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Water Poverty in Rural Communities of Arid Areas in China

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Abstract: For developing countries, an adequate domestic water supply is conventionally assessed based on the proportion of communities that are covered by improved water sources. However, it is difficult to evaluate water poverty accurately, as it is multidimensional. For this reason, this paper used the Water Poverty Index (WPI) to measure water poverty in rural communities of arid areas in China. This study also uses the Least Square Error (LSE) model to analyze the influencing factors of water poverty. Based on the WPI and LSE, the results showed that the rural communities of Sheshu, Fanyao, Dongcao, Qiaodi, and Gouershang (listed in order of priority of need for intervention) are in a water poverty situation. In rural communities with high water poverty, the suggested priority order for the study was environment, capacity, use, resources, and access, with the environmental factor needing to be improved. The results are useful for prioritizing areas and identifying the extent of the need for policy intervention on different scales. The research findings are intended to complement the evaluation of water poverty and to provide a strategy for regional water resources management to relieve water poverty.

Keywords: water poverty; least square error model; arid rural community; water resources management

1. Introduction

Water, a basic human resource, is indispensable to human life and economic development [1]. According to the World Health Organization, approximately 1.2 billion people lack access to safe drinking water, and a third of the world population faces water shortages [2]. In addition, water resources are vital natural resources that form the lifeblood of agricultural production. In the twenty-first century, water shortages are likely to exceed the amount necessary for farmland, which is one of the important factors restricting the development of agriculture, thus endangering economic growth. Worldwide water shortages and water conflict make water the key factor in the production and promotion of livelihood, and water shortages caused by poverty are both increasing and gaining worldwide attention. A lack of supply and demand of water resources is reflected in two ways. The first is traditional water shortage, which refers to the lack of available water in nature and describes water quality as well as the spatial-temporal distribution of water resources that cannot meet the needs of production, life, and ecological systems [3]. The second is to consider the dominance of human activities, and to expand water resources into the socio-economic sphere: some people lack the ability or right to access water [4]. Water resource shortages have been testified as having impacts on health, education, land, gender, social inclusion, and income/consumption [5] in many developing countries, on urban [6], rural [7,8], and basin [9,10] scales.

In this context, several efforts have been implemented following various theories to evaluate the situation of water resource shortages at various scales. Swedish hydrologist Mark Falkenberg proposed that the annual per capita water resources for a country or region can be determined by the water resources supply and demand based on a variable standard. According to this standard, the Hydrological Water Stress Index (HWSI) marked the beginning of water poverty research, but it failed to consider countries or regions, and economic ability when adjusting scarce water resources in a social system [11]. To improve the HWSI, German scholar Leif Ohlsson introduced the Human Development Index (HDI) to reduce its weaknesses. The HDI uses average life expectancy, adult literacy, education level, and parameters such as per capita gross domestic product; there is a connection between water resources utilization and management, even if the latter does not reflect other human activities [12]. In addition, the Relative Water Stress Index (RWSI) computes the ratio of total water demand (from the agricultural, industrial, and domestic sectors) to river discharge (representing renewable water supply); however, this method also does not take into account the societal capacity to address water stress or reflect the mutual relationship between humans and their environment [13]. Traditional water resource evaluation methods are limited to water resources systems and do not examine the links between water, society, economic structures, and the environment [14]. These methods evaluate water quality and quantity in isolation, and thus artificially sever these links and do not reflect the importance of water resources to economic development. With the rapid development of a national economy, the importance of water resources keeps growing; therefore, the importance of methods used to evaluate water resources in the development of a national economy is particularly urgent and is also a difficult problem to resolve. Therefore, solving the water resources issue on multiple scales requires a multidimensional perspective. Caroline Sullivan proposed the Water Poverty Index (WPI) to evaluate the degree of relative water shortages between countries and regions; the index also reflects social and economic factors, especially those related to water resources and water supply facilities, capacity, efficiency, and environmental quality [4]. The index creates an understanding and a relatively unique research perspective to solve water resource shortage issues; the research results provide a theoretical basis for integrated water resources management and, through integrated management, the achievement of harmonious coexistence between our species and water [15,16].

Although scholars agree on the advantages of the WPI, it has some weaknesses that need to be addressed, including the weighting definition among variables, the single evaluation method, and the fact that the research scale is mainly macroscopical. The ambiguity of the weighting definition among the variables can lead to inaccuracy and inefficient explanations. A single evaluation method may not effectively explain temporal change, spatial variation, and the main influencing factors of water poverty. Moreover, the current research mainly focuses on the macro scale, that is, whole countries, provinces, and basins. There have only been a few studies on the micro scale. Research on the macro scale can provide a policy reference for decision makers, however, on the micro scale, it is easier to master the real data and materials, and to discover problems from the data. To summarize, furthering our understanding of local water resource shortage is a necessary task with several important applications. First, it will strengthen the design and planning of services, enabling providers to better target those most in need, increasing scheme reliability, and thus maximizing the benefits derived from sector investments. Second, assigning a specific weight to the index will help improve the reliability of the results. Third, using a dual model to evaluate water resource shortages can improve the accuracy of the results. Finally, in arid areas such as Shaanxi, which are beset by water poverty, there is an urgent need to better understand the drivers of water poverty, and to identify drought preparedness measures that would protect livelihoods before lives are threatened. The importance of investing in water for drought preparedness is recognized, but planners lack the data and analytical tools to identify and target the locations, populations and factor where intervention is most important.

