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Regionally differential water pricing strategy: An example from Karst region of China

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ABSTRACT

The study objective is to analyze the water expenditure of 4315 rural households in the Karst region of China. The empirical results have been analyzed by using the extended linear expenditure system model. The study has been based on water expenditure, which provides a feasible differential water pricing strategy in the karst region of China. The result shows that (1) the coefficient for water expenditure has been examined as low. The coefficient of water expenditure in the Karst region ranges from 0.534 to 1.025%, the average value is 0.723%, and the modified coefficient ranges from 0.814 to 1.508%, with an average value of 1.070%. (2) The marginal consumption propensity of rural residents in the Karst region is 0.2%, and the marginal consumption propensity in each province ranges from 0.1 to 1%. (3) The per capita basic water demand has 3 m^3. In this scenario, the study recommended that basic water prices range from CNY 2.091 to CNY 3.468 per cubic meter. If the water consumption exceeds basic demand (3 m^3 per month), then the bearing water price shall not be lower than CNY 2.091 to CNY 3.468 per cubic meter and not higher than CNY 7.122 per cubic meter.

Key words: basic water price, rural China, water pricing, water supply

HIGHLIGHTS

- Analyzed the water expenditure of 4,315 rural households in the Karst region of China.
- The basic water prices range from CNY 2.091 to CNY 3.468 per cubic meter.
- The water price reform in rural China should be subsidies and flexible.
- Increasing financial subsidies for low-income households and charging discount fees to households with idle water equipment.
- Water pricing mechanism should be flexible for everyone.

1. INTRODUCTION

'I see your pipe is connected to the roof. Do you get water from the roof?' 'Yes, the roof received rainwater for our daily life.' 'Why?' 'Because rainwater is free, and our tap water supply is unstable. So, we like to use rainwater, but sometimes we also used tap water.' This interviewee comes from a rural Karst region in China. Because in rural areas, the local water supply is unreliable, and rural residents often use other alternative resources of water. The Karst region water supply survey revealed that water supply is cheap or even free in some areas, which is the main reason for the unstable tap water supply. Due to insufficient revenue or limited financial funds, it is difficult to maintain a continuous rural water supply. The survey investigation found that the water pricing mechanism in the Karst region of China has not been stabilized. The allocation water supply mechanism has not been fully regulated; water supply prices have generally been low but cannot reflect the scarcity of water resources. The rural resident is not aware of saving water, which leads to the waste of water resources.

The 'user pays' principle is one of the principles of Integrated Water Resource Management (Muldianto *et al.* 2020). China's rural water pricing mechanism still needs to be improved, and the literature shows a variety of reasons for the improvement in water pricing. In rural China, if the water prices are high then water consumption is low (Renwick *et al.* 1998) and encourage them to use other water resources, which could increase the risk of water-borne diseases (Lishi 2011; Ellawala & Priyankara 2016; Alazzeh *et al.* 2019). However, low water price is difficult to meet the operation of small water conservancy projects. Economists typically advocated using the pricing mechanism to balance the supply and demand for scarce resources (Howe & Linaweaver 1967; Chesnutt & Beecher 1998; Dalhuisen *et al.* 2003; Grafton *et al.* 2015). But a scientific pricing mechanism can be difficult to design. Renwick *et al.* (1998) pointed out that pricing policies could burden the city's poorest residents.

Luby *et al.* (2018) studied water prices in America and pointed out that prices on extra water used could be higher to cover the costs of water supply. However, most of the cities effectively had declined water prices per unit. So Muldianto *et al.* (2020) proposed that water prices should be set optimally and highly enough but within the ability of users to afford the water. In fact, balanced pricing is not a simple way in the water pricing mechanism. Due to differential water resource endowment, different regions may have different pricing strategies. Thus, the findings from different regions could not be necessarily the same. The current research status on water pricing in rural China is mostly based on qualitative research, and few studies put forward specific pricing mechanisms based on survey data.

Over the last few years, due to the recent economic crisis, water affordability issues have drawn the great attention of researchers (Fagundes *et al.* 2023). In this regard, this study aims to offer differentiated pricing strategies for different regions instead of a unified pricing strategy for rural water supply. The Karst region has unique geomorphic conditions with uneven distribution of water resources. The surface water storage capacity is relatively low, and abundant water resources have not been fully utilized (Dianfa *et al.* 2001; Yulin *et al.* 2018), resulting in a typical 'engineering water shortage'. This kind of situation not only exists in China but also is a common phenomenon in Karst areas around the world. The study has surveyed the Karst region of highly representative areas and searched the value of strengthening water price management in water-scarce areas and proposes a differential pricing strategy to ensure that rural residents can use running water safely. Meanwhile, the results of the study on water prices in other countries show that the influence of other factors besides the price makes it difficult to attribute the change in demand for water, exclusively to price change. Due to differences in the way water bills are paid (e.g., in the Netherlands and most EC countries, water meters are read annually). So, these circumstances are taken into account (Achttienribbe 1998). Factors such as regional economic development level and residents' differentiated water consumption habits have been fully considered in this study.

