Research on Development Level Measurement and Spatial Differentiation of Small Hydropower in Southern Shaanxi

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Abstract: To understand the development level of small hydropower (SHP) and its spatial differences in Southern Shaanxi, this study takes the cities of Southern Shaanxi as the research object, constructs the measurement index system of the development level of SHP in Southern Shaanxi, establishes a comprehensive measurement model based on the projection pursuit model, and analyzes the spatial differences of the development level of SHP in Southern Shaanxi from two aspects of comprehensive evaluation and sub-dimensional evaluation by means of the visual measurement results of ArcGIS software. The results show that the spatial differentiation of the development level of SHP in Southern Shaanxi is obvious, among which Ankang City is higher than Hanzhong city than Shangluo city. Based on the research results, the paper puts forward some policy suggestions for the development characteristics of SHP in Southern Shaanxi. The research results have certain value for understanding the development status and spatial distribution difference of SHP in Southern Shaanxi, and provide important reference for the future development of SHP in Southern Shaanxi.

1 INTRODUCTION

Under the current standards of China, small hydropower (SHP) refers to hydropower stations with an installed capacity of 50 MW and below, also known as rural hydropower stations, which are renewable energy with significant benefits. China has a large number and wide distribution of SHP, with a development capacity of 128 million KW (Wang et al., 2016). Southern Shaanxi is rich in hydropower resources, and the SHP market is large. As an important water source of the Middle Route Project of South-to-North Water Diversion, Southern Shaanxi attaches great importance to ecological environmental protection, adheres to the positive and orderly development of SHP, and promotes the green development of SHP.

At present, domestic and foreign scholars' research on SHP measurement evaluation and spatial differentiation mainly focus on the relationship between hydropower stations and the external environment and its influence on the external environment. In terms of the measurement and evaluation of SHP, scholars have conducted in-depth research on the impact of SHP on the economy, society, and ecological environment (Prakasam et al., 2021; Zali et al., 2019; Liu et al., 2015; Xia et al., 2019), the evaluation of sustainable development of SHP (Nautiyal and Goel, 2020; Zhang et al., 2019), the benefit evaluation of energy conservation and emission reduction (Ding et al., 2016), and the evaluation of green SHP (Wang et al., 2016; Li et al., 2018). Using the AHP method, fuzzy comprehensive evaluation method, whitening weight function, semi-structured interview survey method, GIS analysis, and other methods, relevant conclusions are obtained, and policy suggestions are put forward based on the research. In terms of spatial differentiation, Qiao H J, Huang Z, and other people take Chinese provincial as the object, using entropy TOPSIS method and coupling coordination model to evaluate the development level of SHP in each province and analyze its spatial pattern evolution (Qiao et al., 2019a; Qiao et al., 2019b), but the relevant research is still less.

Overall, the research on the evaluation of SHP has made some achievements, which lays a good foundation for further deepening the research of SHP.

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However, the research on the measurement of SHP development level and the difference of spatial pattern is relatively less, and the research on the analysis from the perspective of the city is scarcer, and the evaluation method is subjective, which needs to be introduced into the new objective evaluation method. In view of this, on the basis of existing research, this paper takes the cities in Southern Shaanxi as the research object, constructs a comprehensive evaluation index system combined with the actual situation of SHP development in Southern Shaanxi, and introduces the projection pursuit model evaluation method suitable for multi-sample and multi-index evaluation. Through GA algorithm and GIS tools, the development level of SHP in Southern Shaanxi is measured, the current development pattern of SHP in Southern Shaanxi is recognized, and the differences in urban space are studied, the causes of differences are analyzed and targeted policy suggestions are put forward, in order to provide important reference for the follow-up work of SHP in Southern Shaanxi and promote the green development of SHP industry, and provide reference for the development of SHP in other regions.