This study poses the following questions: what water poverty types are used by communities in dry areas, and for which purposes? Which factors are most important? How do households cope when access to water becomes difficult? Which measure of rural water poverty is most appropriate in the study area? What causes this distribution? There are deeper reasons for the differences between water resources, irrigation facilities, and natural conditions, such as species planting structure and economic development level.

The objective of this paper was based on the Shaanxi rural community water poverty measure, which analyzes the regional differences in water poverty, and the rural water influence, which analyses the poverty-related factors influencing the rural water supply. Based on this background, the increase in Shaanxi rural water poverty corresponds to policy suggestions and provides a reference for governmental decision making. We believe that the method presented in this article will serve as a valuable reference for water resources studies in other countries. The paper is organized as follows: the basic circumstances of the study area are introduced in Section 2, the structure of the WPI is described, analysis using the LSE model is presented, and the construction of an indicator system and the detailed methods and weight methods are introduced in Section 3, the water poverty situation and the main findings on the spatial differences of the water poverty of rural communities in arid areas in China are discussed in Section 4, and finally, a summary is provided and some conclusions are highlighted in Section 5.

2. Study Area

Shaanxi is located in the hinterlands of Eurasia. The drought there is serious, precipitation is rare, and water shortage is severe. Shaanxi occupies a narrow north–south strip of land that is influenced by polar air masses and tropical air masses that form a continental monsoon climate. The arid–semiarid climate and surface runoff result in a scarcity of water resources in the province. Its total number of water resources is 442 billion m^3, with an average of 850 m^3 per capita. This is 45.9% of the national average, and 36% of the world average. In particular, the Guangzhong Plain has 81.1 million acres of irrigated land which is not only an important guarantee of food supply, but also an important basis for the coordinated and healthy development of the social economy and ecological system. For the entire Shaanxi province, the Guanzhong Plain constitutes 59.7% of the population, 51.8% of the land, 72.7% of the industrial and agricultural output value, and 86.6% of the farmland irrigation area. However, the water resources total only 7.8 billion m^3, and the per capita water resources are only 380 m^3, so the absolute lack of 500 m^3 for each line meets the international standard of lower than 120 m^3. In this study, 750 households from five villages were selected in the Jingyang County, and all the data came from farmers and the government. (Figure 1). Jingyang is located in the central plain, which is 27 kilometrers wide and 37 km long, covering a total area of 780 km^2. Jingyang has 4.06 million acres of arable land and a warm temperate continental monsoon climate, with four seasons of cold, dry and clear weather. The annual average temperature is 13 °C: in the cold winter (January), the average temperature is −20.8 °C, and in the hottest part of the summer (July), the average temperature is 41.4 °C. Average annual rainfall is 548.7 mm, with a maximum precipitation of 829.7 mm and a minimum of 349.2 mm. The total surface water resources total 19.233 billion m^3. In 2016, the Jingyang County regional GDP totaled 2.45 billion dollars, and the agricultural added value was 69.88 million dollars. In 2016, the Jingyang county local fiscal expenditures were 37.27 million dollars, which represented an increase of 13% when compared to 2015; these expenditures included science and technology, education, culture, sports, media, health care, family planning, social security, and employment priority spending, which amounted to 26.73 million dollars, accounting for 71.7% of the financial expenditures. By the end of 2016, there were 537,959 people in Jingyang. Among them, the agricultural population was 489,913, accounting for 91%, while the per capita net income of farmers was only $1644 per year). Therefore, based on the water resources concept, the influence and the role of the social economy and the environment—through the comprehensive evaluation and research of water resources, the social economy, and the environment—help us to understand the degree of water resources to obtain a further comprehensive and objective analysis of the internal causes of water poverty, so that options for water poverty alleviation with valuable policy recommendations can be provided.

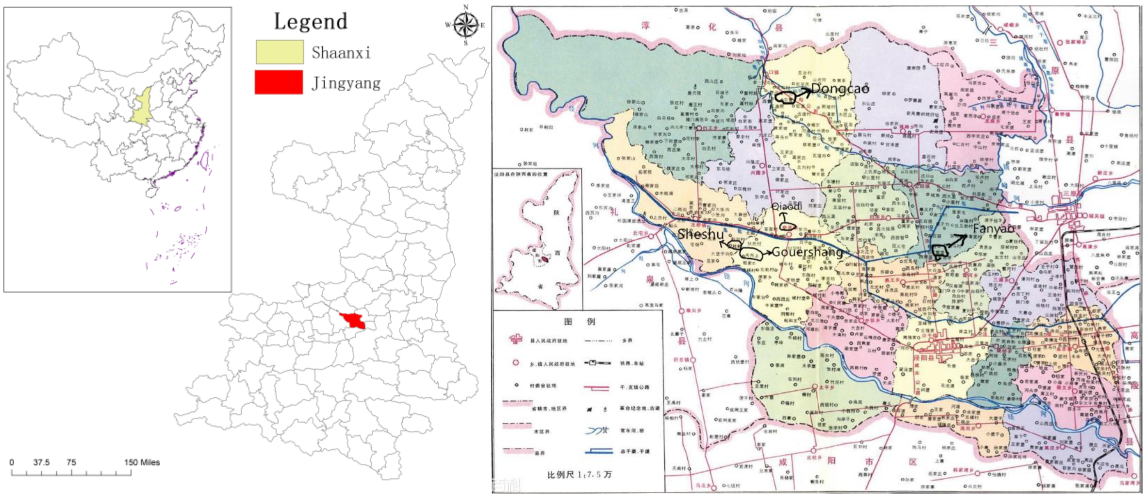

Figure 1. Study area in arid China.