The major contributions of this article are grouped into two aspects: (1) This study makes an important marginal contribution to the literature on rural water pricing. Most previous works on water pricing looked at broader national or urban contexts. Those works zoomed on the unique geographical and economic conditions of rural Karst regions. This research not only generates insights that are highly relevant locally but also provides learning applicable to other rural contexts facing similar challenges. (2) The use of a large micro-level dataset from over 4,000 rural households allows for an in-depth analysis of water demand and consumption patterns in the study area. This granular understanding of user behavior and preferences at the grassroots level informs the formulation of a pricing strategy tailored to local needs and capacities. The differentiation of pricing for basic versus nonbasic water demand takes into consideration both affordability and cost recovery objectives. (3) Methodologically, the application of the extend linear expenditure system (ELES) model to quantify the basic water demand and expenditure provides a rigorous empirical basis for setting an appropriate basic water price range. This approach could be adopted in other regions to balance equity and efficiency in rural pricing. More broadly, the identification of factors like the marginal propensity to consume water enrich economic theorizing on nonurban demand. (4) Globally, many rural communities still lack stable or affordable water access. The subsidized yet tiered pricing framework proposed based on comprehensive survey findings offers a viable reference for policymaking seeking to extend services sustainably. Flexible solutions are needed, and this research contributes toward place-based lessons on universal service goals with financial self-sufficiency in the water sector. Its insightful discussion of challenges such as low incomes, idle infrastructure, and resource scarcity will resonate for marginal rural communities worldwide. In summary, this study advances knowledge on an understudied topic through its in-depth mixed-methods exploration of local water use patterns and priorities. Insofar as many global challenges are localized, its identification of pragmatic, equitable policy approaches tailored to community circumstance contributes significantly to addressing rural water security internationally.

2. BACKGROUND

2.1. The present situation of rural water pricing in the Karst region

There are three main forms of rural water supply in the Karst region of China: (1) integrated urban and rural water supply. This kind of water supply is mainly supplied by urban waterworks. By extending the urban water supply network to rural areas, a large-scale water supply pattern has been formed. (2) Centralized water supply in rural areas. This kind of water supply is mainly aimed to supply water with relatively large water demand or concentrated population areas. (3) Rural decentralized water supply, which is mainly built by villagers.

Depending on the relevant regulations of the Chinese government, China's rural water standard charge is 2 yuan/m^3. But in practice, the price of water supply in the Karst region has been managed by classifications according to different water supply modes. In general, the pricing principle is based on maintenance prices in some specific places. The maintenance water supply charge has been introduced in places where water consumption is relatively low. The specific pricing strategies have also been divided into three situations depending on the water supply modes: First, implementing the same price as the urban, for those rural areas supplied by the urban waterworks. Second, the water price has been set by the government and can also be adjusted by the market for rural centralized water supply areas. Third, the water price has been mainly regulated by the market, and demand and supply parties negotiate the price.

A rural unified water pricing system has not yet formed due to the restriction of infrastructure and the differentiated water supply methods. At the same time, some areas do not have access to running water, or the supply of running water is unstable. It is common for farmers to retain spring water, ground water, or surface water in their homes through self-built pipes or by pipes that carry water from other public water sources. Except for the basic equipment, there are no incurring water charges. Therefore, the rural water supply management in the Karst region of China still needs to be well implemented, and the water pricing mechanism still needs to be further improved.

2.2. Pricing mechanism framework in the rural Karst region

The natural monopoly of water resource development and utilization in China determines that the water price must be based on maintenance price. At present, China's urban water supply consists of three parts: resource water price, environmental water price, and project water price, which have formed a relatively perfect pricing mechanism. Among them, resource water price reflects the scarcity and usefulness of water resources, and it measures the cost that users need to pay for using water resources from nature. Environmental water price reflects the pollution control cost, specifically referring to the cost of treating domestic sewage environmental protection. Project water price refers to the cost of water resource treatment, construction of water supply infrastructure, maintenance of water supply projects, and other costs incurred for the use of water resources (Yu & Wenjin 2011).

As rural residents live in relatively scattered areas, the extension of the water supply network is long and wide, which increases the difficulty of the water supply and the construction cost. The water supply sources are different from the centralized and unified urban areas. The water supply in rural areas with dispersed residents usually uses nearby water sources. So, the types of water sources vary greatly. Second, it is difficult to measure the price of environmental water. Due to the insufficient construction of sewage treatment facilities in rural areas, some villages even have no sewage treatment system. For example, it was found that some farmers in the survey area directly dumped domestic sewage into the land or the ditches near their homes. Third, the project water price is also difficult to measure. According to the results of our survey, the construction ages of rural water supply projects are older, and some projects have a long history. In addition, the construction funds come from various sources, some have been supported by the government, some have been raised by villagers, and some villagers participate in the construction with labor funds.

In summary, the rural water pricing mechanism cannot completely refer to the 'triple composition' principle adopted by urban areas. Limited by the economic development, farmers generally have a low income, resulting in low affordability of water charges. Therefore, the rural water pricing mechanism in the karst region should fully consider the actual situation of each area, from the perspectives of basic water price (to ensure the basic demand of rural residents) and from the water pricing bearing capacity.