2 OVERVIEW OF THE STUDY AREA

Southern Shaanxi refers to the southern region of Shaanxi, including Hanzhong City, Ankang City and Shangluo City from west to east. Southern Shaanxi is mostly mountainous, north by Qinling, south by Bashan, Han River from west to east through. Except that Luonan County of Shangluo City is located in the Yellow River Basin, the rest of southern Shaanxi is located in the Yangtze River Basin, accounting for 35.4% of the total area of Shaanxi Province. The average annual rainfall in southern Shaanxi is 894.7 mm, the total water resources is 262.2 billion m^3, and the river network density is generally more than 0.5 km/km^2. The regional situation is shown in Figure 1.

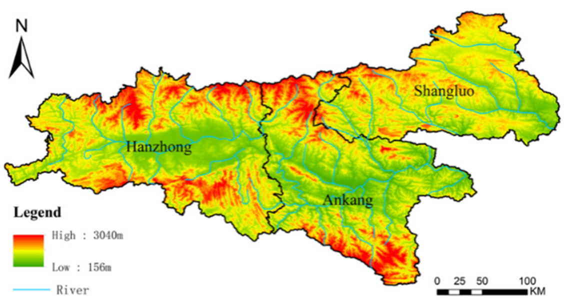

Figure 1: Regional overview of Southern Shaanxi.

The development capacity of SHP resources in Shaanxi Province exceeds 3110 MW, of which 74.3% is in Southern Shaanxi, which is the key development area. By the end of 2019, there are 479 SHP stations operating in Southern Shaanxi. The total installed capacity of 1164.02 MW is shown in Figure 2 and Figure 3. It can be seen from the figure that the number of SHP installations with installed capacity below 0.1 million kilowatts accounts for 60.33% of the total number of SHP in Southern Shaanxi, but power generation and installed capacity account for only 7.28% and 7.49% respectively, which brings great pressure to the standardized management of SHP industry.

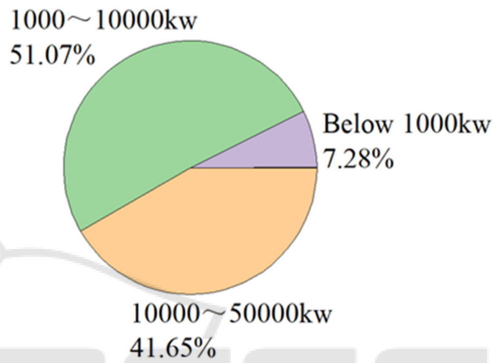

Figure 2: Distribution of SHP generation by installed capacity in Southern Shaanxi, 2019.

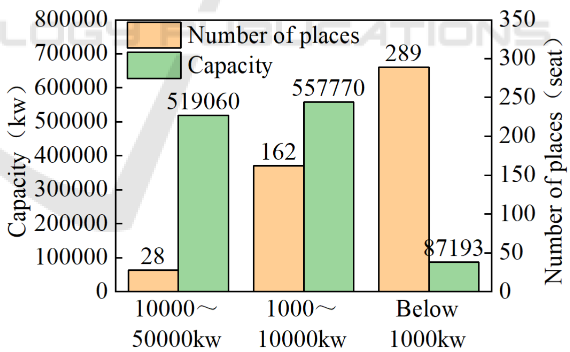

Figure 3: Installation of SHP stations in Southern Shaanxi at the end of 2019.

3 RESEARCH METHODS AND DATA SOURCES

3.1 Research Method

3.1.1 Construction of Index System

The development level of SHP in Southern Shaanxi is essentially a measure of the development status of

SHP in Southern Shaanxi. Its measurement index system should reflect the connotation and description of the development of SHP. Therefore, before selecting the index, it is necessary to analyze and define the elements of the measurement of the development level of SHP. The development level of SHP in Southern Shaanxi represents the development quality of the SHP industry in Southern Shaanxi and is a quantitative judgment of the current development status of SHP in various cities in Southern Shaanxi. This requires that the development of SHP to a higher level must meet the requirements of relatively advanced economy and technology of SHP, a certain scale of development and utilization of SHP, and green and sustainable development. Therefore, this paper believes that the measurement of the development level of SHP should focus on three aspects: technological advancement, development and utilization degree, and green level.