3. Methodology

3.1. The Water Poverty Index

The methodology adopted in this study is based on the Water Poverty Index (WPI) [4,15,16], which evaluates the extent of water shortage using five components: Resources (R), Access (A), Capacity (C), Use (U), and Environment (E). Resources indicate the physical availability and reliability of ground water and surface water. Access is the prevalence of tap water and irrigation; this component accounts for the demand of water for basic functions as well as for agriculture and sanitation, and reflects the extent of the public's proximity to clean and safe water. Capacity refers to water management ability and is based on aspects such as the education, health, and financial situation of the population. This component reflects the influence of one's socioeconomic status on water resources. Use denotes water use efficiency in the domestic, industrial and agriculture sectors. Finally, environment reflects the environmental situation as related to water resources management, including the potential pressure of the ecotope on water quality [10,17].

If the WPI is applied to evaluate water resources in rural China, specific conditions should be considered when choosing and weighting indicators. For the purposes of this research, firstly, rural water resources allocation rights were taken into account within the resource component. Secondly, access includes not only production, living water, and other water supply facilities, but also considered the facilities' level of drainage and sewage treatment conditions. Thirdly, capacity included indicators that reflect the utilization of government support, household water consumption, water intake capacity, and people's water-saving consciousness. The environmental component was applied to environmental protection indicators, enriching the original indicators system. Finally, the use component comprehensively evaluated the use of water resources and refined it with indicators of domestic use, agricultural water use, and water use efficiency. The five WPI components were set to the same weight, as shown in the following equation:

$$WPI = r \times Resource + a \times Access + c \times Capacity + u \times Use + e \times Environment.$$

3.2. LSE Model

The Least Square Error (LSE) method, also known as Weaver's Combination Index, was first put forward by the American geographer John C. Weaver and has been applied successfully in Chinese agriculture [18]. The Weaver index determines the best number of elements for characterizing a system by minimizing the variance (LSE), by comparing the actual distribution to an ideal uniform distribution for different choices of numbers of elements, selecting the number of elements, which minimizes the

LSE, characterizes the optimal combination. It has significant advantages, such as a clear analysis of the combination of elements, an easy explanation, and strong operability. Variance reflects the sample data x_i around the average of changes $\overline{x}$. When close to the average, variance values are smaller, indicating data dispersion. This study used the LSE method to analyze the driving factors responsible for different types of water poverty as well as for spatial differences.

The formula is as follows:

$$S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2$$

where S^2 represents LSE (variance); and n represents sample size (number of elements compared). x_i represents actual sample data (as proportion); and $\overline{x}$ represents the mean for the sample size.

3.3. Indicators

The choice of indicators within these five aspects was not simply drawn from the WPI routine index system, but also reflected the specific situation in arid China's rural areas (Table 1).

3.3.1. Resources

With regard to resources, the indicators reflect the current state or trend of water resources; in addition, the consequences of the interaction of physical or chemical characteristics can be measured. The amount of surface and groundwater that is currently available in a given region is identified [19]. Rainfall (R1) reflects the fact that more rainfall increases the reliability of water resources and translates to more surface water and groundwater recharge [20]. Water resources (R2) reflects the water availability and emphasizes the comparative advantage provided by available water resources in the region [20]. Water resources per capita can comprehensively reflect the water resource conditions for regional development. For a country and region, water resources per capita can be a measure of fresh water scarcity. Therefore, per capita water resources is the most representative index of water resources in the region, and is an indicator of the degree of water shortage.

3.3.2. Access

With regard to access, the indicators reflect the extent to which farmers have access to agricultural and domestic water resources in the region. Access reflects the ease of access to water for human use, including drinking, cooking, as well as agricultural and non-agricultural use. Adequate access to water and sanitation facilitates encourages better hygiene and sanitary conditions, which are necessary (but not sufficient) for the elimination of extreme poverty [21]. Access refers to a population with reasonable access to an adequate amount of safe drinking water and sanitation for better health and well-being [22,23]. The number of reservoirs (A1) reflects the significance of adequate access to domestic water, which leads to decreased time spent on water collection and better health [17]. Water-saving facilities (A2) reflects the actual water-saving capacity of the facilities in the region. In the process of our field investigation, we found that most of the water-saving facilities in the study area were covered by mulch. Mulch improves the ground temperature, increases water and soil conservation, protects fertilizer to improve its effects, destroys the grass, prevents diseases and pests, decreases droughts, improves the surface condition of fields, and provides many functions, including sanitary ones. For newly unearthed seedlings, mulch has the effect of protecting the roots. Actual irrigation capacity (A3) is the significance of adequate access to agricultural water, which leads to decreased time spent on water collection, and better production.

Table 1. Details of the WPI (Water Poverty Index) components, indicators, and references.

