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Investigation and evaluation of water literacy of urban residents in China based on data correction method

Kang Tian[a], Han Wang[b] and Yanrong Wang[a,*]

[a]*School of Management and Economics, North China University of Water Resources and Electric Power, Zhengzhou, China*
**Corresponding author. E-mail: wyr223@126.com*
[b]*School of Water Conservancy, North China University of Water Resources and Electric Power, Zhengzhou, China*

Abstract

This study proposes an evaluation index system of water literacy levels. Thirty-one provincial capitals in mainland China were selected for the survey. The preliminary evaluation results were revised to obtain the comprehensive evaluation value of water literacy. The results of the questionnaire show that the water literacy score is relatively high, but the water behavior score is relatively low; the modified evaluation results are closer to the actual water literacy level of urban residents; and the comprehensive evaluation value of water literacy has a certain correlation with the distribution of water resources in China. The research results can provide theoretical support for China's future work to improve citizens' water literacy, and the water sector can formulate policies that are more in line with China's water resource status based on the level of water literacy, differences in water behavior, and water resource distribution.

Keywords: Evaluation index; Questionnaire survey; Revision and adjustment; Water literacy; Water literacy evaluation value

Highlights

- Try to propose a set of water literacy evaluation index system from the aspects of necessary water knowledge, scientific water attitude, and standardized water behavior.
- This article attempts to propose data correction methods based on two ways.
- After the sampling population structure and water-saving efficiency value are revised, the evaluation result is closer to the actual water literacy level of urban residents.

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Introduction

With the advancement of urbanization and the gradually deepening impact of urban residents' activities on water resources, water shortages, water pollution and flooding have emerged as important challenges constraining the high-quality development of the economy. These problems are no longer just natural science problems but have extended to the social and economic systems, as have the solutions (Tong, 2016). At this point, the urban water problem is still worsening. The solution is not only to further optimize allocation of water resources, water pollution prevention and control, water ecological restoration and other measures, but also to raise the water literacy level of urban residents so that the behaviors of appreciating, saving and protecting water become the conscious actions of urban residents.

Water literacy is a type of comprehensive quality related to the ecological environment of water, the relationship between humans and the water ecological environment, as well as human's behavior toward that environment formed by people's study and accumulation in production and daily life. It is the sum of the necessary water knowledge, scientific water attitudes and normative water behaviors (Wang *et al.*, 2018). The formation of water literacy starts with the mastery of water knowledge, and then water knowledge is internalized into water attitude (motivation, interest, emotion, values, etc.), which is used to guide their actions and cultivate and form correct water behavior. Water knowledge is the most basic level of water literacy, water attitude is the link between water knowledge and water behavior, and water behavior is the core content of water literacy.

At present, there are few studies focusing on water literacy at home and abroad; most research is focused on water-related knowledge, attitudes toward water, or water-saving or water-use behaviors in a particular region, industry or social group. In terms of water knowledge, a survey of 17 U.S. states indicated that fewer than half of the respondents were very familiar with 14 water-related terms (e.g. groundwater) (Pritchett *et al.*, 2009). Another survey of South Carolina residents reported that only 28% of respondents could identify the correct definition of a watershed (catchment) (Giacalone *et al.*, 2010). Guo (2009) conducted an in-depth investigation and analysis of the water knowledge of Dai people in Xishuangbanna and found that the traditional water culture of the Dai people promoted the formation of technologies and systems for sustainable use and management of water resources; Wang & Li (2009) pointed out that the reduction of pollution accident rates and the safe protection of drinking water can be promoted by water pollution knowledge training for residents near water sources. Different scholars use different indexes to investigate water knowledge. Dean *et al.* (2016a) used urban water cycles, water management and other indexes to design 15 questions to evaluate the mastery of water knowledge among Australian adults. Additionally, the impact of demographics, psychosocial characteristics, water-related information disclosure, and water-related behaviors and policies on water knowledge mastery has been studied. A range of life experiences – or 'situation-specific' factors – can influence such knowledge, including geographic experience, such as region of residence and experience of drought, or particular rainfall patterns; household context, such as homeownership or the presence of gardens; social experiences, such as participation in community groups, use of waterways or life satisfaction; and exposure to information (Miller & Buys, 2008; Wagner *et al.*, 2011; Dean *et al.*, 2016b).

In terms of water attitude, Hao *et al.* (2010) believe that water-saving awareness is measured through three dimensions. Attitude toward water resources is one's understanding of the natural attributes of water resources, sensitivity refers to one's perceptions of changes in water resources, and sense of responsibility examines whether one believes one is responsible for water conservation. Lawrence & McManus (2008) used indexes such as 'over-utilization will reduce available resources', 'over-utilization will lead to ecological degradation' and 'everyone has the responsibility to protect energy, water and other resources' when crafting questions to examine respondents' attitudes toward water. Tian (2012) believes that the ecological concept of water ethics is the moral proof of water in the aspect of ecology. This concept contains the ecological explanation for water itself and the intention of injecting spiritual elements into the ethics of rational utilization of water resources. Therefore, water ethics is an ecological orientation established in the ethical way of life in accordance with natural water ethics. Based on survey data of residents of Hangzhou in Zhejiang Province, Wang *et al.* (2016) verified the significant impact of value cognition, positive emotions and negative emotions on citizens' water-saving effects; the results showed that positive emotions had the greatest impact. Yuan *et al.* (2015) defined a water-saving attitude as a 'water saving viewpoint' and 'results expectation'. Through investigation and research, exploratory factor analysis (EFA), confirmatory factor analysis (CFA) and hierarchical regression methods were used to verify the positive impact of a water-saving attitude on water-saving behavior.

