Influencing factors for water use behaviors of population groups in hospitals based on multi-layer perceptron model

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ABSTRACT

As a public institution with high water consumption, hospitals play an important role in the process of urban water conservation. In this paper, we analyzed the characteristics of daily water use behavior of different hospital populations in different regions and types based on actual research data, and used the multi-layer perceptron (MLP) neural network model to further explore the predictive discrimination and relative importance ranking of gender, age, region and personnel classification on the water consumption behavior of different hospital populations. The results showed that the daily water use behaviors of different regions and types of people were somewhat different; the MLP neural network model had a reference value: different factors influenced each water use behavior to different degrees, with the occupation of hospital personnel influencing the water use behaviors of different people to the greatest extent. By analyzing the daily water use behavior of different groups of people in hospitals, this study can effectively analyze their water use habits and thus reflect their awareness of water conservation, provide a theoretical basis for improving water conservation management in hospital logistics or other departments, and lay the foundation for studying the water use efficiency of people's social activities.

Keywords: Water use behavior; Hospitals; Multi-layer perceptron

1. Introduction

At present, all countries in the world are challenged by the imbalance between water supply and demand. In order to develop reasonable and effective water management plans for various industries and households, and arouse people's consciousness of water saving, policymakers need to fully analyze people's water use behaviors [1]. As an important part of China's economy and society, hospitals need to address various water use problems, such as large water consumption [2], concentrated water use, water waste, high population density and mobility. Therefore, there is a great potential to be tapped in hospitals, and water conservation measures in hospitals have an obvious effect on reducing the water consumption of the tertiary industry.

Based on the purposes of water use, the water use of hospitals can generally be divided into: (1) Clean water: water for toilet flushing, hand washing and shower, accounting for about 48% of the total water consumption; (2) Canteen water, taking about 16%; (3) Cooling tower water, accounting for about 12%; (4) Others (including landscape, irrigation, laundry, pure water system, etc.), accounting for 24% [3]. According to the location of water use, the water use structure in hospitals can be divided into outpatient water use, inpatient water use and other water uses. Among them, other water uses refer to water for canteens, greening, boiler rooms, vehicles and staff dormitories, etc. The water use composition differs in different hierarchies of hospitals. For the hospitals with lower hierarchy, the outpatient water use gradually increases and the inpatient water use decreases. The proportion of other water use basically remains the

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same. The hospital water consumption in different regions also varies greatly [4].

Studies have shown that in social activities, people have water use behaviors different from at home [5–7]. Under this context, it is very important to study people's water use behaviors in social activities (such as hospitals). Focusing on the water (clean water) use behaviors of different population groups in hospital, this research conducted a characteristics analysis on the different water use behaviors of different population groups from different regions, social attributes, and occupations (doctors, patients or logistics personnel) in hospitals constructed an multi-layer perceptron (MLP) model for the water use behaviors of different population groups in the hospitals, and simulated the influences of gender, age, region and occupations on the water use behaviors of different population groups in the hospitals. This research aims to provide some insights for the hospital logistics department or other relevant staff to develop people-centered water-saving strategies [4,8]. The water use behaviors of different population groups in hospitals can also reflect people's general water use behaviors in social activities, and provide reference for the analysis of water use behaviors in other water saving service areas [9].

2. Survey and analysis methods

2.1. Questionnaire survey

In order to cover comprehensive and representative data, and recover and analyze the questionnaires more easily, this study was conducted using the web-based questionnaires. As people in hospitals come from different walks of life and there is a large number of population involved in hospitals, the population groups of different regions, ages and occupations were included in this study.

A total of 599 questionnaires were collected. The questionnaire results are as follows: gender ratio: about 6:4; age ratio: about 40% (the largest proportion) of hospital population aged 35–49, followed by 35% of hospital population aged 20–34; occupation: about 60% (the largest proportion) of outpatients or escorts, which was in line with the characteristics of large outpatient mobility, followed by about 20% of logistics or other staff; region: 35% and 33% of hospital population from Northwest China and East China, respectively, followed by 17% and 13% of hospital population from North China and Central China, respectively. The basic classification information of hospital personnel is shown in Fig. 1 below. Different colors and shadows in Fig. 1 denote the symbols and sizes of the standardized residuals of the data [10]. The survey data are generally in line with the composition of hospital population, so it is of great value for reference.