3. MATERIALS AND METHODS

3.1. Data sources

The study data are obtained from the '2020 China Karst Rural Water Survey (CKRS)'. The household survey was conducted through face-to-face interviews. The survey has covered the provinces and major cities from the Karst region of China. The data included Chongqing City, Guangxi Zhuang Autonomous Region, Yunnan, Guizhou, Hubei, Hunan, Sichuan, and Guangdong Province. In this survey, a total of 31 cities, 81 counties/districts, 164 towns/townships, and 641 villages have been included. This survey contained rich information about the utilization of rural water resources and villagers' water use behavior, which allowed researchers to study water pricing in the Karst region.

It is ensured that the sample can reflect the overall situation of the research area as much as possible. We conducted this survey by using the PPS (Probability Proportionate to Size Sampling) sampling method in the PSU (Primary Sampling Units) sampling frame to select the first tier of samples (districts/counties), and a total of 40 counties were selected. The village houses in the counties had been selected by sorting number, and no less than four natural villages had been selected in each county. The PPS method used a random sample of village houses, and finally, 641 natural village samples had been selected. Some cannot be investigated due to special reasons during the implementation process. The nearest natural village had been selected for replacement according to the sampling principle. The sampling of households did not adopt the conventional household registration roster method but adopted the 'right-hand principle'. The first household in the village had been used as the starting point for interviews. After successful sampling, the next households had contacted at intervals of three to five households. Only 15–25 households were required to be sampled, and the minimum household sample in a village was 15 households and the maximum was 25 households.

It should be noted that a total of 10,011 valid samples were interviewed in this survey, but as mentioned earlier, 42% (4212/10011) of them had no water expenditure. At the same time, some households cannot provide accurate monthly water consumption due to the special water sources they use, such as rainwater. Therefore, this part has not been included in our paper. So, a total of 4,315 households that meet the needs of this study are finally screened out.

3.2. Methods

3.2.1. Water expenditure coefficient method

To grasp the current water consumption of rural residents in the karst region, we first calculated the coefficient of water expenditure. The coefficient refers to the percentage of water expenditure in disposable income.

$$R = U/I \tag{1}$$

In Equation (1), R is the coefficient of water expenditure, U is the per capita water expenditure, I is the resident income level, and per capita, disposable income is taken as a proxy variable. Studies have shown that different ratios of water expenditure to disposable income lead to different levels of responses (Luby *et al.* 2018). These studies have mainly focused on urban residents because rural residents are generally more price sensitive than urban residents (Wichman *et al.* 2016). To capture this sensitivity in the coefficients, Zhou (2016) argued that the model needs to be modified according to local incomes and water costs:

$$L = R + 3\% \frac{I - Y}{I} \tag{2}$$

In Equation (2), L is the modified water expenditure coefficient, R is the actual water expenditure coefficient, I is the resident income level, with per capita disposable income as the proxy variable, and Y is the per capita total consumption expenditure.

Many scholars show that the water expenditure coefficient within 3% is a more appropriate range. Meanwhile, according to the Economic Evaluation Specifications for Water Conservancy Construction Projects (SL72-2013) issued by the Chinese government, when the per capita water expenditure of urban residents accounts for less than 1.5–3% of disposable income. That is within the acceptable range of water users. Beyond this range, the market price leverage effect will increase. Similarly, internationally, the World Bank has also set 3% as the threshold for water conservation. Based on the previous studies (Yu & Wenjin 2011; Jianhao *et al.* 2018; Guanjun *et al.* 2021), this study has summarized the reference table of water expenditure coefficient as follows.

3.2.2. Bearing water pricing capacity

Residents' bearing water pricing capacity is an important reference for water pricing, which reflects the highest water price that residents can bear. The formula is as follows:

$$P = I \times \frac{L}{W} \tag{3}$$

In Equation (3), P is the price of water supply, I is the income level of residents, with per capita disposable income as a proxy variable, L is the modified coefficient of water expenditure, and W is the per capita water consumption.

3.2.3. ELES model

To ensure the basic water demand of rural residents in the Karst region, we need to measure the basic water price. The ELES model reflects the demand by expenditure and then divides consumer demand into basic demand and nonnecessary demand. Therefore, we adopt the ELES model for subsequent research, and its basic construction is as follows:

$$p_i q_i = q_i r_i + \beta_i \left(I - \sum_{j=1}^{n} p_j r_j \right), i = 1, 2 \ldots n; j = 1, 2 \ldots n \tag{4}$$

In Equation (4), i and j represent categories of household consumption expenditure. n is the total number of categories, p_i is the price of good $_I$, q_i is the demand of consumers for good $_I$, r_i represents the basic demand for commodity $_i$ ($q_i > r_i > 0$), I is the consumer's disposable income, and β_i is the marginal propensity of the consumer to the good $_i$. ($0 < \beta_i < 1$; $\sum_{i=1}^{n} \beta_i \leq 1$).