There are more studies on water-saving behaviors. To examine personal water-use behaviors, it is necessary to fully understand water consumption, such as reduction of water-use frequency and time, changes in the method of water use, water-saving and water-saving appliance utilization. Additionally, some behaviors that result in changes to water use can positively influence other people, such as persuasion and other forms of communication (Corral-Verdugo *et al.*, 2003; Clark & Finley, 2007; Randolph & Troy, 2008; Jiang & Zhao, 2015). Yang & Liang (2007) conducted an empirical analysis of urban residents' water-saving behavior and its influencing factors and noted that the surveyed characteristics are some of the influencing factors in water-saving behavior. Dolnicara *et al.* (2012) used multiple linear regression analysis and decision-tree analysis to analyze survey data; their results showed that high-level environmental protection behavior and more attention to water-related information can best predict water-saving behaviors. Wang *et al.* (2019) designed a questionnaire based on 12 indexes including participation in water-saving and protection activities and participation in water ecological environmental protection activities to explore regional differences in typical city residents' water behaviors. Russell & Fielding (2010) review of water demand management research categorized the determinants of water conservation behavior into five root causes:

1. attitudinal predictors: attitudes, subjective norms and perceived behavioral control;
2. belief predictors: environmental beliefs, ecological world view, and water-specific beliefs;
3. habit and routine predictors: clothes-washing, showering and general water-use habits;
4. personal capability predictors: various age, educational, income, occupation and knowledge groups;
5. contextual factor predictors: number of residents in households, home ownership, water pricing and type of home.

At present, most studies on water literacy involve characterization factor analysis, pilot city investigation, etc. (Tian *et al.*, 2018; Wang *et al.*, 2018), while few have carried out large-scale investigations or evaluations and put forward optimized evaluation methods based on the investigation data. In this paper, we start with the concept of water and construct an evaluation index system of urban water residents' water literacy, and then we develop a questionnaire according to the evaluation index system. Based on the investigation and analysis of 31 provincial capital cities in China, the evaluation results are preliminarily evaluated, and these results are revised according to the structural deviation of the sampled population and the value of water-saving efficiency to obtain the final comprehensive evaluation value of water literacy. Through an analysis of the final results, the water literacy level of urban residents is objectively evaluated, laying a solid foundation for future theoretical and practical research.

Evaluation index system of the water literacy of urban residents

When designing the index system for water literacy evaluation, the scientific theories used must be complete and correct, and the concept of the index must be defined accurately to determine the weight of each index. It is also necessary to have a comprehensive understanding of the amount of water resources in each region, the distribution of water resources, social and economic status and regional functional positioning. Through practical investigation, demonstration, research and analysis, the utilization rate of water resources, water resource reuse capacity and regional population distribution can be fully understood.

Through literature tracking and expert consultation, based on relevant concepts and connotation analysis of water literacy and on basic criteria such as the scientific nature and dynamics of indexes, the correlational and hierarchical relationships of indexes are defined to construct a preliminary index system that conforms to the reality of water literacy in China. To improve the scientific nature and rationality of the index system of water literacy evaluation, the research group selected 29 index factors as the research basis of the system (Wang *et al.*, 2018) and then used the qualitative expert consultation method to revise and improve it. For example, through interviews, networks, etc., the general public was surveyed so that everyone could discuss and comment on the citizen water literacy evaluation index system. Expert consultations (the expert database mainly includes related experts, such as the water conservancy department and education department) were then conducted through interviews, telephone calls, etc., to obtain respondents' opinions and suggestions on the index system. After listening to the opinions of the experts, the revised citizen water literacy evaluation index system was further refined. The opinions and suggestions of the research experts focused mainly on the following two aspects: (1) The selection of evaluation indexes was reasonable, but the observation points were classified too carefully, so deleting or merging could be considered; (2) Indexes should be expressed as accurately and clearly as possible in the process of questionnaire design.

The experts confirmed that our evaluation index system of residents' water literacy constructed by combining existing literature and expert advice is scientifically sound and reasonable. It is composed of three first-level indexes, 10 second-level indexes, 29 third-level indexes and a number of observation points. The weight of water knowledge, water attitude and water behavior in the water literacy assessment was determined by using the analytic hierarchy process (AHP), with the following calculation steps: (1) determine the hierarchical structure; (2) use the evaluation scale (1–5), and consult experts to compare the evaluation indexes of the same level and the building judgment matrix; and (3) calculate the weight of each index using the square root method. The calculation procedure of the square root method was as follows: First, the product of each row element of the judgment matrix was calculated by using the formula $M_i = \prod_{j=1}^{n} a_{ij}$, $i = 1, 2, \cdots n$. Second, we calculated the nth root of M_i as follows: $w_i = \sqrt[n]{M_i}$. Again, the vector $w = [w_1, w_2, \cdots w_n]^T$ was normalized, and $\omega_i = w_i / \sum_{i=1}^{n} w_i$ was the weight of each index. Then, we calculated the maximum eigenvalue of the judgment matrix

$\lambda_{\max} = 1/n \sum_{i=1}^{n} (Aw)_i/\omega_i$. Finally, we used the formula to calculate $CI = \lambda_{\max} - n/n - 1$, $C.R = CI/RI$, where CI is the consistency index value, RI is the average random consistency index value, $C.R$ is the consistency ratio of each index, and when $C.R < 0.1$ is considered, the matrix is a consistency matrix and the weight determination is valid as shown in Table 1. The index system and its weight could be used as the theoretical basis for designing the questionnaire.

