consumption/total water resources |
| WQR   | Actually water qualification rate of water function area / target water qualification rate of water function area |
| CODR  | COD loads into river/COD capacity of water function area |
| NH₃-N-R | NH₃-N-R loads into river/NH₃-N-R capacity of water function area |

The indicator of total water use control is a multi-year average value, while the actual regional water consumption varies each year. Therefore, in order to make the above two values comparable, it is necessary to convert the total water consumption in the evaluation year into the multi-year average level according to the regional precipitation frequency, which is called the comparable water consumption. The conversion steps are as follows:

Step 1: Calculate the water conversion coefficient according to the typical frequency. According to Yunnan Water Resources Comprehensive Planning, the water supply amount of each county under the four frequencies of P=25%, P=50%, P=75%, P=95% is W₂₅%, W₅₀%, W₇₅%, and W₉₅%, respectively. Set W₅₀% when P=50% as the multi-year average, and calculate the water conversion factors K₂₅%, K₅₀%, K₇₅%, and K₉₅% according to the following formula.

\[
\begin{align*}
K_{25\%} &= \frac{W_{50\%}}{W_{25\%}} \\
K_{50\%} &= 1 \\
K_{75\%} &= \frac{W_{50\%}}{W_{75\%}} \\
K_{95\%} &= \frac{W_{90\%}}{W_{95\%}}
\end{align*}
\]

(10)

Step 2: Calculate \( K_p \), the water conversion coefficient of the evaluation year based on the interpolation \( p \), the abundance frequency of the evaluation year. The calculation formula is as follows:

\[
K_p = K_{up} + \frac{(K_{up} - K_{dp})}{(up - dp)}(p - dp)
\]

(11)

In the formula, \( dp \) and \( up \) represent the typical frequency of the lower and the upper limit that is the closest to the precipitation frequency in the evaluation year, respectively. \( K_{up} \) and \( K_{dp} \) are the water amount conversion coefficient corresponding to \( dp \) and \( up \).

For regions where the precipitation frequency is less than 25% or greater than 95%, the conversion coefficient \( K_p \) is calculated by linear epitaxy interpolation of its corresponding typical endpoint water conversion coefficient.

Step 3: Calculate the comparable water consumption amount \( \bar{W}_i \) of the evaluation year, which is the product of the total water consumption \( W_i \) and the water volume conversion coefficient \( K_p \):

\[
\bar{W}_i = W_i K_p
\]

(12)

According to the calculated \( \bar{W}_i \) and the calculation formula in Table 1, the total water utilization rate can be obtained.

3.2. Index classification
According to the index classification listed in the frame of Monitoring Warning Mechanisms for
Carrying Capacity of the National Water Resources\textsuperscript{[44]}, the evaluation grade is divided into non-overloading state, critical state, overloading state, and serious overloading state. The division threshold of TWCUR, WQR, CODR, NH$_3$-N-R also follow the literature No 44. Wang Xiqin and Zhang Yuan\textsuperscript{[45]} pointed out through research that the water resources utilization thresholds of the Yangtze River and the Pearl River are 31\% and 32\% respectively. This paper takes the thresholds of the overloading, non-overloading, and serious overloading as 30\%, 20\% and 40\% respectively. The thresholds of evaluation index are showing in Table 2.

| Index  | non-overloading state | critical state | overloading state | serious overloading state |
|--------|-----------------------|----------------|-------------------|--------------------------|
| TWCUR  | < 0.9                 | <1             | <1.2              | ≥1.2                     |
| WRUR   | <20\%                 | <30\%          | <40\%             | ≥40\%                    |
| WQR    | >80\%                 | >60\%          | >40\%             | ≤40\%                    |
| CODR   | <1.1                  | <1.2           | <3                | ≥3                       |
| NH$_3$-N-R | <1.1             | <1.2           | <3                | ≥3                       |

3.3. Distribution characteristics of the evaluation indicator
The spatial distribution of TWCUR in the counties of LRGR in 2015 is shown in Figure 1a, showing that there are a total of 20 counties with the water consumption accounting for 0.9 or more of the total water consumption control indicator in 2015. They are roughly distributed in the shape of two strips along the latitude. One starts from Ximen County in the westernmost of Pu'er City to Luchun County in the westernmost of Honghe City, with a total of 7 counties; the other starts from Linxiang District in the easternmost of Lincang City to Eshan County in the middle of Yuxi City, covering five counties, and the remaining seven counties are scattered in the three counties of Honghe, Chuxiong and Dali.