Component	Indicator	Relation with Water Poverty	References
Resources (0.2)	Rainfall (R1) +	High R1—Less water poverty	[24]
	Per capita annual rural water resources (+) (R2) +	High R2—Less water poverty	[24]
Access (0.2)	Numbers of reservoirs (A1) +	High A1—Less water poverty	[8]
	Water-saving facilities (A2) +	High A2—Less water poverty	[8]
	Actual irrigation capacity (A3) +	High A3—Less water poverty	[24]
Capacity (0.2)	Per capita annual rural gross domestic product (C1) +	High C1—Less water poverty	[8]
	Number of doctors per ten thousand people (C2) +	High C2—Less water poverty	[16]
	Male migrant workers (C3) −	High C3—High water poverty	[25]
	Literacy rate (C4) +	High C4—Less water poverty	[16]
Use (0.2)	Per capita per day rural domestic water use (U1) +	High U1—Less water poverty	[22]
	Portion of water use for irrigated land (U2) +	High U2—Less water poverty	[24]
Environment (0.2)	Chemical fertilizer uses per hectare of cultivated area(E1) −	High E1—High water poverty	[1]
	Soil and water loss control area(E2) +	High E2—Less water poverty	[1]
	Water quality (E3) +	High E2—Less water poverty	[25]

(+) and (−) mean that the indicator is a positive and negative value.

3.3.3. Capacity

With regard to capacity, it exhibits the effectiveness of people's ability to manage water. With close links between society and water management, the importance of social and economic capacity to manage water scarcity is increasingly recognized [26]. This component points to the current potential for managing agricultural water at a farm level. Per capita GDP (C1) is a source of social and personal capital that provides the ability to improve water use efficiency and water resources management [24]. Per capita GDP reflects the response and ability to address these problems. The number of doctors per ten thousand people (C2) reflects the ability in the face of water conflict or water pollution. Male migrant workers (C3) reflects the water intake capacity of rural residents. Here, we surveyed migrant workers, and the number of male migrant workers in China is very large. The province where the study was located is a source of migrant workers; the more there are men who work outside the province, the worse their ability to obtain water from home. This metric aimed to assess the social capacity that allows people to become aware of access to effectively improved water, sanitation, health, and environment [16]. Literacy rate (C4) is defined as the percentage of the literate population aged 15 years and above [15]. A higher value reflects more literate people who have the ability to read, have access to information, understand water-related issues and, in some ways, think and take action to manage water [27].

3.3.4. Use

With regard to use, the indicator correlates with the ways in which water is used for different purposes and its contribution to the wider economy, because water use is an essential pre-requisite for human activity, and its consumption tends to increase with economic development [4]. This indicator estimates the physical water use efficiency of available agricultural water. Domestic and agricultural uses are two major water uses that are considered as indicators of water availability [27]. Domestic water use (U1) reflects the current situation regarding water resource use in daily household activities, such as cooking, laundry, livestock, and hygiene. As China has a large and dense population, high domestic water consumption puts pressure on water resource infrastructure [17]. Agricultural water (U2) reveals the irrigation facilities available in an area. The development of irrigated agriculture has been a major engine for economic growth and poverty reduction, not only due to its role in reducing the natural risk of agricultural activities, but also due to its large contribution to the improvement of livelihoods [28,29]. A higher value reflects higher water use for irrigation, which improves agricultural production, enhances employment opportunities, stabilizes income, and fulfils the multiple needs of households [16,30].

3.3.5. Environment

With regard to environment, this indicator measures environmental factors influencing the quality and quantity of agricultural water. Maintaining the quality of environmental and ecosystem health is important for achieving sustainable use of water resources. The indicators for the environmental component describe the human actions undertaken to adapt to or even prevent unintended changes to the environmental status of an area, as well as the development and positive measures to abate or improve the environmental system and change the impact on human health and survival. Chemical fertilizer use (E1) reveals the pressure of human activities on the environment coming from the agricultural sector. As agriculture has been extended and intensified, the use of fertilizers is increasing, which consequently increases pressure on the environment. From the perspective of ecological damage, the indicator reflects the human pressure on the environment. The soil and water control area (E2) reflects a focus on the main proportion of the water use of agricultural waterways and the scale of environmental management by humans [17]. This indicator reflects the environmental impact of humans on the ecosystem and the variable degree of influence degree on water resources [31]. Water quality (E3) reveals the immense pressure on the environment coming from agricultural production. Agriculture is the main engine of rural economic growth and poverty reduction in China. However, water consumption by the domestic sector is highly responsible for today's rural environmental pollution [29]. The influence on the ecological status of the water environment is difficult to perceive; it embodies a kind of dynamic change to a large extent and has both advantages and disadvantages.

3.4. Assigning Weights to the Indicators

Commonly used in multidimensional indexes, weights are determined by each dimensional value to obtain a comprehensive poverty measure. While it is easy to estimate poverty across various regions, the choice of weight is a key problem, and simple weight methods have ignored the inherent relationship between different indicators [32]. In addition, the assignment of weight affects the reliability and accuracy of the final results, which in turn influences decision-makers referencing the results in their management decisions. Past studies provide two approaches to assign weights: equal relative weights and different relative weight [33,34]. To calculate the most reliable results, this study combined the two methods. In the process of ascertaining the weight of the variables, the importance of both weights was different, because the equal weight will ignore the differences between the indicators. In turn, it affects the results of water poverty, ultimately affecting policy making. Hence, this study used integrated weights to illustrate the importance of the indicators. While the importance of both weights was the same in all five components, equal weight was attributed to the five components in the WPI [4,25]. Furthermore, this study applied a Multi-Criteria Decision-Making (MCDM) method to determine the indicator weight. In general, many researchers have applied subjective and objective MCDM weighting methods to improve decision-making [35]. Subjective methods, such as the Delphi or the Analytic Hierarchy Process (AHP), determine weights on the basis of expert experienced judgment, and can reflect the specific situation of indicators; however, they do not reflect their economic and technical significance [36]. The AHP-determined subjective weighting vector is defined in Appendix A.