Questionnaire and preliminary evaluation

According to the idea of sampling statistics, respondents' water literacy was assessed by randomly sampling from different groups based on a certain sample rate and questionnaire content (including the combination of an online survey and a household survey). The questionnaire was presented in the form of objective questions for the convenience of data statistics and analysis. The water knowledge scale mainly evaluates citizens' understanding of water-related knowledge. The water attitude scale mainly assesses how citizens treat and deal with water-related emotions, responsibilities, ethics and other behavioral intentions. The water behavior scale mainly assesses citizens' participation in solving various water problems. The water knowledge scale adopts the form of judgment questions, and the final scoring rules are consistent with a Likert five-level scale. The water attitude and water behavior scales are all calculated by a Likert five-level scale, with different scores assigned to different orders of magnitude.

Design of the sampling survey

Water literacy surveys include background information on survey samples, understanding of water literacy, sources of water knowledge, residents' attitudes toward water, and residents' water behavior. Based on the established index system, the questionnaire quantitatively measures whether each sample has a high level of water literacy based on the three aspects of 'necessary water knowledge', 'scientific water attitude' and 'normative water behavior'. The numbers of questions on water knowledge, water attitude and water behavior in the questionnaire were set according to the weight of each index. On this basis, the question bank and pre-survey questionnaire were developed. We selected Beijing, Zhengzhou, Hechi and Qingtongxia as the pilot cities, and a certain number of permanent residents were selected for evaluation. According to the answer conditions of the four pilot cities, the answer conditions of different scales and the overall effect were analyzed, and the test question bank was improved accordingly. Based on a complete test database, the research group held a seminar for experts in hydrology and sociology. After repeated discussion and modification, the questionnaire to evaluate the water literacy of residents of provincial capitals was finally developed. The questionnaire consists of four parts: basic personal characteristics, water knowledge scale, water attitude scale and water behavior scale. The first part consists of basic personal characteristics, including six demographic indexes such as gender, age, education, occupation, residence and family annual income. The second part is the water knowledge scale. The third part is the water attitude scale. The fourth part is the water behavior scale (see Table 2).

The water literacy survey was conducted among residents over six years of age in China. The survey selected 31 inland provincial capitals excluding Hong Kong, Macao and Taiwan. This study used quota

Table 1. Evaluation index system of residents' water literacy and its weight.

First grade index (weight)	Second grade index (weight)	Third grade index (weight)	Observation point
Water knowledge (0.0914)	Basic knowledge of water science (0.2763)	Knowledge of the physics and chemistry of water (0.0370)	Three states of water and its color, odor, freezing point and boiling point; artificial rainfall phenomenon; water chemical composition and formula; water hardness; water quality
		Knowledge of water distribution (0.4350)	Distribution and characteristics of water resources on earth; scarcity of fresh water resources; reserves and distribution of water resources in China; local reserves and distribution of water resources; local sources of drinking water
		Water cycle knowledge (0.0535)	Process of the water cycle on earth; factors affecting the water cycle
		Knowledge of commodity properties of water (0.1875)	Water rights; water price
		Knowledge of water and life (0.2870)	Water and the origin of life; water around you and in your body
	Knowledge of water resource development, utilization and management (0.1273)	Knowledge of water resource development and utilization (0.2)	Common types of water; development and utilization of water resources
		Knowledge of water resource management (0.8)	Water resource management organization system; administrative, legal, economic and technical means of water resource management
	Knowledge of water ecological environment protection (0.5964)	Impact of human activities on the aquatic ecological environment (0.5083)	Understanding the positive and negative effects of human activities on the ecology of the water environment
		Knowledge of water environment capacity (0.0555)	Meaning and influence factors of water environmental capacity
		Water pollution knowledge (0.2908)	Main water pollutants and their main sources
		Knowledge and skills of water eco-environmental action strategies (0.1454)	Main ways to protect the aquatic environment and laws and regulations; phone number to make reports to the aquatic environmental protection department
Water attitude (0.2176)	Water feelings (0.1047)	Water interest (0.3333)	Famous ancient and modern water conservancy engineering, water landscape, and water conservancy experts; poetry and culture related to water in the region, sightseeing experience of scenic spots and historic sites related to water, visiting experience of water museum/water culture base
		Water attention (0.6667)	Flood disasters; water shortage; water pollution; personal judgment on the effectiveness of existing water resource management methods
	Water responsibility (0.6370)	Water-saving responsibility (0.6667)	Individual citizens' willingness to save water
		Water protection responsibility (0.3333)	Individuals' personal willingness to protect water
	Water ethics (0.2583)	Water ethics (0.6)	Value orientation related to the water ecological environment
		Water moral principles (0.4)	Water justice; water sharing; water ecological compensation

Water behavior (0.6910)	Water ecology and water environment management behavior (0.1201)	Participate in publicity of water saving and water protection (0.0882)	World Water Day, China Water Week and other theme activities; water-related public service advertisements; water-saving, water-protection and love for water propaganda organized by community/school
		Participate in the protection of ecological water environment (0.1569)	Afforestation; water source protection experience
		Proactive learning of water-saving skills (0.2717)	Water-saving educational experience; cultivating water-saving skills
		Proactive learning of disaster avoidance skills (0.4832)	Understanding the types and hazards of water disasters; mastering emergency measures
	Persuasion (0.0621)	Participating in prevention of water pollution events (0.8333)	Preventing water pollution by other people or organizations
		Participating in public welfare activities of environmental protection organizations (0.1667)	Accepting and participating in the activities carried out by public welfare environmental protection organizations
	Consuming behavior (0.5751)	Production and domestic wastewater reuse behavior (0.5396)	Water reuse and domestic wastewater recycling
		Domestic sewage recycling behavior (0.2970)	Impact of habits and lifestyle on water consumption (handwashing, bathing, laundry, etc.)
		Domestic water consumption (0.1634)	Water-saving facility utility in family, company/community
	Legal behavior (0.2427)	Water-saving facility utility; abide by the water-related laws and regulations (0.6250)	Other people break the water-related laws and regulations
		Report or supervise water environment incidents (0.1365)	Reporting illegal activities to the environmental supervision and law enforcement department
		Supervise the management effectiveness of law enforcement department (0.2385)	Judgment on the management effectiveness of law enforcement department