In Equation (4), $p_i r_i$ represents the basic requirement, which is the part of the demand that consumers can be satisfied regardless of the commodity price. When the basic demand is satisfied, the consumer allocates the surplus income ($I - \sum_{j=1}^{n} p_j r_j$) between consumptions and savings according to the marginal propensity to consume β_i. So, transformed Equation (4) is given as follows:

$$p_i q_i = p_i r_i - \beta_i \sum_{j=1}^{n} p_j r_j + \beta_i I \tag{5}$$

Mathematical transformation of Equation (5) is as follows:

$$\alpha_i = p_i r_i - \beta_i \sum_{j=1}^{n} p_j r_j \tag{6}$$

Then, the actual consumption of the commodity $_i$ by residents' $p_i q_i$ can be expressed as follows:

$$p_i q_i = \alpha_i + \beta_i I + \mu_i \tag{7}$$

In Equation (7), α_i and β_i are to be estimated, and μ_i is the random disturbing term. The ordinary least squares (OLS) is used to estimate Equation (7).

According to the definition, both sides of Equation (6) are added:

$$\sum_{i=1}^{n} \alpha_i = \left(I - \sum_{i=1}^{n} \beta_i \right) \sum_{i=1}^{n} p_i r_i \tag{8}$$

By substituting Equation (8) into Equation (6), we obtain

$$p_i r_i = \alpha_i + \frac{\beta_i \sum_{i=1}^{n} \alpha_i}{\left(I - \sum_{i=1}^{n} \beta_i \right)} \tag{9}$$

According to Equation (9), we can calculate the basic demand $p_i r_i$ of residents for commodity $_i$.

Considering the meaning of the ELES model, this article analyzes the basic demand for domestic water. Specifically, we assume that the consumption expenditures of rural residents in the Karst region are restrictive. Then, the data of total consumption expenditure, water expenditure, and per capita disposable income are put into the ELES model for estimation. Then we can obtain the marginal propensity to consume water β_i, basic water expenditure $p_i r_i$, and basic water price p_i, to provide a reference for policymakers to set water prices.

4. RESULTS

4.1. Coefficient of water expenditure in the Karst region

In Table 1, the water expenditure coefficient has been calculated by province according to Equation (1). The specific results are presented in Table 2. The results show that without modification, the coefficient ranges from 0.534 to 1.025%, which is relatively low and not enough to attract the attention of residents. As mentioned earlier, rural residents have more sensitive to water prices than urban residents with higher incomes, so the coefficient needs to be modified. After modification by Equation (2), it has been found that the coefficient rises overall, within the range of 0.814 to 1.508%, and there are no obvious differences among provinces. In conclusion, the coefficient of water expenditure in the Karst region is within the appropriate range, but due to the low coefficient, it has not played the role in regulating the water consumption behavior.

4.2. Bearing water pricing capacity in the Karst region

The bearing water pricing capacity of rural residents in the Karst region has been calculated by using the modified coefficient and Equation (3). This price can be treated as the upper limit reference value for water pricing. The results in Table 3 show that the bearing water pricing capacity is relatively high, with an average bearing price of 4.950 CNY/m^3, specifically, 7.122 in Guangdong Province, 4.964 in Yunnan Province 3.643 in Sichuan Province, 5.746 in Guangxi Zhuang Autonomous, 4.940 in Hubei Province, 4.100 in Hunan Province, 4.030 in Guizhou Province, and Chongqing City is 5.237. It shows that with the development of the economy, the income level of rural residents in China has been significantly improved. The bearing price of residents is higher than the current water price and the water supply safety has been guaranteed everywhere.

4.3. ELES model results

The study has used the ELES model twice. First, this study has examined the survey data of all regions in the model to obtain the results of the whole Karst region. Second, the study has examined the data of each province in the ELES model one by one to get the specific situation of each province.

Table 1 | Influence of water expenditure coefficient on water behavior

Water expenditure coefficient	Influence degree
1%	The little psychological impact that residents can generally accept
2%	People began to pay attention to water consumption, and also, began to realize the conservation of water
2.5%	Start saving water
3%	It has a great influence on residents' water-saving behavior
5%	Save water carefully
10%	Consider water reuse

Table 2 | Coefficient of water expenditure in the Karst region

provinces	Observations	Per capita water expenditure (CNY/month)	Per capita disposable income (CNY/month)	Coefficient of water expenditure	Modified coefficient
Guangdong	518	10.065	1,678.583	0.600%	1.048%
Yunnan	461	8.871	1,070.167	0.829%	1.243%
Sichuan	817	8.360	1,327.417	0.630%	0.814%
Guangxi Zhuang Autonomous Region	267	12.654	1,234.583	1.025%	1.508%
Hubei	462	8.160	1,358.833	0.601%	0.938%
Hunan	327	8.150	1,382.080	0.590%	0.881%
Guizhou	679	9.430	970.167	0.972%	1.184%
Chongqing City	784	7.277	1,363.417	0.534%	0.941%
Mean value (total)	4,315	9.121	1,298.156	0.723%	1.070%

Table 3 | Bearing water price capacity of rural residents in karst regions

Provinces	Observations	Per capita water consumption (m^3/month)	Bearing water price capacity
Guangdong	518	2.466	7.122
Yunnan	461	2.681	4.964
Sichuan	817	3.122	3.463
Guangxi Zhuang autonomous region	267	3.242	5.746
Hubei	462	2.581	4.940
Hunan	327	2.970	4.100
Guizhou	679	2.852	4.030
Chongqing city	784	2.450	5.237
Mean value	4,315	2.800	4.950

The study has used the OLS to obtain the estimated values of α_i and β_i in the ELES model by using per capita water expenditure and per capita disposable income. The model fitting diagram is shown in Figure 1. Then, the regression analysis of per capita consumption expenditure and per capita disposable income has been used to obtain the estimated parameters-$\sum_{i=1}^{n} \alpha_i$ $\sum_{i=1}^{n} \beta_i$ of the ELES model. The model fitting diagram is shown in Figure 2, and the regression results of the ELES model are presented in Table 4.