Based on the above considerations, this paper follows the principles of representativeness, comparability, sustainability, and data availability, and combines the actual needs of SHP development, it innovatively measures the development level of SHP in Southern Shaanxi from the three dimensions of technological advancement, development and utilization degree, and green level. Each dimension is divided into three indicators, a total of nine indicators. The indicators are benefit indicators, and the indicator system is shown in table 1.

3.1.2 Construction of Evaluation Model

The projection pursuit model is a high-dimensional data modeling method proposed by Friedman in 1974 (Friedman and Tukey,1974), which can be used for nonlinear and non-normal distribution. Its basic idea is to project high-dimensional data along a certain direction to low-dimensional space, explore the inherent law of data, and have certain advantages in evaluation (Xiong and Luo,2016). It is widely used in water quality evaluation, bearing capacity evaluation, performance evaluation, and other research. Common algorithms include the GA algorithm and PSO algorithm (Zhao et al., 2020). In this paper, the projection pursuit model is introduced into the measurement of the development level of SHP to make the evaluation results more objective and reasonable.

Step 1-Standardization of index data. To eliminate the influence of dimension and order of magnitude on the evaluation results, the min-max standardized processing method is used to dimensionless the index data. The indexes in this paper are all benefit indexes, and the calculation formula is:

$$X_{ij} = \frac{X'_{ij} - \min\{X_j\}}{\max\{X_j\} - \min\{X_j\}} \tag{1}$$

In this formula: X'_{ij} is the original data for the i region, the j index, $\min\{X_j\}$ and $\max\{X_j\}$ represent the minimum and maximum original values of the j data, respectively. X_{ij} is the value of the i region and the j index standardized.

Step 2-Determine the projection value. Set direction vector $a=\{a_{(1)}, a_{(2)}, \ldots, a_{(j)}\}$, a_j is the weight of index j, project X_{ij} to a vector, get the projection value:

$$Z_{(i)} = \sum_{j=1}^{n} a_{(j)} X_{ij} \tag{2}$$

In this formula: $Z_{(i)}$ is the projection value for the i region, $a_{(j)}$ The weight value for indicator j of the direction vector.

Step 3-Construct projection objective function:

$$Q_{(a)} = S_z \cdot D_z \tag{3}$$

$$S_z = \left(\frac{\sum_{i=1}^{m} (Z_{(i)} - \overline{Z})^2}{m-1} \right)^{1/2} \tag{4}$$

$$D_z = \sum_{i=1}^{m} \sum_{p=1}^{m} \left(R - r(i,p)) \cdot f(R - r(i,p)) \right) \tag{5}$$

In this formula: S_z is the standard deviation of the projection value $Z_{(i)}$. D_z is the local density of $Z_{(i)}$. $\overline{Z}$ is the average projection value. $r_{(i,p)}$ is the distance between samples, $r_{(i,p)} = |Z_{(i)} - Z_{(p)}|$. R is the radius of the local density window, which is generally $0.1S_z$, $f_{(R-r(i,p))}$ is a unit order function, when $R \geq r_{(i,p)}$ takes 1, otherwise, take 0.

Step 4-Construction of fitness function. Optimize the projection index function, construct the fitness function $\max Q_{(a)}$, the formula is:

$$\max Q_{(a)} = S_z \cdot D_z \tag{6}$$

$$s.t. \sum_{j=1}^{n} a_{(j)}^2 = 1 \tag{7}$$

Step 5-Function solution. The traditional method is difficult to solve such complex nonlinear optimization problems. Therefore, this paper uses the GA algorithm to obtain the optimal projection vector a^*, which is substituted into Equation (2) to obtain $z^*_{(i)}$. The larger the value is, the higher the development level of SHP in the region is.