sampling to select respondents. The investigation officer was investigated by administrative region with overall sample mark classification or stratification. Then, the sample amount was determined according to the overall sample of the survey and confirmed by the scale of the total population of each provincial capital. The respondents were classified in detail in the urban and suburban areas. By adopting different proportions of online and offline surveys, samples from different demographic indexes were selected randomly.

A total of 13,850 questionnaires were distributed in 31 provincial capitals of China, and a total of 12,701 questionnaires were recovered. After eliminating the questionnaires that were considered invalid by the research group, the remaining effective questionnaires numbered 10,024, with a total effective rate of 72.38%. The distribution and recovery of the questionnaires is shown in Table 3.

Before the analysis and evaluation of the survey data, SPSS22.0 was used to test the reliability and validity of the scale. As seen in Table 4, the Cronbach's α values of the three subscales of water knowledge, water attitude and water behavior are 0.728, 0.704 and 0.924, respectively, and the Cronbach's α value of the total subscale is 0.901. Both the total subscale and individual subscales meet the requirements of the reliability coefficient (the total subscale is larger than 0.8, and the subscale is larger than 0.7). This indicates that the scale has high reliability. As seen in Table 5, the Kaiser-Meyer-Olkin (KMO) value of the sample suitability measure is 0.922, the Bartlett spherical test value is 109,706.907, and the degree of freedom is 300. The P value is 0.00, which is significant, indicating that factor analysis is suitable between the item variables.

Questionnaire survey and evaluation results

The water literacy questionnaire was evaluated by assigning points to the questions using a Likert scale to calculate the score of each questionnaire. Additionally, the weights of water knowledge, water attitude, water behavior and other indexes at all levels were combined to calculate the evaluation value of each investigator's water literacy. Due to the different densities of permanent residents in different cities, the numbers of questionnaires issued also differed. Therefore, the mean score was adopted to

Table 2. Dimensional distribution of questionnaire questions.

Dimension	Theme	Topic quantity
Water knowledge (judgment questions)	Basic knowledge of water science	2 (8 judgment questions)
	Knowledge of water resource development, utilization and management	1 (4 judgment questions)
	Knowledge of water ecological environmental protection	1 (4 judgment questions)
Water attitude (multiple choice)	Water feelings	2
	Water responsibility	3
	Water ethics	2
Water behavior (multiple choice)	Water ecological environment Management behavior	4
	Persuasion behavior	2
	Consumer behavior	5
	Legal behavior	3

Note: The water knowledge scale is reflected in the form of judgment questions. The score standard is 1 point for answering all errors, 1 point for each correct answer, and so on. We made the score standard consistent with the water attitude five-level scale and the water behavior five-level scale.

Table 3. Summary of the number of valid questionnaires collected in provincial capitals and cities.

City	Number of questionnaires issued/valid	City	Number of questionnaires issued/valid
Chongqing	700/542	Fuzhou	400/325
Shanghai	700/546	Changsha	450/296
Beijing	700/585	Jinan	360/295
Tianjin	700/378	Nanning	440/288
Chengdu	500/361	Kunming	440/335
Wuhan	450/405	Nanchang	540/292
Shijiazhuang	500/392	Guiyang	300/243
Haerbin	520/443	Taiyuan	350/203
Zhengzhou	550/431	Lanzhou	330/224
Hangzhou	530/402	Wulumuqi	300/185
Changchun	400/301	Huhehaote	270/211
Xian	400/321	Xining	360/240
Guangzhou	520/332	Haikou	400/245
Shenyang	350/320	Yinchuan	240/199
Nanjing	350/259	Lasa	300/161
Hefei	500/264		
Total:13850/10024			

Table 4. Cronbach's α coefficient of each index in the scale.

Scale	Topic quantity	Cronbach's α coefficient
Water knowledge scale	4	0.728
Water attitude scale	7	0.704
Water behavior scale	14	0.924
Total table	25	0.901

Table 5. Cronbach's coefficient of each index in the scale.

Project	Index	Value
KMO measuring sampling suitability		0.922
	Approximate chi square	109,706.907
Bartlett's test of sphericity	df	300
	Significant	0.000

calculate the scores of different cities. According to the Chinese residents' water literacy evaluation index system and the water literacy evaluation value calculation method, the residents' water literacy index of 31 provincial capitals in China except Hong Kong, Macao and Taiwan in 2017 was ranked, as shown in Table 6.

As seen in Table 6, the only city with a water literacy evaluation value of more than 80 among the capital cities of China in 2017 is Haerbin. The cities with water literacy evaluation values of 75–80 (excluding 80) are Yinchuan, Lanzhou, Chengdu, Taiyuan, Guiyang, Jinan, Shenyang, Beijing,

Table 6. Evaluation value and ranking of water literacy of residents of provincial capitals.