2.2. MLP model

Neural network aims to simulate the structure and function of the neural system for data processing, and constantly adjust the weights of the chain between the simulated neurons, so that the whole network can better fit the relationship of the training data. Multi-layer perceptron (MLP) is a neural network model, and it is composed of input layer, hidden layer (one or more layers) and output layer [11], as shown in Fig. 2. The complete process for building the MLP model can be divided into two subprocesses: forward propagation and back propagation. Forward propagation computes the output of the neuron using the network structure and the weights and threshold of the previous iteration. In back propagation, the weights is adjusted using a function based on delta rule so as to minimize the errors between the actual output and the predicted output of the ANN [12]. Starting from the output layer, it works backwards so as to adjust the weights accordingly and reduce the average error across all layers. This process is repeated until the output error is minimized.

In this model, the learning process is completed by constantly adjusting the weight value w, until the output value is consistent with the actual output value of the
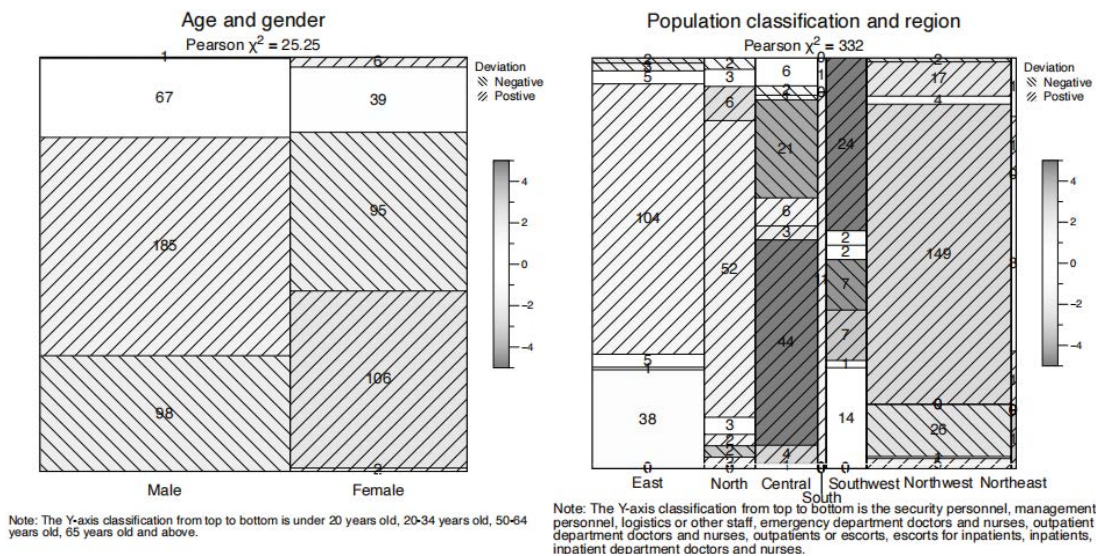

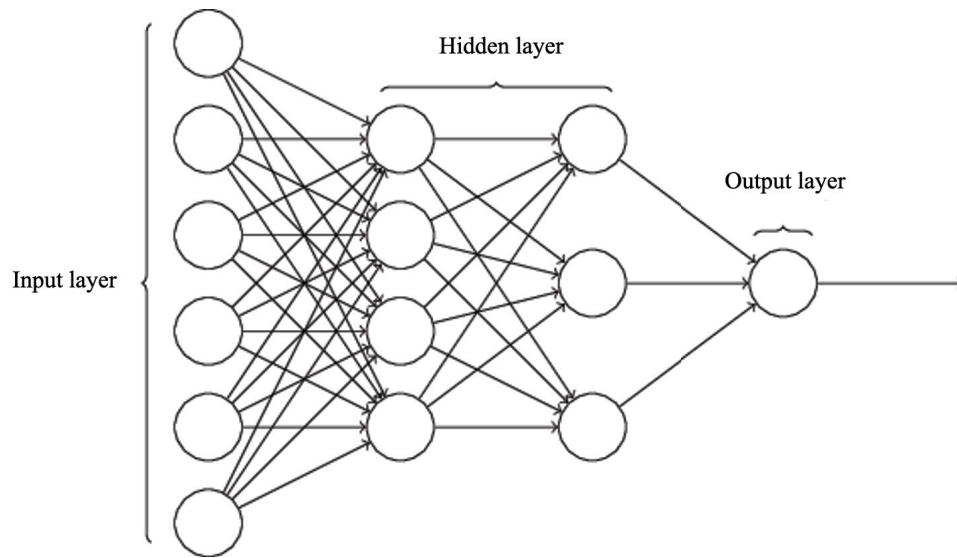Fig. 1. Basic classification information of hospital personnel.