Step 6-Classification of evaluations. In this paper, the Mean-Standard Deviation Method is used to divide the evaluation level (Cui et al., 2016; Wang, 2017). The specific classification standard is shown in table 2.

Table 1: Measurement Index System of SHP Development Level in Southern Shaanxi.

Goal layer	Criterion layer	Indicator layer	Unit	Content	Implication	Maximum	Minimum	Weight $a_{(j)}$
Development Level of SHP in Southern Shaanxi	Technical advancement	Annual utilization hours (X_1)	hour	The quotient of annual generating capacity and average installed capacity of SHP in the region is an important index to measure the utilization degree of SHP equipment	Reflecting the efficiency of SHP utilization	3146	1910	0.2803
		The proportion of technical personnel (X_2)	%	The ratio of persons with the technical post or above (including engineering, economic) or technical secondary school or above to the total number of employees in the SHP industry in the region	Reflecting the Specialization Degree of SHP Operation Management	45.22%	25.51%	0.4435
		Industry per capita value creation (X_3)	CNY 10000/ person	Revenue per capita generated by SHP industry in the region	Reflecting the advanced level of SHP technology and economy	31.50	6.98	0.2783
	Developmental and utilization degree	Installed capacity (X_4)	kw	The total capacity of all SHP units in the area	Reflecting the scale of SHP development	539517	102391	0.2916
		Exploitation rate (X_5)	%	The ratio of developed to exploitable SHP in the region	Reflecting the degree of SHP development	61.89%	28.62%	0.1399
		Investment completed this year (X_6)	million yuan	Amount of investment actually completed in the year of SHP projects in the region	Reflecting the strength of SHP development	21654	4630	0.4688
	Green level	Green SHP creation number (X_7)	seat	Total number of SHP in the region that received green SHP titles by the end of 2019	Reflecting the Green Development Level of SHP	31	0	0.4678
		Substitution effect (X_8)	t/kw	Energy Saving and Emission Reduction Capability of SHP Replacing Thermal Power in the Area	Reflecting the Contribution Ability of SHP to Ecological Environment	96.57	58.64	0.1973
		Social contribution (X_9)	%	The ratio of total annual taxes paid by SHP industry to total annual revenue from electricity generation and sale	Reflecting the contribution of SHP to economic society	5.87%	4.30%	0.2553

Table 2: The standard for Classification of SHP Development Levels.

Comprehensive evaluation index	$[\bar{Z}+S_Z, \infty)$	$[\bar{Z}, \bar{Z}+S_Z)$	$[\bar{Z}-S_Z, \bar{Z})$	$[0, \bar{Z}-S_Z)$
Level	I	II	III	IV

3.2 Data Sources

In this paper, the research data are mainly derived from the annual statistical data of rural hydropower of Shaanxi Province in 2019, some of which are from the series and reports of "*Annual Development Report of Small Hydropower Industry in Shaanxi Province 2019*" and "*Design and Construction of Small Hydropower Station in Shaanxi Province*".

4 RESULTS AND ANALYSIS

4.1 Evaluation of SHP Development Level

4.1.1 Model Solving

The index data of the cities in Southern Shaanxi were collected and sorted. The index data were standardized by formula (1). MATLAB2020a software was used to solve the fitness function by GA algorithm. The initial population was set to 400, the maximum iteration number was set to 100, and the crossover and mutation probability was 0.5. The weight value of each index $a_{(j)}$ (see table 1) and the scores of each region in three dimensions were obtained, and then the projection value $Z_{(i)}$ was determined. The specific results are shown in figure 4.

4.1.2 Classification of Evaluations

According to the grading standards listed in Table 2, the grading of development level is determined. At the same time, the levels of technological advancement, development and utilization degree, and green level are divided according to the proportion of weight. The specific grading standards are shown in Table 3. According to the grading standards, the development level of SHP in the cities of Southern Shaanxi is determined, and the results are shown in Figure 5.