The regression results show that the F-statistic value of model 1 is 39.20, indicating the model can be used to explain the relationship between water expenditure and household income. Meanwhile, according to Figure 1, per capita water expenditure ranges from CNY 0 to 20, and the overall fitting effect has not been ideal. R^2 is also at a low level, only 0.041, indicating that the explanation of the model is not strong enough. The results show that per capita disposable income is a significant impact on water expenditure at the 1% level, but the coefficient is only 0.002. Considering the explanatory power of the model, it shows that the expenditure on domestic water is positively affected by the income level, but the marginal effect is small.

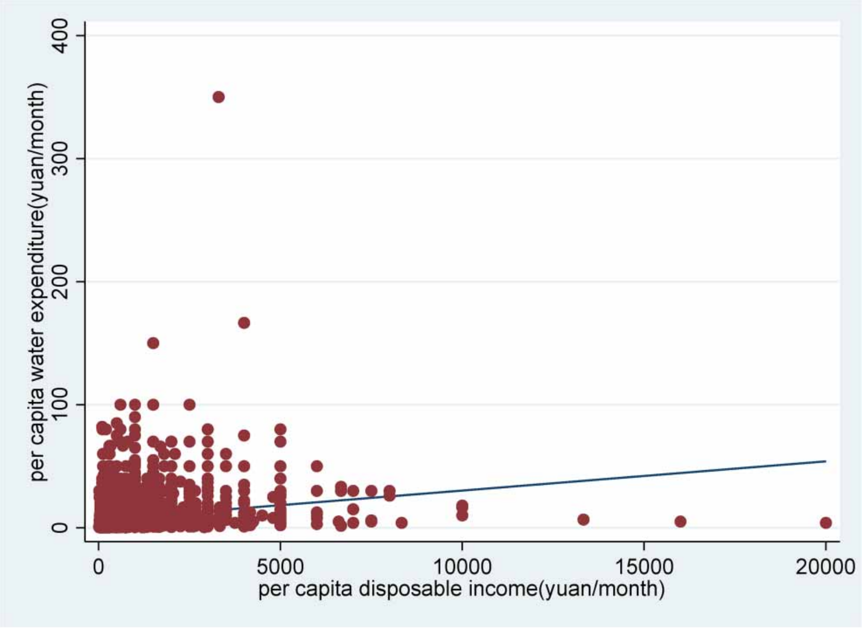

Figure 1 | Per capita, water expenditure, and disposable income regression fitting.

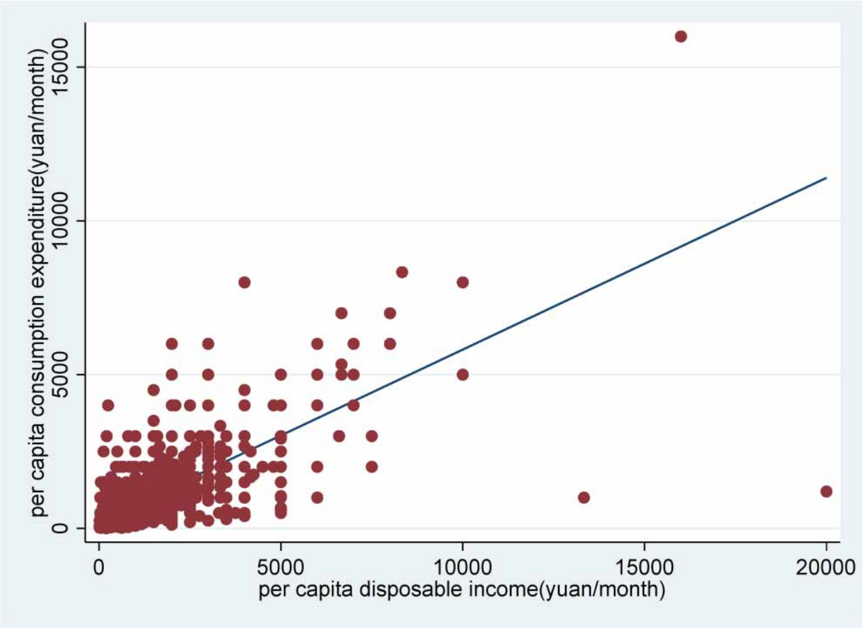

Figure 2 | Regression fitting of per capita consumption expenditure and disposable income.

Table 4 | ELES model results

Variables	**Model 1 - per capita water expenditure**	**Model 2 - per capita consumption expenditures**
Per capita disposable income	0.002*** (0.000)	0.559*** (0.054)
constant	6.528*** (0.327)	229.377*** (47.789)
F-test	39.20***	108.82***
R^2	0.041	0.566
observe	4,315	4,315

Note: Robust standard error is presented in parentheses.
$^{***}P < 0.01$, $^{**}P < 0.05$, $^{*}P < 0.1$.