Fig. 2. MLP model structure.

training samples. The formula for weight value adjustment is shown as follows:

$$w_j^{k+1} = w_j^k + \beta \left(y_i - \hat{y}_i^k \right) x_{ij}$$

where w_j^k refers to the weight value of the j-th input link after the k-th cycle; β is the learning efficiency; x_{ij} is the j-th attribute value of the i-th training sample; $y-\hat{y}$ is the deviation of the predicted value relative to the actual value. When $y-\hat{y}$ is greater than 0, the weight value of all positive chains is increased to increase the predicted value of the output; when $y-\hat{y}$ is smaller than 0, the weight value of the positive chain is decreased, and the weight value of the negative connection is increased to decrease the predicted value of the output [13].

3. Results and discussion

3.1. Water use behaviors of population in hospitals in different regions

The daily water use behaviors of population in hospital s mainly includes water drinking behaviors, toilet flushing behaviors and hand washing behaviors. The questionnaire survey was conducted on the daily water consumption, the number of times to use the toilet per day in the hospitals, the number of times to wash hands in a single day visit and duration for each hand washing. Furthermore, the questionnaires were analyzed based on different regions (according to the physical geography of China), as shown in Table 1.

As for the daily water drinking consumption, the population in hospitals in different regions showed a decreasing trend as a whole, that is, the population with a drinking water amount of less than 1 L accounted for the largest proportion. In addition, the population with a daily water drinking amount of less than 1 L in the hospitals of West China and Central China accounted for a far smaller proportion than other regions, while that with a daily water drinking amount of 1–2 L accounted for a relatively large proportion. The population with a daily water drinking consumption of less than 1 L in the hospitals of East China, North China, South China and Northeast China all accounted for more than 70% of the total respondents, with the highest proportion in Northeast China and South China, 85.71% and 83.33%, respectively. However, the population with a daily water drinking consumption of 1–2 L in the hospitals of Central China, Northwest China and Southwest China accounted for more than 30%, 10%–20% higher than that in other regions.

As for the daily toilet flushing frequency, the number of times to use the toilet per day in the hospital, which was mainly between 1 and 4 times, tended to be normally distributed. According to the sparkline, it can be observed that the peak in East China, North China, South China, Northwest China and Northeast China appeared earlier than that in Central China and Southwest China, which indicates that the average number of times the hospital population flushed the toilets in the five regions were less on average, so more water could be saved. The maximum probability of the number of times the hospital population flushed the toilets in East China, North China, South China, Northwest China and Northeast China was 1, accounting for 40%, 30.56%, 58.33% and 29.27%, respectively, while that in central China was 2, accounting for 25.32%.

As for the daily hand washing times, the frequency for population in hospitals to wash hands also showed a normal distribution, similar to the daily toilet flushing times. Population in hospitals of Central China and Southwest China washed hands more than other regions each day.

As for the hand washing duration, it cost less than 10 s, 10–15 s, and 15–30 s for different population groups to wash hands in hospitals, which already took most people's hand washing habits into consideration. The survey results showed that it took less than 10 s and 10–15 s for all

Table 1
Water use behaviors of population in hospitals in different regions (%)

	East China	North China	Central China	South China	Southwest China	Northwest China	Northeast China
Water drinking behaviors daily water drinking consumption							
Less than 1 L	71.85	76.39	46.84	83.33	56.14	65.37	85.71
1–2 L	23.70	18.06	34.18	8.33	38.60	30.24	14.29
2 L or above	4.44	5.56	18.99	8.33	5.26	4.39	0.00
Sparkline							
Toilet flushing behaviors daily toilet flushing frequency							
0	7.41	11.11	2.53	0.00	0.00	7 32	0.00
1 time	40.00	30.56	11.39	58.33	7.02	29.27	28.57
2 times	15.56	16.67	25.32	25.00	24.56	20.49	14.29
3 times	13.33	20.83	24.05	0.00	29.82	20.98	14.29
4 times	11.85	15.28	16.46	8.33	15.79	7 80	42.86
5 times and more	11.85	5.56	20.25	8.33	22 81	14.15	0.00
Sparkline							
Hand washing behaviors daily hand washing frequency							
0	4.44	5.56	1.27	8.33	0.00	3.90	0.00
1–2 times	45.19	40.28	21.52	41.67	8.77	34.15	14.29
3–5 times	20.00	23.61	29.11	41.67	26.32	34.15	42.86
5–10 times	22.96	22.22	27.85	8.33	26.32	19.51	14.29
10–20 times	5.19	5.56	12.66	0.00	28 07	6 83	14.29
20 times and more	2.22	2.78	7.59	0.00	10.53	1.46	14.29
Sparkline							
Hand washing behaviors each hand washing duration							
Less than 10 s	51.85	52.78	37.97	58.33	33.33	52.20	28.57
10–15 s	40.74	38.89	55.70	41.67	49.12	40.49	14.29
15–30 s	7.41	8.33	6.33	0.00	17.54	7.32	57.14
Sparkline							