Objective weighting methods, such as Entropy, criteria importance, inter-criteria correlation and TOPSIS are based on the analysis of measurable data. Although the results may not be made by analysts, the importance assigned to weights may differ [37]. The entropy-determined objective weighting vector is defined as:

(1) if the increase in the variable value results in the worst situation:

$$z_i = (x_{max} - x_i)/(x_{max} - x_{min}),$$

if the increase in variable value results in the best situation:

$$z_i = (x_i - x_{min})/(x_{max} - x_{min}).$$

where x_i is the standardized value of an indicator for location i; x_{max} and x_{min} are the original values for location i, the highest value and the lowest value location, respectively.

(2) Because we used the logarithm in the entropy method, the normalization values cannot be used directly. In order to properly deal with the shadow caused by negative numbers, the sound, translation of the normalized value is as follows:

$$Z_i = x_i + A,$$

Z_i is the value of translation, and A is the magnitude of translation.

(3) By quantifying each index, the proportion of the index in the i region is calculated under the j index.

$$p_{ij} = Z_i / \sum Z \ (i = 1, 2 \ldots \ \ldots, n; j = 1, 2, \ldots \ \ldots, m),$$

n is the number of regions and m is the number of indicators.

(4) Calculate the entropy value of j.

$$e_i = -k/p_{ij} \sum ln(p_{ij}), k = 1/ln(n),$$

$$e_j > 0.$$

(5) Calculate the difference coefficient of j.

$$g_i = 1 - e_j.$$

(6) The difference coefficient is normalized to calculate the weight of j.

$$w_i = g_i / \sum g_i \ (j = 1, 2, \ldots \ \ldots, m).$$

Based on the consultation of experts and their experience, AHP is an effective and widely applied method in assigning weight and plays a crucial role in the evaluation and analysis of indicators. The entropy method of weighting allows for the consideration of an ideal water poverty situation [38]. Therefore, to systematically assign weights to the indicators, this study combined two MCDM methods: AHP and entropy. Integrated weights combine those of AHP and entropy to highlight the importance of each indicator [39], using the weighted synthesis of the WPI (Table 2).

Table 2. Subjective weights, objective weights, and integrated weights of the WPI components, indicators, and variables.

Component	Variable	AHP	Entropy	Integrated
Resources (0.2)	Rainfall	0.500	0.446	0.473
	Per capita annual water resources	0.500	0.554	0.527
Access (0.2)	Numbers of reservoir	0.311	0.304	0.307
	Water-saving facilities	0.196	0.404	0.300
	Actual irrigation situation	0.493	0.292	0.393
Capacity (0.2)	Per capita annual rural gross domestic product	0.391	0.234	0.312
	Male migrant workers	0.195	0.235	0.215
	Doctor per capita	0.138	0.254	0.196
	Education funds per capita	0.276	0.277	0.277
Use (0.2)	Per capita per day rural domestic water use	0.333	0.484	0.409
	Portion of water use to irrigated land	0.667	0.516	0.591
Environment (0.2)	Chemical fertilizer use per hectare of cultivated area	0.493	0.325	0.409
	Soil and water loss control area	0.311	0.350	0.330
	Water quality	0.196	0.325	0.261

Integrated = (AHP + Entropy)/2 [25].

4. Results and Analysis

4.1. Water Poverty Results in Five Rural Communities and Its Implications

The water poverty values in five rural communities were calculated as follows: firstly, the indicators corresponding to different measurements of raw data were addressed by data standardization. Secondly, the comprehensive weight of each indicator was determined by the integrated weight method, after which the water poverty values were calculated by the weighted summation to obtain the comprehensive evaluation score for each component, using its indicators. Thirdly, we obtained the total water poverty values through a component of the WPI using the weight sum method. The WPI was calculated for five arid area rural communities in China. The results are presented in Table 3 and discussed in detail in this section. According to the calculation results, the water poverty values ranged from 0.336 to 0.614 (Table 3). The greater the value, the more the situation of water resources and water supply is improved. In general, the WPI values have many implications for water resource planning, management, and research. They help improve the situation of shortage in water resources on every scale, but may lead to inefficient investment and limit their own conditions, and in addition may give preferential policy to some areas where levels of socio-economic conditions and resource availability may result in failure towards alleviating water poverty [40]. With the WPI component (Table 3), including indicator and variable values, this study clearly showed that specific policies should be formulated. The component values help to prioritize a focus area in the relevant study area, as well as to monitor the degree of shortage in water resources to be improved in the specific focus areas.

Table 3. Calculated values of WPI and its components.

WP	Resource	Access	Capacity	Use	Environment	Total Scores
Sheshu	1.127	0.679	0.932	0.240	0.090	0.614
Fanyao	0.632	0.642	0.542	0.012	0.101	0.386
Dongcao	0.685	0.162	0.451	0.495	0.052	0.369
Qiaodi	0.132	0.281	0.534	0.472	0.398	0.364
Gouershang	0.382	0.505	0.282	0.364	0.147	0.336

4.2. Status of Water Poverty Variables, Indicators, and Components

It is worth noting that water resources and rainfall in the five regions were the same; however, each region had a different water poverty scores. Among the five rural communities, Sheshu, with the highest WPI value (WPI = 0.614), was in a slightly better position than the national average level (WPI = 0.392), which was reported by Sun [25]. The other four rural communities were below the national water poverty level. Based on their WPI scores, the five rural communities in decreasing order of priority were Sheshu, Fanyao, Dongcao, Qiaodi and Gouershang. The WPI component values and contribution rates revealed the real cause of water poverty and their variation in the study areas (Figure 2). For example, Gouershang was poor in capacity and environment, respectively, while Dongcao was weak in access and environment. The very low values for the capacity and environment components in Gouershang when compared to other communities was the main reason for its lowest position for all the study areas.