The F-statistic value of model 2 is 108.82, and the R^2 value is 0.566, which has ideal values. At the same time, in Figure 2, it is found that the scatter points are mainly distributed on both sides of the fitting line, and the distribution is relatively symmetrical, indicating that the model is well-fitted and the explanatory power is strong. Specifically, per capita disposable income has a significant positive impact on consumption level at 1%, with an impact coefficient of 0.559.

The current water price has a limited influence on residents' water consumption behavior. From the regression results, it can be seen that the marginal propensity to consume water for rural residents in Karst areas is about 0.2%. It indicates that the expenditure on the water will increase by 0.2% for every unit of income increased. This conclusion is consistent with the result of the water expenditure coefficient. Based on the parameters of Models 1 and 2 and Equation (6), per capita basic water expenditure in the Karst region can be estimated:

$$p_i r_i = 6.528 + 0.002 \times \frac{229.377}{1 - 0.559} = 7.568 \text{ (yuan/month)}$$

The result shows that the basic water demand of rural residents in the study region is guaranteed. Theoretically, the average per capita water expenditure in the Karst rural region is about 7.568 CNY/month, while the survey data show the average actual water expenditure of rural water users in this region is 8.819 CNY/month.

The aforementioned steps are repeated to analyze the specific water expenditure of each province one by one in Tables 5 and 6.

Finally, based on the $p_i = p_i q_i / q_i$, the basic water prices of each province is shown in Table 7.

Compared with the results in Table 7 and the actual situation, we find that the current water price implemented in the rural Karst region is low. In terms of the ELES model, the basic water price in each province ranges from 2.091 to 3.468 CNY/m^3, with an average price of 2.708 CNY/m^3. The price of water per unit bearing capacity of provincial residents ranged from CNY 3.463 to CNY 7.122, with an average of CNY 4.950. In contrast, the current implemented water price in rural China is 2 CNY/m^3, which is lower than the basic water price obtained by the ELES model. The results show that the current water price in China is within a reasonable and affordable range for residents, which can ensure the residents' water demand and water safety. However, due to the low coefficient of water expenditure, the current water price is not enough to attract the attention of residents, and the regulation effect of water price has not been obvious. More importantly, the low water price could make it impossible for water conservancy projects to recover their operating costs. Insufficient funding does not guarantee a normal water supply.

The results of this study provide useful strategically water price settings in rural karst regions. However, the statistical analysis helps quantify residents' water consumption patterns and capacity to pay. A deeper discussion of the policy recommendations is warranted to maximize the practical impact. For example, further exploring how to best implement differential pricing approaches across provinces based on economic development levels could ensure that prices are set at an optimal level that balances cost recovery with affordability. In addition, considering incentives or subsidies to encourage conservation behavior change, such as rebates for installing more efficient household water fixtures, may be a more effective demand management strategy than prices. Finally, given water supply infrastructure challenges in some areas, integrating the pricing strategy with targeted investment planning could stabilize access while still incentivizing sustainable usage. Overall, grounding the results in actionable policy design perspectives would strengthen their applied value for water resource managers seeking to reform systems.

5. DISCUSSION

In the ELES model, the water demand can be divided into basic demand and nonbasic demand. Basic water demand refers to the amount that can ensure residents' life, while nonbasic water demand refers to the amount that improves residents' quality of life. That will be charged based on the marginal consumption tendency and the carrying water price. According to the actual situation interviewed in our survey, water pricing mechanisms cannot be generalized, but should be determined according to the use and income level of the rural resident.

Therefore, our study believes that water pricing for rural residents should be divided into two parts. Under the first part, the basic water price has been calculated through the ELES model. Within the basic water demand, this part of the water charges has been fixed and independent. The second part is based on the bearing water pricing capacity, which is the water price based on the combination of residents' demand and consumption tendency. The charged object is the part beyond basic

Table 5 | ELES model results for each province (per capita waterer expenditure)

	Model 3	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**	**Model 9**	**Model 10**
Variables	Guangdong	Yunnan	Sichuan	Guangxi	Hubei	Hunan	Guizhou	Chongqing
Per capita disposable income	0.010*** (0.003)	0.002*** (0.001)	0.001* (0.000)	0.002** (0.001)	0.003** (0.001)	0.003*** (0.001)	0.003*** (0.001)	0.002*** (0.001)
Constant	3.982*** (1.380)	6.641*** (0.652)	7.649*** (0.428)	6.402*** (1.089)	5.173*** (1.038)	5.220*** (0.880)	6.968*** (0.659)	5.113*** (0.510)
F-test	9.45***	14.76***	3.02*	4.60**	6.15**	17.60***	17.68***	13.85***
Observations	518	461	817	267	462	327	679	784
R^2	0.151	0.044	0.013	0.030	0.055	0.068	0.043	0.060

Note: Robust standard errors are given in parentheses.
***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

Table 6 | ELES model results for each province (per capita consumption expenditure)