the people to wash hands each time in the hospitals in all regions except Northeast China. In addition, the daily hand washing duration varied across regions, which was similar to the pattern of daily water drinking consumption, that is, the population in the hospitals of East China, North China, South China and Northwest China washed hands for a shorter time and saved more water. The hand washing duration for population in hospitals with less than 10 s each time in East China, North China, South China and Northwest China accounted for about 51%–59%, while that in Central China, Southwest China and Northeast China accounted for 28%–38%. The number of samples in Northeast China was small, so it had a low reference value. Hand washing duration for population in hospitals with 10–15 s each time in Central China and Southwest China accounted for 55.70% and 49.12%, respectively.

In summary, population in hospitals of Central China and Southwest China saved more water than other regions. In terms of the water use behaviors, the daily hand washing frequency was similar to the daily toilet flushing frequency, and hand washing duration each time was similar to the daily water drinking consumption.

3.2. Water use behaviors of population groups with different social attributes in hospitals

Water use behaviors tend to be influenced by socio-demographic factors, such as age, gender and occupation [14]. Education level and income are not significantly correlated with environmental awareness or pro-environmental behaviors, as found by studies [15–17]. For this reason, education level and income were not taken into consideration in this study. This study mainly explored the differences in water use behaviors caused by different genders and ages, and the results are shown in Fig. 3.

Age is considered to be one of the important factors in determining the differences in water use behavior. According to studies, elder people have more sustainable water consumption habits [17,18]. However, in this study, the water use behaviors of population in different ages in hospitals were inconsistent with the literature results. The daily water drinking consumption and the daily toilet flushing frequency increased with increasing age; but the daily hand washing frequency and the hand washing duration for each time was not significantly correlated with age.
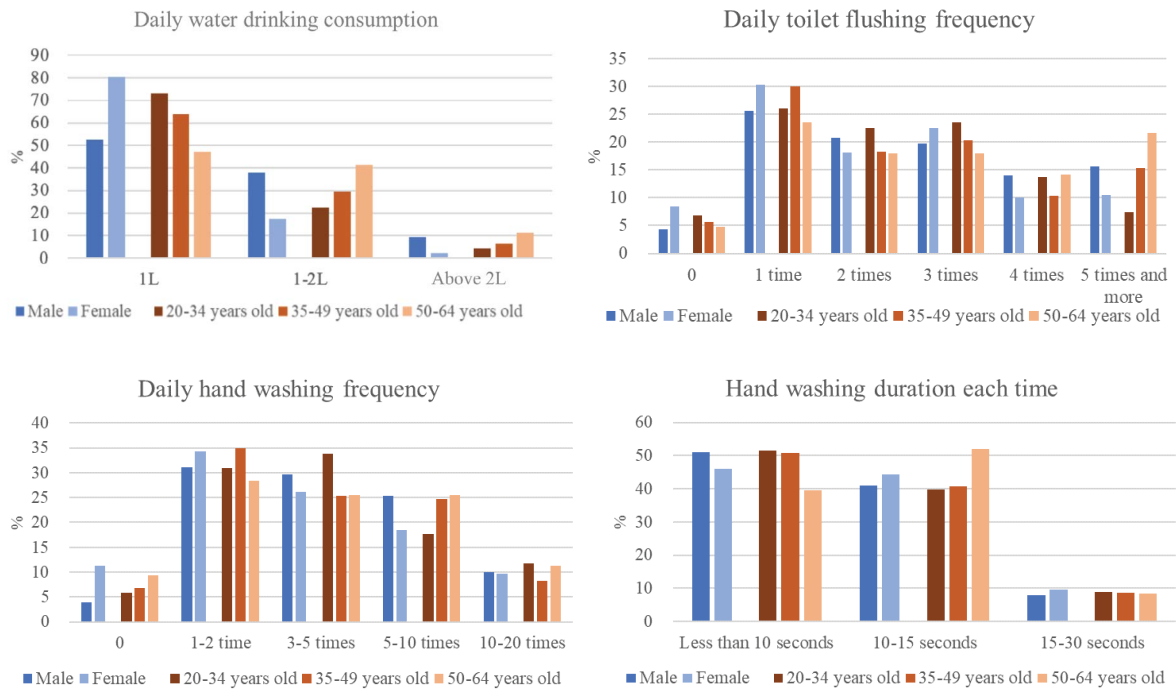
Fig. 3. Water use behavior of hospital personnel with different social attributes.