The WPI is a sophisticated multi-disciplinary, multi-level, framework-based and complex method for investigating water scarcity and its relationship with human welfare [41]. Five factors, namely, resources, access, use, environment and capacity, account for the water poverty in a specific study area. The index value, calculated with equal weight given to all five components, and the contribution of the components to the whole index are discussed below for each rural community. For an easy visualization and a comparison of the strengths and weaknesses of the WPI components in a basin, the component scores are also displayed in a radar plot (Figure 2). Weak water capacity (C = 0.282) and degraded environment (E = 0.147) resulted in Gouershang experiencing the greatest water poverty (WPI = 0.336). Less reliability to water resources, poor access to the water supply and sanitation, relatively low capacity to manage water resources and relatively low vegetation coverage were mainly responsible for the higher water poverty level in the study area. However, water use (U = 0.364), both domestic and agricultural, was remarkably intermediate among the five rural communities. There was a relatively low percentage of the population that was economically active, but there was a high literacy rate and GDP; non-agricultural employment decreased the overall score of the capacity component. The remaining component—access—scored a medium grade, reflecting sufficient space for improvement. Sheshu had the highest resource (R = 1.127), access (A = 0.679), and capacity (C = 0.932) components. A high score for the capacity component reflects a better health and education status as well as the economic strength of its residents. This component has helped people to improve their income and increase access to water resources and technologies, which, in turn helps people to cope with water related stresses. However, areas away from cities did not have adequate or reliable provision of water for domestic and agricultural use; therefore, the score was low for water use (U = 0.240).

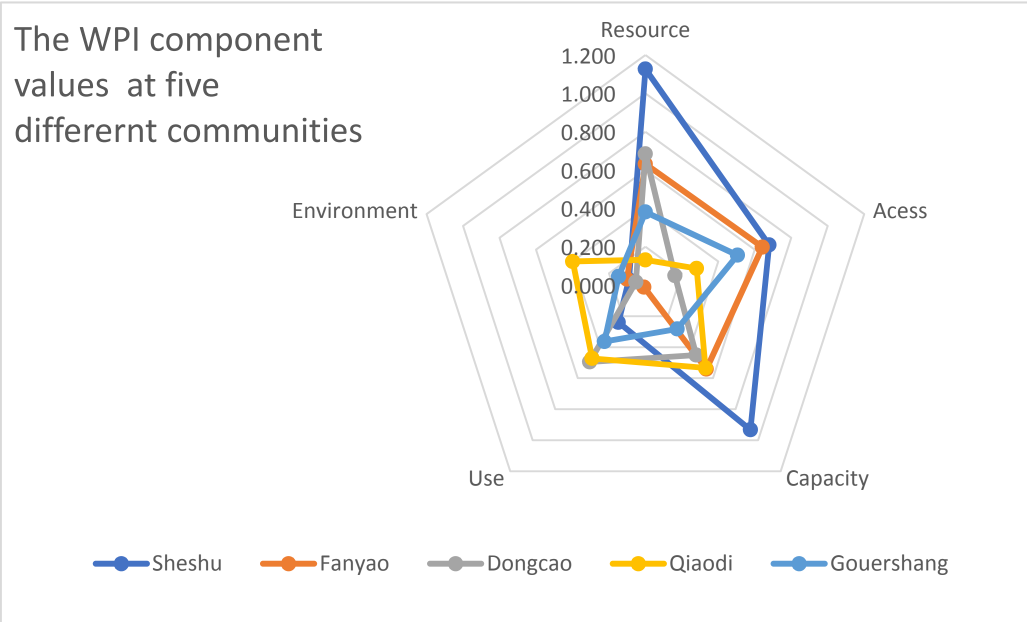

Figure 2. WPI component scores.

Moreover, increasing urbanization, population and demand for agricultural products resulted in a reduction of vegetation coverage and the maximization of chemical fertilizers use, which have deteriorated the environment and contributed to increasing water poverty. However, curbing illegal logging and restoring forests in deforested, marginal or open areas will help restore the natural ecosystem, control soil erosion problems, and maintain the hydrological cycle. The water poverty situation in the five rural communities originated mainly in the environment component. These communities had an inferior environmental condition, due to the large amount of fertilizer use, small percentage of forest coverage, and a low degree of water resource availability. Moreover, a low score for the capacity component implied that societies with low income levels, weak health, and poor educational systems are expected to have inhabitants who lack access to safe drinking water. Thus, such communities score lower for access to water supply and sanitation. Likewise, weak environment and use components also contributed to water poverty. Therefore, the development of all of these components would be beneficial for improving the water poverty in Sheshu. Qiaodi scored relatively higher on capacity, environment, and use than in the resources and access components. The results reflected the fact that environmental quality and ecosystem health were maintained in Qiaodi through the application of less chemical fertilizer and the retention of vegetative cover.