	Model 11	**Model 12**	**Model 13**	**Model 14**	**Model 15**	**Model 16**	**Model 17**	**Model 18**
VARIABLES	Guangdong	Yunnan	Sichuan	Guangxi	Hubei	Hunan	Guizhou	Chongqing
Per capita disposable income	0.536*** (0.070)	0.606*** (0.051)	0.456*** (0.171)	0.598*** (0.073)	0.636*** (0.059)	0.610*** (0.040)	0.639*** (0.046)	0.506*** (0.101)
Constant	212.645*** (34.172)	189.271*** (42.707)	250.751 (180.461)	192.795** (46.999)	161.206*** (50.750)	128.641*** (32.305)	260.322*** (35.602)	306.266*** (85.634)
F test	59.33***	138.53***	7.19***	99.11***	114.96***	229.44***	194.63***	24.87***
Observations	518	461	817	267	462	327	679	784
R^2	0.649	0.612	0.499	0.664	0.710	0.588	0.567	0.509

Note: Robust standard error are given in parentheses.

***$P < 0.01$, **$P < 0.05$.

Table 7 | Basic water prices in each province

	α_i	β_i	$\sum_{i=1}^{n} \alpha_i$	$\sum_{i=1}^{n} \beta_i$	**Per capita water consumption**	**Basic water expenditure**	**Basic water price**
Guangdong	3.982	0.010	212.645	0.536	2.466	8.565	3.468
Yunnan	6.641	0.002	189.271	0.606	2.681	7.602	2.837
Sichuan	7.649	0.001	250.751	0.456	3.122	8.110	2.599
Guangxi Zhuang Autonomous region	6.402	0.002	192.795	0.598	3.242	7.361	2.272
Hubei	5.173	0.003	161.206	0.636	2.581	6.502	2.520
Hunan	5.220	0.003	128.641	0.610	2.973	6.210	2.091
Guizhou	6.968	0.003	260.322	0.639	2.852	9.131	3.204
Chongqing City	5.113	0.002	306.266	0.506	2.450	6.353	2.593
Mean value	6.528	0.002	229.377	0.559	2.795	7.568	2.708

water demand. According to the calculation results, the per capita water monthly consumption is about 3m^3. Within this range, each unit of water has charged from CNY 2.091 to CNY 3.648 (each province is determined according to its basic water price, see Table 7). Monthly consumption over $3\ \text{m}^3$ could be charged higher than the basic water price and not higher than the bearing capacity water price as shown in Table 3.

6. CONCLUSION AND POLICY RECOMMENDATIONS

This article's main objective is to analyze the water expenditure of rural residents in the Karst region of China and to apply the ELES model to study the water consumption through the large micro-level survey data of 4,315 households in the Karst region. The results provide useful strategies for regionally differentiated pricing. The survey findings revealed that in the Karst region of China, 42% (4212/10011) of rural residents are using free water. The coefficient of water expenditure is low, and it is easy to lead to water waste because of insufficient constraints on residents' water consumption behavior. More importantly, the water charge is too low to cover the operation cost of water conservancy projects, so the supply of running water in some rural areas is unstable. The marginal propensity to consume water for rural residents is significant. It indicates that the expenditure on domestic water is positively affected by the level of income, but the marginal effect is smaller.

The study concluded that the per capita basic water demand is $3\ \text{m}^3$, which charged the water pricing ranging from 2.091 to 3.468 CNY/m^3 (each region is determined according to its basic water price). If the monthly consumption of water is more than $3\ \text{m}^3$, it shall be charged according to the basic water price and the carrying water price of each region (Table 2), which ranges from 3.463 to 7.122 CNY/m^3.

However, it may not be the best solution. This article argues that there are two more practical situations to consider. The first one is a reduction in water charges. In other rural areas like China, there are still many residents with low income, and high basic water prices may inhibit their use of running water, resulting in poor livelihood for these residents. During making the water pricing policies, according to the average income, the regions can be divided into more detailed. For areas with lower income, the water price can be lowered appropriately or the government can provide appropriate subsidies. For water users with financial difficulties, the basic water charge can be free. In this way, the project can be guaranteed to pay for itself, while at the same time guaranteeing the basic water of residents.

The second one is to add a management premium. The survey found that the actual use rate of running water in China's karst rural region is only 61.27%, although its penetration rate is as high as 95%. Part of the reason is that some residents choose to use other free water sources, such as river water and well water even if they have no financial difficulties. Thus, it leads to idle water pipes and increases the cost of management and maintenance. The lack of demand makes it difficult for the price mechanism to operate normally. Therefore, the study recommends a petty management premium based on the local basic water price, for households that have had idle water pipes for a long time.

There are some limitations of this study that should be noted: (1) Sample representativeness: Although a large sample size of over 4,000 households was used, the study was conducted only in the karst regions of China. The results may not be fully generalizable to other rural areas with different geographic and socioeconomic conditions. Expanding the survey coverage across more regions would improve representativeness. (2) Unobserved factors: There may be other unobserved household characteristics and contextual factors beyond income that influence water demand and pricing sensitivity. More granular data on these could improve the models. (3) Model limitations: While the ELES model provided useful insights, other modeling techniques could potentially generate even more refined estimates. More advanced econometric techniques could be explored.