Gender-determined water use behaviors are considered to be determined by the social roles of males and females, and females pay more attention to environment [19,20] than males. This is consistent with the results in this study, that is, females saved more water than males in terms of daily water drinking consumption, daily toilet flushing frequency and daily hand washing frequency. For example, more females had a lower drinking water consumption (frequency) than males, and fewer females had a higher drinking water consumption (frequency) than males. This is consistent with the results of Dilaver et al. [21], who studied the effects of gender on the drinking water consumption of inpatient families. The frequency distributions of hand washing for population of different genders in hospitals with were similar, indicating that there was little difference between males and females in hand washing duration each time.

3.3. Water use behaviors of population of different types (occupations) in hospitals

According to the work nature of different population groups (occupations) in hospitals and the different purposes of hospital visits, the classification and analysis were conducted again. The distribution of water use behaviors of doctors and nurses in the logistics department, emergency department, outpatient department, inpatient department, outpatient or accompanying personnel and hospital residents or accompanying personnel was calculated, as shown in Table 2.

As for the daily water drinking consumption, the daily drinking water consumption of different population groups (occupations) in the hospital decreased or showed a trajectory of rising first and then decreasing. The daily water

drinking consumption of logistics personnel, emergency department doctors and nurses, and inpatients or escorts was mainly less than 1 and 1–2 L, accounting for more than 40%; The daily water drinking frequency of outpatient department doctors and nurses, inpatient department doctors and nurses, and outpatients or escorts showed a decreasing trend, with the drinking water consumption of less than 1 L accounting for as high as 59.09%, 70.27% and 76.67%, respectively.

As for the daily toilet flushing frequency, the daily toilet flushing frequency of outpatients or escorts was mainly 1 and 2 times, accounting for 44.09% and 21.90%, respectively, which was in line with the characteristics of large outpatient mobility; The daily toilet flushing frequency of logistics personnel and inpatients or escorts was mainly 3 times, accounting for 31%, followed by 5 times and more, accounting for 26.62% and 29.79%, respectively; The daily toilet flushing frequency of emergency department doctors and nurses, outpatient department doctors and nurses and inpatient department doctors and nurses was mainly 3 times.

As for the daily hand washing frequency, outpatients or escorts as well as other population groups (occupations) in hospitals mainly washed hands for 1–2 times and 5–10 times, respectively, basically in line with the normal distribution. In addition, the daily hand washing frequency of doctors and nurses was mainly more than 10 times, accounting for about 40%, much higher than other population groups (occupations) (less than 20%) in hospitals.

As for hand washing duration each time, hand washing duration for doctors and nurses each time, which was mainly 10–15 s, tended to rise first and then decrease; The hand washing duration for logistics personnel and inpatients

Table 2
Water use behaviors of different population groups (occupations) (%) in hospitals