4.3. Priority Areas

The WPI results clearly show how the water poverty situation varied in the study areas, with respect to the different WPI components. They also provide guidance regarding how development assistance can be prioritized and targeted to maximize benefits [4,8,19]. Although there are improvements to be made in all sectors, the most urgent attention should be given to high water poverty areas and to the component scoring the lowest grade. In short, the height of water depends on the shortest board, so we can formulate specific policies to ease the water shortage situation by finding "the shortest board". American geographer John C. Weaver used variance (also called the Weaver composite index) calculations for agricultural zoning [18]. Weaver mainly used the features of variance, namely, the variance of a set of data; the first is from large to small, which then changes from small to large. The smallest variance of that number, called the minimum variance as the number, is the actual distribution of the minimum variance, and the deviation between the theoretical distribution of that smallest number can reflect the actual situation of a region. Using this method, the first variance can determine what the major industries in the area are as well as the classification of the industrial district. Weaver used the basic idea of the composite index method by comparing the elements of the actual mix proportion and the theory of combination between the proportions, the minimum deviation between the values, and the minimum variance; together these helped to help create an index that uses the most elements that can reflect the actual combination, known as the fitting rate. Whenever a region has a wide industrial distribution, knowledge about the condition of its structure can be applied to this method. In particular, this knowledge can be used to reflect the differences between different regions.

As a guide, this article first determined the proportion of the five components of each location, the actual proportional relationship between the five components to calculate the area proportion of each location (the sum of the five component proportions by location), and the total weight percentage, which resulted in the proportion of the four indexes of the various geographical compositions. Second, to determine the five components of the regional location proportions in descending order according to the proportion, we calculated the actual regional index rate combined with each component type individually, then two components together, then three components together, and so on using the variance of value. Concrete examples of the calculation process are detailed in Table 4.

Table 4. The case calculation of Weaver Combination Index of Gouershang (rural community).

Category	Progress	R	A	C	U	E
Single component	Ideal value: $\overline{x}$	100	0	0	0	0
	Actual value: x_i	22.7	30.1	16.8	21.6	8.7
	Squares of Deviations: $(x_i - \overline{x})^2$	5971.0	905.6	282.5	468.4	76.2
	LSE: S^2	1540.7				
Double components	Ideal value: $\overline{x}$	50	50	0	0	0
	Actual value: x_i	22.7	30.1	16.8	21.6	8.7
	Squares of Deviations: $(x_i - \overline{x})^2$	743.8	396.3	282.5	468.4	76.2
	LSE: S^2	393.4				
Three components	Ideal value: $\overline{x}$	33.3	33.3	33.3	0	0
Four components	Ideal value: $\overline{x}$	25	25	25	25	0
Five components	Ideal value: $\overline{x}$	20	20	20	20	20

To determine the proportion of the score of a subsystem of water poverty that was the main driving factor, the spatial types of water scarcity were used to establish a theoretical standard. According to the LSE method, the ideal standard score for a single component was 100%, and for other components, it was 0. The ideal standard score for two components, which were only two subsystems, was 50% of the total score of water scarcity. By the same token, the ideal standard score for three components was 33.3%, and so on. With regard to the water scarcity score, its composition did not comply with any of the above theory distributions, but it could be a comparison between the real and theoretical distributions. The LSE theory refers to the recent distance distribution standard as well as and the real distribution, which can be classified as belonging to the theory of single components or other types. According to the prescribed standards, firstly, we must determine the regional weighted contribution rate of the components of water scarcity, and the components according to the contribution rate sequence arrangement. Secondly, we use the variance formula to find the number of main spatial types by the variance of the numerical number of the component, which is a major driver of water poverty.

The study areas, listed in order of priority of need for intervention, are Gouershang, Qiaodi, Dongcao, Fanyao and Sheshu. The component and indicator values helped to highlight the priority areas for intervention and planning in each studied area (Figure 3). For example, use and environment in Sheshu and Fanyao, environment in Dongcao, and Eenvironment in Gouershang need to be highlighted.

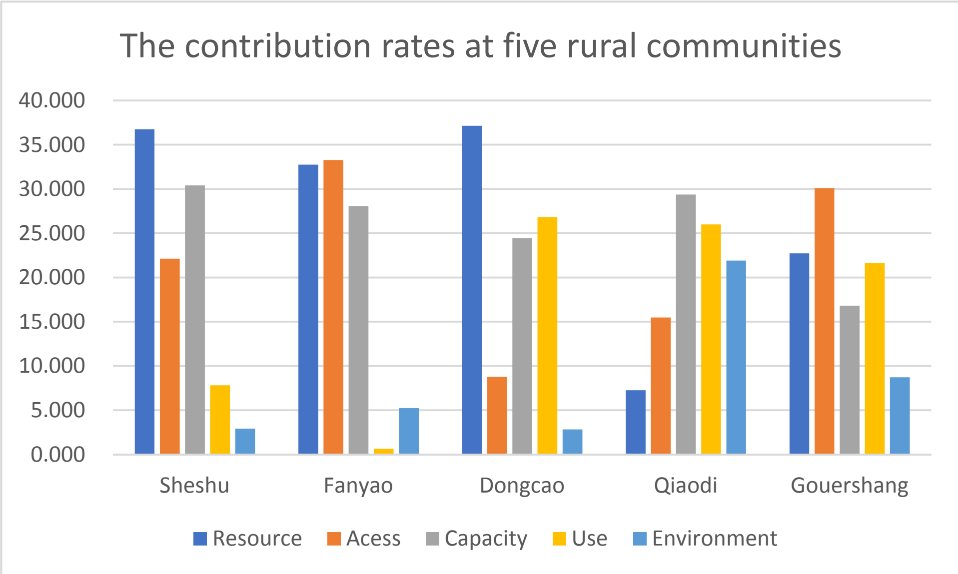

Figure 3. The contribution rates at five rural communities.