Serial number	City	Water knowledge evaluation value	Water attitude evaluation value	Water behavior evaluation value	Water literacy evaluation value
1	Beijing	91.83	83.48	70.77	75.46
2	Tianjin	89.17	85.13	68.69	74.14
3	Shijiazhuang	87.46	83.34	70.90	75.12
4	Taiyuan	87.57	83.17	74.01	77.24
5	Huhehaote	81.84	77.41	73.03	75.00
6	Shenyang	90.80	86.13	70.56	75.80
7	Changchun	90.91	77.48	64.73	69.90
8	Haerbin	95.29	90.29	79.24	83.11
9	Shanghai	92.57	81.08	61.90	68.87
10	Nanjing	91.87	77.67	61.87	68.93
11	Hangzhou	87.83	82.65	66.61	72.04
12	Hefei	87.26	76.43	65.53	69.89
13	Fuzhou	92.40	84.70	68.51	74.21
14	Nanchang	94.15	81.88	69.74	74.61
15	Jinan	88.57	85.87	72.58	76.94
16	Zhengzhou	92.85	84.36	67.19	73.27
17	Wuhan	88.64	79.42	63.46	69.24
18	Changsha	91.77	82.67	67.20	72.81
19	Guangzhou	93.07	81.75	64.58	70.92
20	Nanning	89.04	77.67	62.49	68.22
21	Haikou	84.67	81.14	69.40	73.35
22	Chongqing	90.91	81.44	66.10	71.70
23	Chengdu	89.96	84.86	73.90	77.75
24	Guiyang	86.95	86.61	72.63	76.98
25	Kunming	91.39	81.97	67.07	72.54
26	Lasa	92.09	82.73	65.40	71.61
27	Xian	86.35	76.84	61.67	67.23
28	Lanzhou	89.24	85.32	74.34	78.09
29	Xining	91.13	78.13	70.02	73.71
30	Yinchuan	89.22	87.47	74.09	78.38
31	Wulumuqi	86.48	77.17	65.02	69.62

Note: All the urban water literacy evaluation values are calculated on a percentage basis, which is a 20-fold increase based on the average value of the Likert scale.

Shijiazhuang and Hohhot. The cities with water literacy evaluation values of 70–75 (excluding 75) are Nanchang, Fuzhou, Tianjin, Xining, Haikou, Zhengzhou, Changsha, Kunming, Hangzhou, Chongqing, Lhasa and Guangzhou. The cities with water literacy evaluation values below 70 (excluding 70) are Changchun, Hefei, Urumqi, Wuhan, Nanjing, Shanghai, Nanning and Xi'an. Overall, the water literacy levels of Chinese residents differ considerably, without obvious common characteristics. In the process of calculation, the evaluation values of the water knowledge and water attitude scales are relatively high, while the evaluation value of the water behavior scale is obviously low, and the evaluation value of the water behavior scale is the main reason for the low evaluation value of water literacy in many cities. Due to limitations on the length of this article, the internal mechanism and its influence path will be further discussed in a subsequent evaluation.

Revision of the evaluation methods and evaluation results

Based on the preliminary evaluation results of the above-mentioned water literacy questionnaire survey, considering the deviation between the structure of the sampled population and the actual general population and the difference between the actual living water consumption of residents in daily life and the domestic water quota of urban residents, the results of the questionnaire survey were corrected and adjusted. The comprehensive evaluation value of water literacy obtained through correction and adjustment was more in line with and closer to the actual value of the water literacy levels of residents in each provincial capital.

Correction based on the structure of the sampled population

In a sampling survey there will be deviation between the sample and the overall population. This deviation will affect the accuracy and validity of the sampling survey. When the survey index is highly correlated with the target quantity, the deviation between the sample and the overall structure will affect the estimation result of the target estimator. To better estimate the overall relevant information and improve the accuracy of the estimation results, it is necessary to adjust the survey sample structure. This study used the idea of the calibration estimation method. The original weights were determined and then adjusted by using auxiliary information to obtain new calibration weights, making the sample structure as close as possible to the population structure. The reduction of differences between the sample and population structures can improve the estimation accuracy (Deville & Särndal 1992).

There are several basic personal characteristics of the respondents in the scale. Therefore, this paper used Eviews 8.0 to carry out regression analysis on the basic personal characteristics of the sample survey. Regression analysis is the analysis of the degree of correlation between the combination of multiple independent variables and the dependent variable by establishing a regression equation, which can determine the independent variable that affects the change of the dependent variable, and the size of the impact can be determined by the size of the regression coefficient. According to the relevant standards of regression analysis and the regression results in Table 7, the regression analysis of water literacy by the six characteristic variables designed shows that the *P* value of the gender characteristic variable is greater than 0.05, which has no significant influence on water literacy, and the regression effect is not significant, so it is excluded. The *P* values of other variables are all less than 0.01, and the regression effect is significant. Therefore, the regression model is acceptable, and the adjusted R^2 (coefficient of determination – the proportion of the total variation of the response dependent variable that can be explained by the independent variable through the regression relationship) is 0.035, indicating that the characteristic variables account for 3.5% of the variation in water literacy. We know from the column of the standard regression coefficient that five characteristic variables in addition to gender enter the regression equation at the same time. Residents' water literacy is affected and restricted by five characteristic variables, such as age and education level. However, education level entered the model before other characteristic variables, indicating that the influence of education levels on residents' water literacy is greater than those of other characteristic variables. At the same time, based on the survey data, the collinearity diagnosis of the dataset was performed by SPSS24.0, and water literacy was taken as the dependent variable. All the basic characteristics of the individual entered the model as independent variables. The results showed that the tolerance values are all above 0.8 and less

Table 7. Regression analysis of characteristic variables.