	Logistics personnel	Emergency department doctors and nurses	Outpatient department doctors and nurses	Inpatient department doctors and nurses	Outpatients or escorts	Inpatients or escorts
Water drinking behavior daily water drinking consumption						
Less than 1 L	40.29	42.86	59.09	70.27	76.37	44.68
1–2 L	46.04	57.14	31.82	29.73	20.17	42.55
2 L or above	13.67	0.00	9.09	0.00	3.46	12.77
Sparkline						
Toilet flushing behavior daily toilet flushing frequency						
0	2.16	0.00	0.00	2 70	8.93	2.13
1 time	2.88	0.00	18.18	2.70	44.09	6.38
2 times	17.27	14.29	18.18	18.92	21.90	12.77
3 times	31.65	14.29	13.64	37.84	13.83	31.91
4 times	19.42	42.86	22.73	21.62	6 63	17.02
5 times and more	26.62	28.57	27.27	16.22	4.61	29.79
Sparkline						
Hand washing behavior daily hand washing frequency						
0	2.16	0.00	0.00	0.00	4.32	4 26
1–2 times	10.07	14.29	4.55	2.70	50.14	6.38
3–5 times	30.94	14.29	31.82	5.41	28.53	36.17
5–10 times	38.13	28.57	27.27	32.43	12.97	36.17
10–20 times	12.23	28.57	18.18	45 95	3 17	17 02
20 times and more	6.47	14.29	18.18	2.70	0.86	0.00
Sparkline						
Hand washing behavior each hand washing duration						
Less than 10 s	42.45	28.57	31.82	18.92	57.06	42.55
10–15 s	46.76	42.86	63.64	56.76	37.18	46.81
15–30 s	10.79	28.57	4.55	24.32	5.76	10.64
Sparkline						

or escorts each time kept stable first and then decrease, and the hand washing duration for logistics personnel and inpatients or escorts each time had the similar probability (about 42%–46%) of less than 10 s and 10–15 s.

To sum up, the population groups in hospitals greatly affect the frequency distribution law of water use behaviors. Doctors and nurses, as regular staff in hospitals, had similar water use behaviors due to their occupations; Logistics personnel and inpatients or escorts had similar water use behaviors, because they had to stay for a period of time; Outpatients had an obviously different water use behaviors from other population groups due to the large outpatient mobility.

3.4. Analysis on the importance of influencing factors based on MLP model

The modelling dataset of the MLP model constructed in this study consisted of a total of 599 samples, including 420 training samples and 179 test samples. The input layer variables included gender, age, region and occupation. For these four types of water use behaviors, the number of hidden layers was 1, and the number of hidden layer units was 3, 2, 4 and 6, respectively. Receiver operating characteristic (ROC) curve was used to assess the accuracy of the model prediction by drawing the sensitivity (1 specificity) of the classification test. ROC curves were obtained by taking the actual water use behaviors of the sample individuals as the criterion to judge the optimal solution point, and the probability of the sample individual classification results given by the model as the judgment basis for the classification, as shown in Fig. 4 below. The area under the curve (AUC) in Fig. 4 was all greater than 0.5, which indicates that the model fitting is effective. The larger the AUC, the better the predictive ability of the model. Therefore, the model fitting is the most suitable method for predicting the daily drinking water consumption.