Some directions for future work building on this study include the following: (1) conducting repeated global surveys to collect panel data over time, (2) testing alternative modeling approaches such as hedonic demand models, (3) comparing results across different geographic, economic contexts, and (4) evaluating actual policy impacts through natural experiments. In summary, while this study provides a good foundation, expanding its scope, time period, variables, methods, and real-world applications can help develop an even more robust understanding to guide water pricing reforms.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Achttienribbe, G. E. 1998 Water price, price elasticity and the demand for drinking water. *Aqua* **47** (4), 196–198. https://doi.org/10.1046/j.1365-2087.1998.00099.x.

Alazzeh, S., Galaitsi, S. E., Bishara, A., Al-Azraq, N. & Durant, J. L. 2019 Impacts of intermittent water supply on water quality in two Palestinian refugee camps. *Water* **11** (670), 1–12. https://doi.org/10.3390/w11040670.

Chesnutt, T. W. & Beecher, J. A. 1998 Conservation rates in the real world. *Journal/American Water Works Association* **90** (2), 60–70. https://doi.org/10.1002/j.1551-8833.1998.tb08378.x.

Dalhuisen, J., Florax, R., de Groot, H. & Nijkamp, P. 2003 Price and income elasticities of residential water demand: Why empirical estimates differ. *Tinbergen Institute Discussion Paper* **79** (2), 292–308.

Dianfa, Z., Ziyuan, O. & Shijie, W. 2001 Population resources environment and sustainable development in the Karst Region of Southwest China. *China Population Environment* **11**, 77–81.

Ellawala, K. C. & Priyankara, D. P. M. P. 2016 Consumer satisfaction on quantity and quality of water supply: A study in Matara, southern Sri Lanka. *Water Practice and Technology* **11** (3), 678–689. https://doi.org/10.2166/wpt.2016.073.

Fagundes, T. S., Marques, R. C. & Malheiros, T. 2023 Water affordability analysis: A critical literature review. *Aqua Water Infrastructure, Ecosystems and Society* **72** (8), 1431–1445. https://doi.org/10.2166/aqua.2023.035.

Grafton, R. Q., Chu, L. & Kompas, T. 2015 Optimal water tariffs and supply augmentation for cost-of-service regulated water utilities. *Utilities Policy* **34**, 54–62. https://doi.org/10.1016/j.jup.2015.02.003.

Guanjun, W., Dai, X. & Fei, Z. 2021 Research on the water price level and its measurement to promote residents’ water saving––Taking the urban water supply in Beijing as an example. *Price Theory and Practice* **9**, 59–62 + 141. https://doi.org/10.19851/j.cnki.CN11-1010/F.2021.09.344.

Howe, C. W. & Linaweaver, F. P. 1967 The impact of price on residential water demand and its relation to system design and price structure. *Water Resources Research* **3** (1), 13–32. https://doi.org/10.1029/WR003i001p00013.

Jianhao, W., Weiping, S. & Xiqin, W. 2018 Analysis on the farmers’–willing to pay for the irrigation water and effecting factors in Guanzhong area. *Journal of Arid Land Resources and Environment* **32** (3), 77–82. https://doi.org/10.13448/j.cnki.jalre.2018.076.

Lishi 2011 *The Study of Full Cost Urban Pricing Method*. Liaoning University, Shenyang, Liaoning, China.

Luby, I. H., Polasky, S. & Swackhamer, D. L. 2018 U.S. urban water prices: Cheaper when drier. *Water Resources Research* **54** (9), 6126–6132. https://doi.org/10.1029/2018WR023258.

Muldianto, H., Andawayanti, U., Suhartanto, E. & Soetopo, W. 2020 Determining water price for public water supply from Jatigede Reservoir. In: *Earth and Environmental Science*. IOP Publishing, Malang, East Java, Indonesia. pp. 1–8. https://doi.org/10.1088/1755-1315/437/1/012027.

Renwick, M. E., Archibald, S. O. & A, S. O. 1998 Board of regents of the University of Wisconsin system demand side management policies for residential water use: Who bears the conservation demand side management policies for residential water. *Source: Land Economics* **74** (3), 343–359. Available from: http://www.jstor.org/stable/3147117%5Cnhttp://about.jstor.org/terms.

Wichman, C. J., Taylor, L. O. & von Haefen, R. H. 2016 Conservation policies: Who responds to price and who responds to prescription? *Journal of Environmental Economics and Management* **79**, 114–134. https://doi.org/10.1016/j.jeem.2016.07.001.

Yu, H. & Wenjin, G. 2011 Problems and countermeasures in the application of stepped water price in my country. *Price Theory and Practice* **02**, 38–39. https://doi.org/10.19851/j.cnki.cn11-1010/f.2011.02.018.

Yulin, Z., Xing, C., Hengsong, W., Xiangxiang, Z., Wei, W. & Huihua, Z. 2018 Characteristics and exploitation of groundwater resources in the Northern Part of Wudang District, Guiyang. *Geographical and Environmental Sciences* **36**, 74–80.

Zhou, Y. 2016 *Price Determination and Management of Rural Drinking Water – A Case Study of Dianjun*. Wuhan University of Technology, Wuhan, Hubei, China.

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