					Collinear statistics	
Variable	Coefficient	Std. Error	t-Statistic	Prob.	Tolerance	VIF
C	3.621	0.047	76.773	0.000		
Gender	–0.004	0.013	–0.317	0.751	0.995	1.005
Age	–0.034	0.006	–5.212	0.000	0.832	1.202
Education level	0.071	0.006	10.982	0.000	0.893	1.120
Occupation	0.027	0.004	7.652	0.000	0.833	1.200
Residence	–0.073	0.015	–4.833	0.000	0.897	1.115
Income	–0.034	0.005	–6.909	0.000	0.994	1.006
R-squared	0.035	Mean dependent var.		3.645	Using water literacy as a dependent variable, all individual basic characteristics enter the collinearity diagnostic model as independent variables	
Adjusted R-squared	0.035	S.D. dependent var.		0.676		
S.E. of regression	0.664	Akaike info criterion		2.019		
Sum squared resid.	4,411.205	Schwarz criterion		2.024		
Log likelihood	–10,107.380	Hannan-Quinn criter.		2.021		
F-statistic	60.832	Durbin-Watson stat.		1.484		
Prob. (F-statistic)	0.000					

Note: Due to the low degree of influence of the characteristic variables on water literacy, the adjusted R-squared below 0.05 can also be compared and analyzed.

than 1, and all the variance inflation factors (VIFs) are less than 10, so there is no collinearity problem between the independent variables.

Therefore, in the process of structural adjustment, the evaluation results were modified based on the residents' education level by referring to the method for correcting scientific literacy evaluation results suggested by Xu *et al.* (2014) and Lv & Yu (2018) for data correction and adjustment. The specific correction methods used were as follows:

1. According to the above results, the questionnaire was classified according to education level, and the evaluation value of water literacy of provincial capitals in primary school and below, junior high school, senior high school (including technical secondary school, technical secondary school, vocational high school and technical school), bachelor's degree (including junior college), master's degree and above was calculated as N_1, N_2, N_3, N_4, N_5. The total number of respondents is denoted as A, and the number of people with different education levels is denoted as A_1, A_2, A_3, A_4, A_5.
2. In the sample survey, the proportions of the five groups by education level are denoted as L_1, L_2, L_3, L_4, L_5.
3. In the actual total population of provincial capital cities, the actual proportions of the five groups by education level are denoted as K_1, K_2, K_3, K_4, K_5.

The corrected evaluation value of water literacy is denoted as F_1, that is:

$$F_1 = (A_1 * \frac{K_1}{L_1} * N_1 + A_2 * \frac{K_2}{L_2} * N_2 + A_3 * \frac{K_3}{L_3} * N_3 + A_4 * \frac{K_4}{L_4} * N_4 + A_5 * \frac{K_5}{L_5} * N_5)/\mathrm{A} \quad (1)$$

Adjustment based on the domestic water-saving efficiency value

The water-saving efficiency value of life will fluctuate with changes in the domestic water consumption of urban residents and the quota of domestic water use in the area. Consequentially, this paper adjusts the water literacy evaluation value of the residents in this area based on the water-saving efficiency value generated by the difference between the actual domestic water consumption of urban residents and the residential water quota for a certain period of time. The resident water use quota represents the standard value that meets the basic needs of people in daily life. Considering the different levels of regional economic development and geographic location, there will be some differences in the resident water quota. In some areas, the water administration department adopts an interval form when formulating water use quota standards. The upper limit of the index value is based on the temperature change and the monthly peak change parameter. In a year, the water for residents can be assessed in stages, and the upper limit can be used as the index value of the highest month of the year. Therefore, for the area where the interval value is used, the reference value of the resident water use quota is selected within the interval value of the area in which it is located. Comprehensive expert opinion: Considering the actual situation of the domestic water consumption of the Chinese residents, it is recommended to choose the maximum value of the residents' domestic water quota interval so that the calculation result of the water-saving efficiency value is more in line with the actual situation of urban residents. For example, in some provincial capital cities such as Wuhan, where relevant documents give clear water quotas, the most recent standard values are used, which makes the provincial city adjusted values closer to the actual situation (Table 8).

Table 8. Actual domestic water consumption and water quota for each city (unit: L/D• person).

City	Residents' actual living water consumption	Water quota	City	Residents' actual living water consumption	Water quota
Beijing	254.98	180.00	Wuhan	142.31	137.00
Tianjin	98.22	116.66	Changsha	142.67	160.00
Shijiazhuang	94.99	110.00	Guangzhou	331.08	200.00
Taiyuan	121.85	120.00	Nanning	173.34	190.00
Huhehaote	92.23	135.00	Haikou	341.44	220.00
Shenyang	125.24	125.00	Chongqing	183.46	150.00
Changchun	103.67	135.00	Chengdu	180.56	220.00
Haerbin	156.74	160.00	Guiyang	116.88	160.00
Shanghai	284.72	180.00	Kunming	176.03	160.00
Nanjing	336.32	150.00	Lasa	158.81	150.00
Hangzhou	333.28	180.00	Xian	126.87	140.00
Hefei	147.69	180.00	Lanzhou	76.19	110.00
Fuzhou	143.93	180.00	Xining	129.36	120.00
Nanchang	150.02	185.00	Yinchuan	147.15	110.00
Jinan	86.97	120.00	Wulumuqi	115.76	90.00
Zhengzhou	111.223	120.00			

Note: Data on the actual living water consumption of residents are based on the 2016 Statistical Yearbook and Water Resources Bulletin of each provincial capital.