The MLP model was used to analyze the importance of the four influencing factors for water use behaviors, namely, gender, age, region and occupation, as shown in
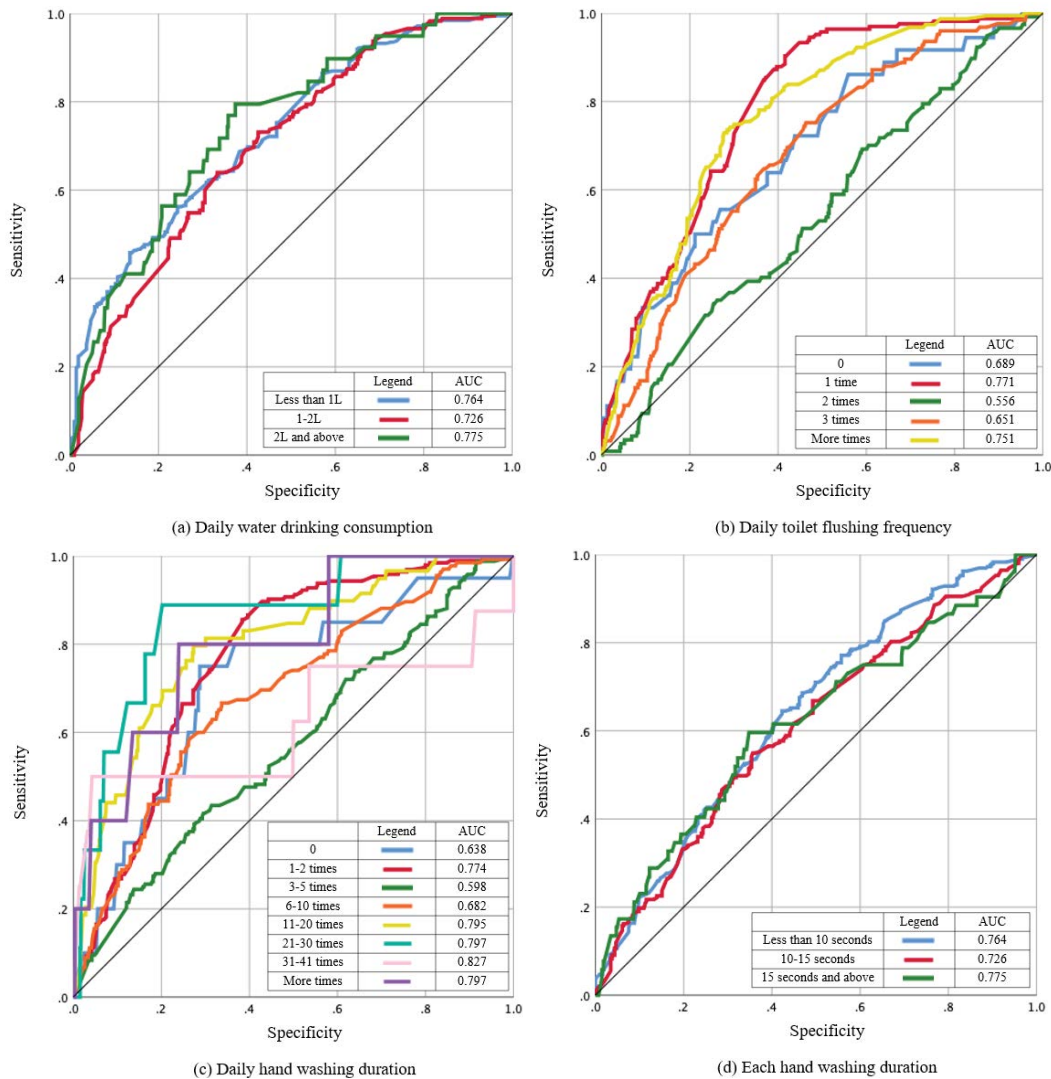
Fig. 4. Receiver operating characteristic curves of the prediction model for the four water use behavior of hospital personnel.

Table 3
Comparison of the importance of the four influencing factors

		Gender	Age	Region	Occupation
Daily water drinking	Importance	0.228	0.283	0.219	0.27
consumption	Importance of normalization	80.60%	100%	77.50%	95.30%
Daily toilet flushing	Importance	0.162	0.157	0.185	0.496
frequency	Importance of normalization	32.70%	31.60%	37.20%	100%
Daily hand washing	Importance	0.182	0.334	0.077	0.407
frequency	Importance of normalization	44.80%	82.00%	18.90%	100%
Each hand washing	Importance	0.043	0.29	0.157	0.51
duration	Importance of normalization	8.50%	56.80%	30.90%	100.00%

Table 3. As can be seen from the table, the four influencing factors were ranked from large to small according to the degree of influence. For the daily water drinking consumption: age > occupation > gender > region; For the daily toilet flushing frequency: occupation > region > gender > age; For the daily hand washing duration: occupation > age > gender > region; For each hand washing duration: occupation > age > region > gender. To sum up, occupation was the most important influencing factor of water use behaviors, which indicated that the purpose of hospital visits greatly

influenced the water use behaviors of different population groups, which was consistent with the above conclusions about the water use behavior of different population groups (occupations) in hospitals. The rank of the four influencing factors varied greatly, which indicates that different factors influenced water use behaviors to different degrees.

4. Conclusions

The water use behaviors of population in hospitals of different regions and with different categories were different. Populations in Central China and Southwest China saved more water than other regions; Females saved more water than males, and age was not significantly related with water use behaviors; The population in hospitals, which had a great influence on the law of water use behavior, was divided into three groups, including doctors and nurses, logistics personnel/inpatients or escorts, and outpatients or escorts according to the differences in water use behaviors, which was in line with the classification of theoretical water use behavior characteristics of populations in hospitals. The importance analysis of the influencing factors based on MLP model showed that occupation was the most important influencing factor of water use behavior; The rank of the four influencing factors varied greatly, which indicated that different factors influenced water use behaviors to different degrees. Through summarizing the water use behaviors of different population groups in hospitals from different regions, this thesis will provide reference for the analysis on water use behaviors of people in different industries, and is of great significance to cultivate people's awareness of water saving and alleviate the water shortage.

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