The WRUR in most areas in LRGR in 2015 is within 10\% (Figure 1b), which is relatively low. The area with relatively high utilization rate is mainly distributed in the central Yunnan Province at the edge of the LRGR with an obvious lack of water, especially in the hinterland and the surrounding counties (cities), where the rate is above 30\%. The rate in Anning County and Jinning County in Kunming City even reaches 50.5\% and 91.8\% respectively.

As shown in Figure 1c, most counties have reached the targeted water qualification rate of water function area in 2015 The counties with WQR less than 0.8 are mainly distributed in the five Provinces of Wenshan, Honghe, Chuxiong, Dali and Lijiang on the edge of the LRGR and the surrounding area.

As shown in Figure 1d, the actual COD loads into river of all counties is within the COD capacity of water function area in 2015, except the Yangbi County and Dali County of Dali Prefecture, Yanshan County, Maguan County, and Wenshan County of Wenshan Prefecture, Yuanyang County and Jinping County of Honghe Prefecture, Simao District, Jiangcheng County of Pu'er City, and Mengla County of Xishuangbanna Prefecture.

The NH$_3$-N over-discharge situation is significantly better than the COD over-discharge situation (Figure 1e). In 2015, there are six counties that exceeded the NH$_3$-N capacity of water function area, namely, Yangbi County of Dali Prefecture, Lufeng County of Chuxiong Prefecture, Wenshan County of Wenshan Prefecture, Simao District and Ninglang Count of Pu'er City, Mengla County of Xishuangbanna Prefecture.
4. Projection Pursuit Model for grading water resources carrying capacity

4.1. Model calculation

Previous studies [36, 37] have shown that insufficient number of sample leads to inaccurate mathematical model. In view of the fact that the accurate data used for water resources carrying capacity evaluation is difficult to obtain, it is necessary to take the boundary value of each grade interval in Table 2 as a sample value, and randomly generate 80 indicator samples to form a total of 320 sample points (including 80 sample points randomly generated within the non-overloading range) as the samples to solve the nearest projection vector. In this way, the algorithm can be more persuasive. The genetic algorithm is used to optimize the projection indicator function, which delivers the maximum projection function of 185.547 and the best projection direction $\hat{a}_{opt} = (0.393, 0.524, 0.276, 0.575, 0.404)$. It can be seen that the water resources utilization rate, COD over-discharge rate, and NH$_3$-N over-discharge rate have a relatively great impact on water resources carrying capacity. The projection eigenvalues of the sample points are calculated according to formula (9), as shown in Table 3.

| Index   | Thresholds 1 | Thresholds 2 | Thresholds 3 |
|---------|--------------|--------------|--------------|
| TWCUR   | 0.9          | 1            | 1.2          |
| WRUR    | 20%          | 30%          | 40%          |
| WQR     | 80%          | 60%          | 40%          |
| CODR    | 1.1          | 1.2          | 3            |
| NH$_3$-N-R | 1.1        | 1.2          | 3            |
| Projection value | 1.7567 | 1.8912 | 3.7296 |

The grade evaluation method based on the empirical grade and the corresponding projection value is established to evaluate the grade to which the sample belongs. The classification of water resources
Table 4. Stability classification based on projection value

| Evaluation Grade     | Non-overloading State | Critical State | Overloading State | Serious Overloading State |
|----------------------|-----------------------|----------------|-------------------|--------------------------|
| **Projection Value** | <1.7567               | <1.8912        | <3.7296           | ≥3.7296                  |

4.2. Evaluation of water resources carrying capacity

The corresponding projection values of the six evaluation indicators of 80 counties in LRGR are calculated according to Formula (3). As shown in Figure 2a, the two high-value areas are distributed in the Jinping Country and Yuanyang Country area of Honghe Prefecture, and Simao District of Pu’er and the Wenshan Country and Maguan Country of Wenshan Prefecture, while the low-value areas are mainly distributed in the counties along the Basins of southwest China and Red River Basins, including Weixi Country of Deqing Prefecture, Mang Country, Luanchuan Country and Ruili Country of Dehong Prefecture, Tengchong Country of Baoshan Prefecture, Zhenkang Country and Genma Country of Pu’er Prefecture, and Xichou Country and Malipo Country of Wenshan Prefecture as well as Xiangyun County in Dali Prefecture.