Improving water use should be the first priority in the study areas. Agriculture constitutes the largest share of the total economy and is a major contributor to livelihoods in China.

Therefore, there is a clear need for investment and planning to improve domestic as well as agricultural water uses. In Sheshu and Fanyao, the focus should be on the use and environment components. In addition, other areas should also focus on the environment component. The use of chemical fertilizers is very high and needs to be controlled through farm level training and awareness campaigns. Therefore, appropriate water management planning should be the first priority to efficiently use the limited available resources in the study areas. Research into the regional water environment is weak: it indicates that existing policies and programs are insufficient and need to be updated and improved. Improving water use is still a key priority, followed by others. Thus, there is enough room to improve water poverty in all the study areas, and it would be beneficial if further interventions were prioritized, as indicated by the WPI results.

Giving the same priority to a specific sector in all of the basins in different geographic locations with various levels of development, resource availability and socio-ecological conditions may result in the failure of policies directed towards alleviating water poverty (Table 4), for example, in the five rural communities mentioned in this paper. The component values help to prioritize focus areas in the selected study area; the indicator value helps to prioritize the sub-areas (of selected areas) as well as monitor the level of progress in the sub-areas of the selected focus area. For example, in Sheshu, use and environment components should be the first and second priorities, respectively, as their scores were the lowest when compared to the other WPI components. Additionally, within these two components, the priorities should be to improve the domestic water use situation and control excessive fertilizer use, respectively, as their scores were quite low when compared with the other variables within those components. However, some of the components and indicators cannot be controlled (e.g., resource availability and variability), because some directly refer to development policies (e.g., water supply and sanitation), while some refer to other socio-demographic and economic elements in the area. Improvement to the water poverty situation would be relatively easier if the factors that need attention were related to development policies and controllable by policy interventions. If the focus needs to be on increasing socio-demographic and economic status, long-term policies and programs become necessary.

5. Conclusions

This study selected fourteen indicators based on the WPI framework to assess the water poverty situation in five rural communities, taking into consideration local issues and limited data availability. Policies should focus on strengthening water management plans to ensure the efficient use of the available water resources. Based on the LSE method, we could better solve the problem using a quantitative analysis of the differences in regional water poverty. Through the analysis of the related numerical indicators, we could evaluate the driving type of water poverty and the cause of its spatial variations. By assessing the spatial distribution of the different driving types, this study aimed to reveal the regional drivers of water poverty, and to provide the necessary theoretical reference for relevant departments, in order to implement measures and adjust the local conditions of water resources management.

In this study, a careful analysis of the WPI components' contribution rate in all the study areas identified a poor water environment as the main cause of the water poverty, followed by other limitations. This suggests that investment and policy interventions for increasing water supply and consequently water use should be the first priority in these areas, followed by policy interventions and long-term planning for improvements to socio-economic capacity, access, and the environment, respectively. In this way, the WPI results can be used to prioritize rural areas, and its components can help judge the areas to focus on within the selected regions, which would lead to the efficient management of water resources in the study areas. It would be advantageous for future studies to focus on evaluating the WPI by considering different weights and scenarios based on consultation with stakeholders and the acquisition of relevant information and experiences. It would further help policy-makers and planners to examine the possible impacts of alternative planning and the development of interventions in these study areas.

In this paper, the water resources shortage evaluation based on WPI and LSE remains a preliminary study. There are a few problems that have yet to be researched. Firstly, the different indicators selection criteria and weight method would produce different water poverty results, and further affect LSE analysis. In the future, there is still a need to use a variety of other indicators, evaluation standard and methods, the analysis of the existing the robustness, and a reliability of inspection. Secondly, the LSE method is essentially "data driven", mainly by the data statistical description, and lacks the theory of the explanatory power of the model. Considering the effect of space, Exploratory Spatial Data Analysis (ESDA)—confirming the space data analysis method—could be a further interpretation of regional water scarcity differences.

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Appendix A

Experience judgment and expert consultation was an important aspect of the AHP weighting for each indicator in this study. In the process of the evaluation of AHP, the comparison matrix of urban and rural areas with a similar weighting of every indicator is shown in Tables A1–A5.

Table A1. Pairwise comparison matrix of Resources indicators.

	R1	R2	Weight
R1	1	1	0.500
R2		1	0.500

Table A2. Pairwise comparison matrix of Access indicators.

	A1	A2	A3	Weight
A1	1	1/2	2	0.311
A2		1	2	0.196
A3			1	0.493

Table A3. Pairwise comparison matrix of Capacity indicators.

	C1	C2	C3	C4	Weight
C1	1	2	2	2	0.391
C2		1	1/2	1/2	0.195
C3			1	2	0.138
C4				1	0.276

Table A4. Pairwise comparison matrix of Use indicators.

	U1	U2	Weight
U1	1	2	0.333
U2		1	0.667

Table A5. Pairwise comparison matrix of Environment indicators.

	E1	E2	E3	Weight
E1	1	2	2	0.493
E2		1	2	0.311
E3			1	0.196

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