The domestic water quota mentioned in this paper is based on the standard of domestic water consumption of urban residents (GB/T 50331-2002) and refers to the specific documents of the standard of domestic water consumption of urban residents in each region to obtain the specific data of the domestic water quota of each provincial capital city. To make the calculation results more realistic, the highest water quota for ordinary houses is used as the standard.

The data of provincial capital cities such as Shijiazhuang, Hefei, Zhengzhou, Lasa and Xining are incomplete or abnormal, and the average value of the latest data of the province is adopted.

The specific formula for adjusting the water-saving efficiency value is:

$$F_2 = \theta * (1 + \omega);\ \omega = \frac{W_2 - W_1}{W_2} \tag{2}$$

where F_2 is the water-saving efficiency value adjustment, ω is the water-saving efficiency value adjustment coefficient in the area, and θ is the evaluation reference value. It is currently determined to be 60, indicating that when the actual living water of the residents is consistent with the domestic water quota, the water use behavior reaches the qualified benchmark. W_1 is the actual domestic water consumption of the resident (unit: L/D• person), and W_2 is the resident water quota (unit: L/D• person). The water-saving efficiency value ranges from –1 to 1, and the water-saving efficiency value adjustment coefficient can be from 0 to 1. Residents' water consumption is lower than the domestic water quota in the area, indicating that residents in the area have a strong awareness of water conservation and will restrict their water use behavior in daily life. Conversely, when the water-saving efficiency value adjustment coefficient is –1 to 0, the per capita water consumption in the region is high, and the awareness of water conservation is weak.

Comprehensive evaluation results of the water quality of residents in provincial capital cities

Based on the two correction methods above, the weights of the two adjustment methods in the adjustment process differ. In consultations with relevant experts and combining the theoretical bases of water literacy, experts and research groups agreed that the water literacy evaluation value obtained through the questionnaire is more objective and should be given a higher weight. Through a theoretical discussion and analysis of relevant data, it was finally determined that 0.8 should be used as the weight of the revised water literacy evaluation value and that the water-saving efficiency adjustment value should be set at 0.2.

The comprehensive evaluation of water literacy is indicated by the final formula:

$$W = 0.8F_1 + 0.2F_2 \tag{3}$$

Here, W is the comprehensive evaluation value of water literacy, F_1 is the water literacy evaluation value after correction, and F_2 is the water-saving efficiency adjustment value.

According to the above calculation method, the comprehensive water literacy values of residents in 31 provincial capital cities except Hong Kong, Macao and Taiwan in 2017 are calculated and ranked accordingly, as shown in Table 9.

Research conclusions and suggestions

Research conclusions

Through surveying and evaluating the water literacy of residents in 31 provincial capitals in China, the following research conclusions are obtained.

The results of the questionnaire on urban residents' water literacy are closer to the actual water literacy level of urban residents based on the structure of the sampled population and the adjustment of the water-saving efficiency value of the surveyed cities. According to the analysis of Eviews 8.0, the impact of education level on water literacy of residents is higher than that of other individuals.

Table 9. Comprehensive evaluation and ranking of water literacy in provincial capital cities.

City	Questionnaire score	Corrected score based on the structure of the sampled population	Adjusted score based on water-saving efficiency value	Comprehensive evaluation value	Sort
Lanzhou	78.09	79.19	78.44	79.04	1
Haerbin	83.11	83.06	61.22	78.69	2
Chengdu	77.75	80.09	70.76	78.23	3
Guiyang	76.98	75.73	76.17	75.82	4
Huhehaote	75.00	73.65	79.01	74.72	5
Fuzhou	74.21	73.37	72.02	73.10	6
Shenyang	75.80	76.01	59.89	72.79	7
Shijiazhuang	75.12	73.18	68.19	72.18	8
Taiyuan	77.24	75.39	59.08	72.12	9
Tianjin	74.14	72.69	69.49	72.05	10
Changsha	72.81	73.01	66.50	71.71	11
Nanchang	74.61	70.84	71.35	70.94	12
Yinchuan	78.38	77.27	39.74	69.76	13
Jinan	76.94	66.31	76.51	68.35	14
Changchun	69.90	66.43	73.92	67.93	15
Hefei	69.89	66.96	70.77	67.72	16
Lasa	71.61	70.40	56.48	67.62	17
Zhengzhou	73.27	68.20	64.38	67.43	18
Xining	73.71	70.04	55.32	67.10	19
Nanning	68.22	67.22	65.26	66.83	20
Beijing	75.46	74.75	35.01	66.80	21
Chongqing	71.70	68.47	46.61	64.10	22
Wuhan	69.24	64.87	57.67	63.43	23
Kunming	72.54	65.51	53.99	63.21	24
Guangzhou	70.92	73.24	20.68	62.72	25
Xian	67.23	59.09	65.63	60.40	26
Haikou	73.35	67.90	26.88	59.69	27
Wulumuqi	69.62	63.80	42.82	59.60	28
Shanghai	68.87	67.11	25.09	58.71	29
Hangzhou	72.04	70.42	8.91	58.12	30
Nanjing	68.93	65.59	–14.53	49.57	31

Therefore, the structure of the sampled population is adjusted by the residents' education level. Data found between the water literacy evaluation value based on the questionnaire and the water literacy evaluation value adjusted based on the education level are not obvious, indicating that the sample of this questionnaire has good representativeness and can be used as the data basis for subsequent analysis and research. Because the water consumption effect value of residents' actual living water consumption can more objectively reflect residents' water behavior, this paper introduces the water-saving efficiency value for the first time to adjust the water literacy evaluation of urban residents. The results show that the corrected water literacy evaluation value and the questionnaire evaluation value differ significantly.