Based on the projection eigenvalues and the evaluation method (Table 4), the comprehensive evaluation grade of water resources carrying capacity in LRGR in 2015 can be obtained, as shown in Figure 2b. It can be seen that the water resource of 73 counties in LRGR is not overloaded in 2015; four counties, namely, Binchuan County, Jinning County, Maguan County and Simao District are in the critical state; Wenshan County and Yuanyang County are in the overloading state, and Jinping County is in the state of serious overload.

4.3. Evaluation of the potential of water resources carrying capacity

Figure 3 is the scatter diagram of the projection value $Z_j$ of 320 samples and the evaluation index value.
It can be seen that $Z_j$ grows in the shape of S as each index value (normalized) develops: first, $Z_j$ grows slowly, then faster, and then slows down, which is similar to the logistic curve \[46\].

Figure 3. Scatter dots of projection values and evaluation indexes values

Therefore, the change of $Z_j$ with Index$_j$ can be uniformly represented by the logistic curve (the black solid line in Figure 4). This logical curve can be explained as: when the index value is lower than a certain limit, its influence on the water resources carrying capacity status increases slowly; when the index value exceeds a certain limit, its influence decreases; when the index value is between the two limit values, its influence increases rapidly. Since $Z_j$ is a continuous number that monotonically increases with Index$_j$, following the logistic curve, the threshold $T_2$ can be regarded as the maximum water resource carrying capacity of the region, then $T_2 - Z_j$ is the potential of water resources carrying capacity $Q$, which changes with the indicator value in the inverse-S shape (black dotted line in Figure 4).

Figure 4. Logistic curve of WRCC assessment

The potential of water resources capacity in the study area is calculated based on the above and the spatial distribution is shown in Figure 5. It can be seen that the potential of water resources capacity of the central and western regions are higher than that of other regions. The low-value areas are mainly distributed in Wenshan County of Wenshan City, Yuanyang County and Jinping County of Honghe Prefecture, and Simao District of Pu'er City. The high-value areas are mainly located in the west of Baoshan City, the south of Dehong Prefecture, the southwest of Lincang Prefecture, the southwest of Dali Prefecture, the south of Chuxiong Prefecture, the northeast of Honghe Prefecture, and the east of
Wenshan Prefecture. Further analysis finds that these counties with a large carrying capacity are mainly located in the middle and lower reaches of the southwestern rivers in China (including the Nujiang River, the Lancang River and the Irrawaddy River), the upper and lower reaches of the Red River Basin (part of the Panlong River Basin), and the downstream of Pearl River Basin. In addition, most of the counties and cities are in the mainstream of the first-level tributary outlets of the above-mentioned basins, where the water resources are abundant and the natural endowments are good. At the same time, from Figure 5 and Figure 1c, it can be found that the areas with high potential of water resources carrying capacity are all located in the water functional area with a water quality compliance ratio of 0.8 or more (non-overloading area with good water quality). The above analysis shows that the evaluation results of the potential of water resources carrying capacity based on Projection Pursuit are consistent with the actual situation of the region. The evaluation results can provide reference for the layout of the regional development strategy, and guide the future developmental focus to transfer to areas with higher potential of water resources carrying capacity.

4.4. Analysis of result rationality

4.4.1. Analysis of the physical significance of projection eigenvalues. Previous studies [46] show that water resources carrying capacity refers to the strongest support that the water resource after optimized distribution can provide for local socio-economic development during a specific historical development stage, based on predictable technical, economic and social development levels, following the principle of sustainable development, with the condition of maintaining the benign development of the ecology and environment. From the definition, we can see that the regional water resources carrying capacity is mainly affected by the following three aspects: 1) social and economic development pressure on water resource (social economic development level); 2) natural endowment conditions of water resource; 3) water consumption level (technological level). Under the same water resource and consumption conditions, more developed regional social economy requires greater demand of the water resource, causing greater pressure on water resources, thus larger projection eigenvalues. Under the same economic volume and water resource amount, higher water consumption level leads to smaller demand for water, causing less pressure on water resources, thus smaller projection eigenvalues. Under the same conditions of economic volume and water usage level, better water endowment condition leads to less saturation of the regional water resources development, thus smaller projection eigenvalues. Therefore, the projection eigenvalues is positively related to the indicators that characterize the level of socio-economic development and water usage (water quota), and is negatively related to the indicators that characterize resource endowment. Therefore, this paper selects a total of six indicators from three aspects, as shown in Table 5.
Table 5. Impact indexes of WRCC