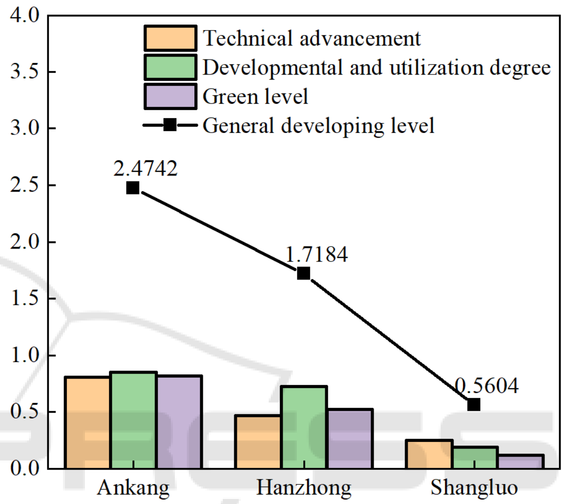

Figure 4: Measurement results of SHP development level in Southern Shaanxi.

4.2 Spatial Variation Analysis

According to the results shown in Table 3, Figure 4, and Figure 5, the differences in the development level of SHP in different cities of Southern Shaanxi are analyzed from the perspectives of comprehensive evaluation and sub-dimensional evaluation.

Table 3: Classification standard of SHP development level measurement in Southern Shaanxi.

Level	Value ranges			
	General developing level	Technical advancement	Developmental and utilization degree	Green level
I	[2.5482,∞)	[0.9046,∞)	[0.8126,∞)	[0.8310,∞)
II	[1.5843,2.5482)	[0.5624,0.9046)	[0.5052,0.8126)	[0.5166,0.8310)
III	[0.6204,1.5843)	[0.2202,0.5624)	[0.1978,0.5052)	[0.2023,0.5166)
IV	[0,0.6204)	[0,0.2202)	[0,0.1978)	[0,0.2023)

(a) General developing level.

(b) Technical advancement.

(c) Developmental and utilization degree.

(d) Green level.

Figure 5: Evaluation grade results of SHP development level measurement in Southern Shaanxi.

4.2.1 Comprehensive Evaluation Result

There are obvious differences in the development level of SHP in Southern Shaanxi. The maximum difference of projection values in each city is nearly 5 times. Ankang City is higher than Hanzhong City and Shangluo City. Among them:

The projection value of Ankang City is 2.4742, ranking first among the three. The overall development level of SHP is in level II, but it is very close to the level I threshold. On the one hand, Ankang City reasonably plans the development and utilization of SHP and attaches great importance to the comprehensive development of SHP, which is ahead of Hanzhong City and Shangluo City in all aspects. On the other hand, due to the advanced technology and green level remains to be improved, so the overall development level of SHP failed to enter the I level.

The projection value of Hanzhong City is 1.7184, ranking the second among the three. The overall development level of SHP is at level II, but it is close to the level III threshold. On the one hand, Hanzhong City is rich in hydropower resources, has a large amount of development, and has a high degree of development and utilization and green level, which promotes the development of SHP. On the other hand, the technical level of SHP in Hanzhong City is relatively backward, which limits the development of SHP to some extent.

The projection value of Shangluo City is 0.5604, ranking the last among the three. The overall development level of SHP is at level IV, but it is very close to the level III threshold. This is mainly because Shangluo City is relatively poor in water resources, low in development, and relatively small in SHP market, which is difficult to achieve comprehensive development, leading to a low overall development level.

4.2.2 Sub-Dimensional Evaluation Results

This part will analyze the measurement results of SHP development level in Southern Shaanxi from three dimensions of technological advancement, development and utilization degree, and green level.