In addition to Hong Kong, Macao and Taiwan, in the 31 provincial capital cities of the mainland, the water literacy evaluation scores based on the questionnaire survey are relatively high, all in the range of 67.23–83.11, indicating that the water literacy level of the provincial capitals is still relatively high. However, from the perspective of water literacy evaluation factors, the water knowledge and water attitude evaluation scores are generally higher, while the water behavior evaluation scores are relatively low; in particular, the results based on the regulation of the water-saving efficiency value further support this finding. A considerable proportion of urban residents' actual living water consumption exceeds or far exceeds the domestic water consumption quota, which greatly reduces the comprehensive evaluation value of water literacy. The reasons for this result are not only the restriction of the general behavioral rules of the 'attitude-behavior gap' but also the understanding of the importance of water resources and water ecology by urban residents. There are also long-term lifestyles, especially water-use habits, due to different levels of water richness in different regions, which are also affected by national water price policies and water management systems and mechanisms. At the same time, this result may also be related to cities' economic development levels, the living standards of the residents and the residents' pursuit of quality of life. However, due to the limited length of the paper, we will continue to explore the relationship between its internal logic and mutual influence in subsequent research.

In general, the comprehensive evaluation values of water literacy and their rankings are correlated with the distribution of water resources in China. China's water resources are distributed more to the south and less in the north. The southern provincial capital cities are rich in water resources, while in the north, water resources are relatively scarce. In most southern cities, the actual domestic water consumption is higher than the domestic water quota, while the actual domestic water consumption in most northern cities is basically the same as the domestic water quota. Therefore, the comprehensive evaluation of water literacy in some northern cities is now generally higher than that in southern cities. However, some northern cities are not fully aware of the reality of severe water shortages under the guarantee of national large-scale water transfer engineering measures. The domestic water consumption is still high, resulting in a lower overall evaluation of water literacy. In terms of regions, cities with higher economic levels and richer water resources, such as Shanghai, Hangzhou and Nanjing, have lower comprehensive evaluation values for water literacy. Due to the large difference between the actual domestic water consumption and water quota of residents, the actual water consumption far exceeds the water quota. In the specific investigation process, a considerable number of respondents indicated that they are unwilling to reduce their quality of life to save water, resulting in a large amount of water used in daily life. Some cities with rich water resources have higher comprehensive evaluation values of water literacy, such as Chengdu, Guiyang, and Fuzhou, and their actual living water consumption and water quota are basically the same, indicating that they are willing to take the initiative to control the amount of water in the process of meeting their own living needs. Cities with more developed economies but fewer water resources, such as Tianjin and Shenyang, have higher comprehensive evaluation values for water literacy, which is consistent with the results of actual visits. In terms of domestic water use, their residents have a strong awareness of water conservation and fully recognize that water resources are scarce. They consciously regulate their own daily water-use behavior.

Research comments and suggestions

Further improvement of the water quality assessment method is recommended. This paper attempts to establish and improve the evaluation index system and evaluation method of Chinese citizens' water literacy and validates the scientific nature and reliability of the evaluation system with 31 provincial capital cities in China as samples. However, due to the limitations of the evaluation conditions, there are still many aspects that need improvement. For example, failure to classify or stratify by the administrative area according to the overall sample of the survey will inevitably lead to inconsistencies in demographic structure. Although the original evaluation data are corrected, the actual effect of this correction still needs further testing. On the other hand, due to the strong subjectivity of the questionnaire survey, we introduced a domestic water-saving efficiency value that reflects the objective effect of urban residents' water-saving life to adjust the evaluation value of water literacy. However, since the water-saving efficiency value of life reflects a major aspect of water literacy levels, especially the different levels of economic and social development in each city and the different time for the formulation of domestic water quotas, there is also a large gap in the domestic water quota. At the same time, different statistical calibers and sources of domestic water consumption of residents in each provincial capital city will also lead to nonuniform data. These problems need to be addressed and improved in follow-up research.

According to the collected domestic water consumption and water quota in provincial capitals, the actual domestic water consumption in most cities is higher than the water quota, which is also the main reason for the large difference between the results of the water literacy survey and evaluation after the adjustment of water-saving efficiency values. First, the water allocation in each basin can be accelerated. Based on the specific situation of different regions, the water standards for different types of water and domestic water quota standards for the water-deficient regions and the water-rich regions are strictly determined, and the total water consumption and water intensity of each region are controlled. The multilevel standard system of domestic water for residents is constructed, and the long-term effective water-saving mechanism is formulated. Second, the national water resources supervision capacity construction project can promote the construction of residential water consumption measurement infrastructure, improve the monitoring system of water consumption measurement and supervise and control actual water consumption in real time, effectively implementing planned water according to the resident domestic water quota and related water use standards.

Presently, the water literacy level of residents of only 31 provincial capitals has been evaluated. According to the evaluation results, the water quality differs among urban residents, and the evaluation results are relatively reasonable, which is in line with the local situation and the general expectations of society. The evaluation scope of water literacy should be further expanded to attract the attention of all sectors of society and governments at all levels, so as to promote the improvement of citizens' water literacy. Currently, it is possible to carry out targeted publicity and education on the comprehensive value of water literacy of residents of different provincial capitals and encourage residents to cultivate good water-saving awareness and develop good water use behavior. Water conservancy experts give lectures on water literacy in some areas with a low comprehensive index of water literacy in order to disseminate water literacy-related theoretical knowledge, increase residents' awareness of water literacy, make them understand water science knowledge, and promote scientific water attitudes, which help citizens regulate their own water behavior and improve their own water literacy.

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Data availability statement

All relevant data are included in the paper or its Supplementary Information.

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