| Index                                                      | Equations                                                                 |
|------------------------------------------------------------|---------------------------------------------------------------------------|
| GDP per capita (PGDP, yuan person⁻¹)                        | PGDP = GDP / Population                                                  |
| Amount of water resources per capita (WRPC, m³ person⁻¹)   | WRPC = Amount of water resources / Population                             |
| Amount of water resources per mu (WRPM, m³ mu⁻¹)           | WRPM = Amount of water resources / Farmland area                         |
| Per capita domestic water use (PDWU, m³ person⁻¹)         | PDWU = Amount of domestic water use / Population                          |
| GDP water use per 10,000 yuan (GDPWU, m³ (10⁴ yuan)⁻¹)     | GDPWU = Amount of domestic water use / GDP                               |
| Average water use per mu (WUPM, m³ mu⁻¹)                  | WUPM = Amount of irrigation water use / Farmland area                    |

Notes:
- PGDP represents the social and economic development pressure on water resource.
- WRPC and WRPM represent natural endowment conditions of water resource.
- PDWU, GDPWU and WUPM represent water consumption level.

The eigenvalues of the water resources carrying capacity of 80 counties and the scatter diagram of the six indexes are shown in Figure 6. It can be seen that the projection eigenvalue is positively related to GDP per capita (Figure 6a), per capita domestic water use (Figure 6d), and GDP water use per 10,000 yuan. (Figure 6e) and the average water use per mu (Figure 6f), and is negatively related to the amount of water resources per capita (Figure 6b) and the amount of water resources per mu (Figure 6c). Therefore, the physical significance of the projection eigenvalues of water resources carrying capacity evaluation based on Projection Pursuit is reasonable. It should be noted that the projection eigenvalues are not strictly positively (negatively) related to the six indicators, which is mainly because the water resources carrying capacity of a region is under the combined influence of the three types of impact indicators, rather than a single one.

4.4.2. Rationality analysis of the evaluation conclusion. Most of the seven counties with poor water resources carrying capacity are those with a relatively developed economy or a large proportion of agricultural water use. Among them, Wenshan County and Simao District are the capital of Wenshan
and Pu’er City, respectively; Jinning District of Kunming is located in the lower reaches of the Dianchi Lake Basin, which are the most densely populated and economically developed area; Binchuan County and Yuanyang County are typical agricultural counties where agricultural water consumption accounted for 88% and 90% of the total water consumption of the county in 2015, respectively, and regional socio-economic development poses greater stress on water resources. In Yuanyang County and Jinping County, due to the current lack of processing capacity of their urban sewage treatment, COD is greatly over-discharged (five times of the discharge limit). The above analysis shows that the evaluation results of water resources carrying capacity based on the Projection Pursuit model are consistent with the regional objective reality.

5. Conclusion
The evaluation of regional water resources carrying capacity grade is an important foundation for the establishment of a monitoring and early warning mechanism for resource and environmental carrying capacity. This paper comprehensively evaluates the water resources carrying capacity of 80 counties in LRGR of Yunnan Province by adopting Projection Pursuit.

(1) The water resources carrying capacity status changes with each evaluation index following the logistic curve. The water resources carrying status of the research area is relatively good and is in the non-overloading state, except that Binchuan County, Jinning County, Maguan County and Simao District are in the critical state, Wenshan County and Yuanyang County are in an overloading state, and Jinping County is in a state of serious overload.

(2) The potential of water resources carrying capacity in the western part of the study area is roughly higher than that in other parts. Among them, Tengchong County, Mang County, Luanchuan County, Yuma County, Wuyuan County, Mengzi City, Qiubei County, Xiqiao County, Malipo County, and Xiangyun County have the highest carrying capacity, and these 10 counties can further their development to an appropriate extent in the future. Jinping County, Yuanyang County and Wenshan County have the lowest and negative carrying capacity potential, and they shall strengthen water environmental protection to improve their water resources carrying capacity.

(3) The Projection Pursuit Model is used to make a comprehensive evaluation of the objects involving multiple factors and samples based on the characteristics of the sample itself. The evaluation results are presented in the form of continuous numbers, which can reflect the spatial and temporal variability of water resources carrying status more precisely than the traditional comprehensive evaluation method. In addition, Projection Pursuit can avoid human interference and deliver intuitive evaluation results, which make it suitable for the dynamic evaluation of regional water resources carrying capacity.

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