From the perspective of technological advancement, the projection value of Ankang City is 0.8075, which is at level II and close to level I, indicating that the level of SHP technology management in Ankang City is high, and the technological advantages are obvious. It is mainly manifested in the good operation and management of SHP, high utilization rate, high degree of specialization, considerable economic benefits, and the formation of a virtuous circle, which continuously promotes the progress of SHP technology. The projection values of Hanzhong City and Shangluo City are 0.4699 and 0.2491, respectively, which are in grade III, indicating that the technical level of SHP is relatively backward, the operation efficiency is low, and the operation benefit is low. It is urgent to improve the technical progress and pay more attention to the operation and management of SHP.

From the perspective of the developmental and utilization degree, the projection value of Ankang City is 0.8513, which is in level I. The scale of SHP installations is large, and the development rate is high. In recent years, SHP has been actively developed, and the investment completed in 2019 is also high, which can be located at the level of level I. The projection value of Hanzhong City is 0.7236, which is in level II. Although the capacity of SHP and SHP installations in Hanzhong City is in the first place and the annual investment is also high, the overall development rate is relatively low, so the overall development and utilization degree still has great room for improvement. The projection value of Shangluo City is 0.1899, which is at level IV. Shangluo City is limited by natural conditions, geographical location, market society and other factors, resulting in a relatively low degree of development and utilization of SHP. Whether from SHP scale, development rate or annual investment, it is relatively backward.

From the perspective of green level, the projection values of Ankang City and Hanzhong City are 0.8153 and 0.5250, respectively, which are in level II. Although both of them are at the same level, there is still a big gap. The projection value of Ankang City is very close to level I, while the projection value of Hanzhong City is very close to level III. This is mainly due to the positive response of Ankang City to the policy call. By the end of 2019, the number of green SHP creation ranks first in the province, and the scale of SHP development is large, the benefit of energy conservation and emission reduction is huge, which has an important contribution to regional economic and social development. The number of green SHP creation and social contribution rate in Hanzhong City are second only to Ankang City, but the substitution effect is not high. The projection value of Shangluo City is 0.1214, which is at level IV. The green development degree of SHP is low, and there is still great room for improvement in the substitution effect and social contribution rate. It is urgent to improve the green level of SHP and realize the transformation and upgrading development.

5 CONCLUSIONS

Taking Southern Shaanxi as the research object, this paper selects nine indicators to construct the development index system of SHP from three dimensions of technological advancement, development and utilization degree and green level. The projection pursuit model is used to measure the development level of SHP in Southern Shaanxi, and ArcGIS10.6 software is used to analyze its spatial differentiation. The main conclusions are as follows:

From the perspective of comprehensive evaluation results, the spatial differentiation of SHP development level in southern Shaanxi is obvious, and Ankang City is higher than Hanzhong City and Shangluo City. The projection values of Ankang City and Shangluo City are 2.4742 and 1.7184, respectively, and the overall development level of SHP is at level II. The projection value of Shangluo City is 0.5604, and the overall development level of SHP is at level IV.

From the results of sub-dimensional evaluation, the spatial differentiation of cities is still obvious. In terms of technological advancement, the projection value of Ankang City is 0.8075, which is at level II. The projection values of Hanzhong City and Shangluo City are 0.4699 and 0.2491, respectively, which is at level III. In terms of the degree of development and utilization, the projection value of Ankang City is 0.8513, which is at level I, the projection value of Hanzhong City is 0.7236, which is at level II, and the projection value of Shangluo City is 0.1899, which is at level IV. In terms of green level, the projection values of Ankang City and Hanzhong City were 0.8153 and 05250, respectively, which were in level II, and the projection value of Shangluo City was 0.1214, which was in level IV.

According to the analysis results, policy suggestions are put forward, one is to strengthen operation management, improve utilization efficiency, and enhance the modernization level of SHP in Southern Shaanxi. The second is to improve the development plan, make rational use of hydropower resources, and properly handle the relationship between SHP stock and increment. The third is to strengthen supervision, accelerate transformation and upgrading, and establish a long-term mechanism for the green development of SHP. Four is to adjust measures to local conditions, positioning, promote the coordinated development of SHP areas.

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