

Research on intelligent management of campus water supply system based on mathematical model

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Abstract. The campus water supply system is an important part of the campus utilities. This paper studies the campus water supply management from the water supply data obtained from the smart water meter of a university campus in China. It used the mathematical modeling method to analyze the water consumption characteristics of each functional area of the campus, drew a mind map of the hierarchical relationship, and made a line graph of water consumption in each area with the change of month, established a model between each water meter data, and obtained the hierarchical relationship and model error of the campus water meter. For the leakage of the water transmission network, a leakage rate model was derived to help the school address the leakage problems that exist.

Keywords: Leakage of pipe network; Intelligent management; Hierarchical relationship; Leakage rate.

1. Introduction

Campus water supply system is an important part of campus public facilities. Schools need to invest a lot of manpower, material resources and financial resources to ensure the normal operation of campus water supply system. Therefore, the logistics department hopes to find and solve the problems in the water supply system in time through mathematical modeling and data mining. According to the information and data given in Question E of the 2020 National Mathematical Modeling Competition for College Students [1], the mathematical model was established to answer the following questions:

Question 1: Statistics and analysis of the change law of each water meter data; The water use characteristics of different functional areas (dormitory, teaching building, office building, canteen, etc.) in the campus are given.

Question 2: Combined with the hierarchical relationship of campus water meters, the relationship model between water meter data is established, and the existing data are used to analyze the model error.

Question 3: The leakage of water transmission network is a serious problem. According to the data, in the well-maintained public water supply network, the average water loss is about 5%; In the older pipe network, there will be more water loss. Please use the data provided in the attachment to establish a mathematical model to analyze the leakage of the campus water supply network.

Question 4: The hidden leakage of underground water pipes is not easy to be found, and it takes a lot of manpower to detect and locate the leakage of water supply pipes. It will be extremely beneficial if the location of leakage can be found and determined in time from the real-time data of water meter. Please help the school solve this problem.

2. Question analysis

Because the water meter readings given in the title give the corresponding water consumption data at intervals of fifteen minutes, the data amount is too large to be analyzed. Therefore, we use our Excel to process the water consumption in four quarters, and get the monthly water consumption of each water meter.

Question 1: First, we integrate the monthly water consumption of each functional area, and then use Excel to draw the line chart of water consumption in different areas with the change of month. Finally, we distinguish four functional areas, namely dormitory, teaching building, office building and canteen. Then, we use Excel to draw the line chart of water consumption in different functional areas and get the water consumption characteristics in different areas.

Question 2: By analyzing the hierarchical relationship of water meters in the campus, we draw a mind map of hierarchical relationship with XMind, and then use Excel to draw a line chart of water consumption in each region with the change of month to establish a model among the water meter data [2], and get the hierarchical relationship of water meters in the campus and the model error.

Question 3: First, we integrated the annual water consumption for each tier table and the annual and monthly water consumption for each location through Excel. Finally, according to the known analysis data, the leakage rate model [3]:

$$a = \frac{A - B}{A} \cdot 100\%$$

The leakage of water supply network can be clearly seen through the model.

Question 4: According to the calculation results of Question 3, in order to help the school solve this problem, we conducted a multi-data analysis and finally checked the areas with leakage problems and then used Excel to select the leakage places in each area [4].

3. Symbol description

Table 1. The following are the symbols used in this paper

Symbol	Meaning	Unit	Remarks
R_i	Radius from level 1 table to level 4 table	cm	$i=1,2,3,4,5,6,7,8$
a	Leakage rate	Yuan	%
A	Total annual water supply	Kiloton	
B	Annual actual water consumption	Kiloton	
V_i	Flow velocity of water pipe	m/s	$i=1,2,3$

4. Model assumptions

- (1) It is assumed that the canal is short;
- (2) It is assumed that the leakage rate has nothing to do with water supply, pressure and pipe diameter;
- (3) It is assumed that the water velocity of 100 caliber is 1.2m/s, that of 50-80 caliber is 0.8m/s, and that of less than 50 caliber is 0.4m/s.

5. Model establishment and solution

First, the data and water meter hierarchy for each quarter were reasonably analyzed to filter the water use by month for each location, and a table was drawn up using a line graph in Excel [4] to make it easy to visualize the monthly water use.

5.1 Model establishment and solution of Question 1

- (1) We use Excel to draw a line chart for the water consumption of each place every month, as shown in Figure 1:

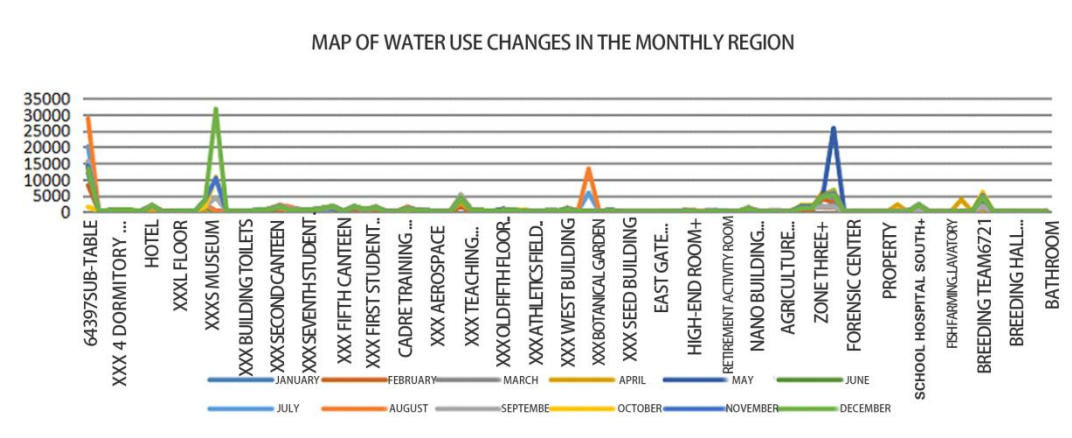


Fig. 1 Water use change in January

According to the line chart, we can intuitively see that:

- A significant increase in water consumption in October-December at the xxxs (high student traffic).
- xxx swimming pool experiences a significant increase in water use in July-August (the summer heat and therefore the high volume of swimming).
- Area 4 (dormitory buildings, supermarkets, etc.) saw a significant and sharp increase in water consumption in May relative to other months.

(2) According to the different functional areas, we used Excel to draw line graphs of water consumption for each month for dormitories, academic buildings, office buildings and cafeterias, as shown in Figure 2 - Figure 5.

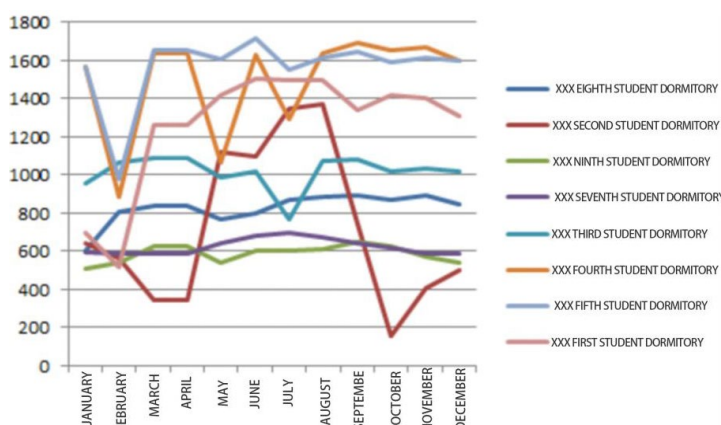


Fig. 2 line chart of monthly water consumption of dormitory building

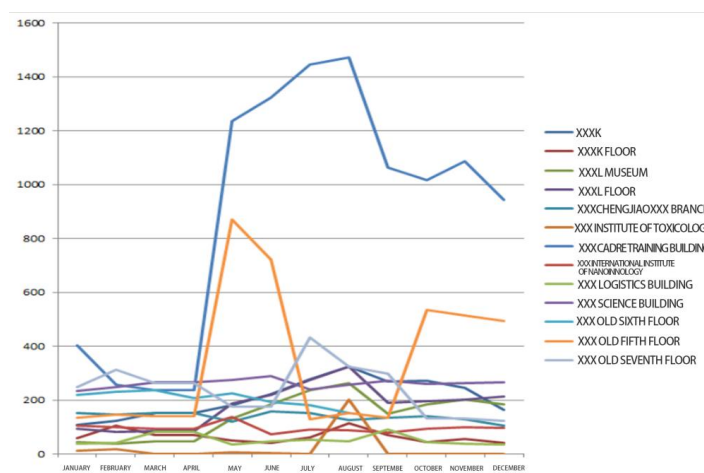


Fig. 3 line chart of monthly water consumption of office building

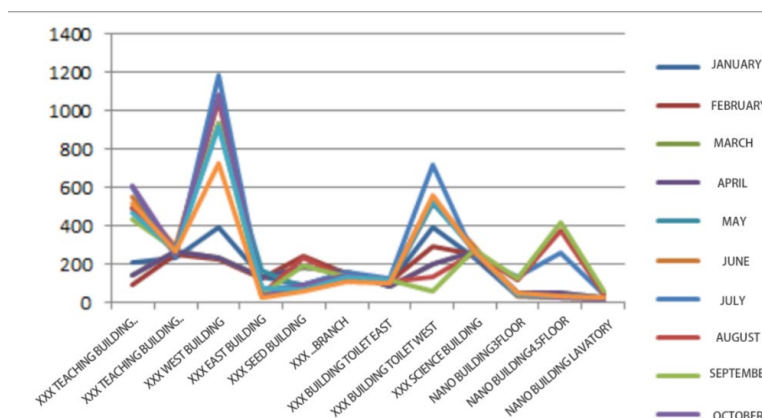


Fig. 4 line chart of monthly water consumption of teaching building



Fig. 5 line chart of monthly water consumption of canteen

Figure 2: Water use in student dormitories is significantly higher during the summer school year, decreases significantly after August when students leave school, and levels off from September to December, so it is evident that the majority of water use in student dormitories comes from bathing.

Figure 3: Compared with the academic building, the water consumption of the office building is within the average value from January to December, except for the two special places where the range of water consumption jumps greatly, which means that the water consumption of the office building is only used for daily life and the number of people is more average.

Figure 4: For school buildings, student mobility determines water consumption, so we can clearly see from the table that there is a significant increase in the number of students in school compared to the number of students on vacation.

Figure 5: During the school year, the cafeteria must serve food every day, and water is used for food cleaning and staff activities, especially in the summer.

5.2 model establishment and solution of Question 2

First, using XMind to draw a mind map of the hierarchical relationship, we can visualize the hierarchical relationship of the water table and know the amount of water used between each level, as shown in Figure 6.

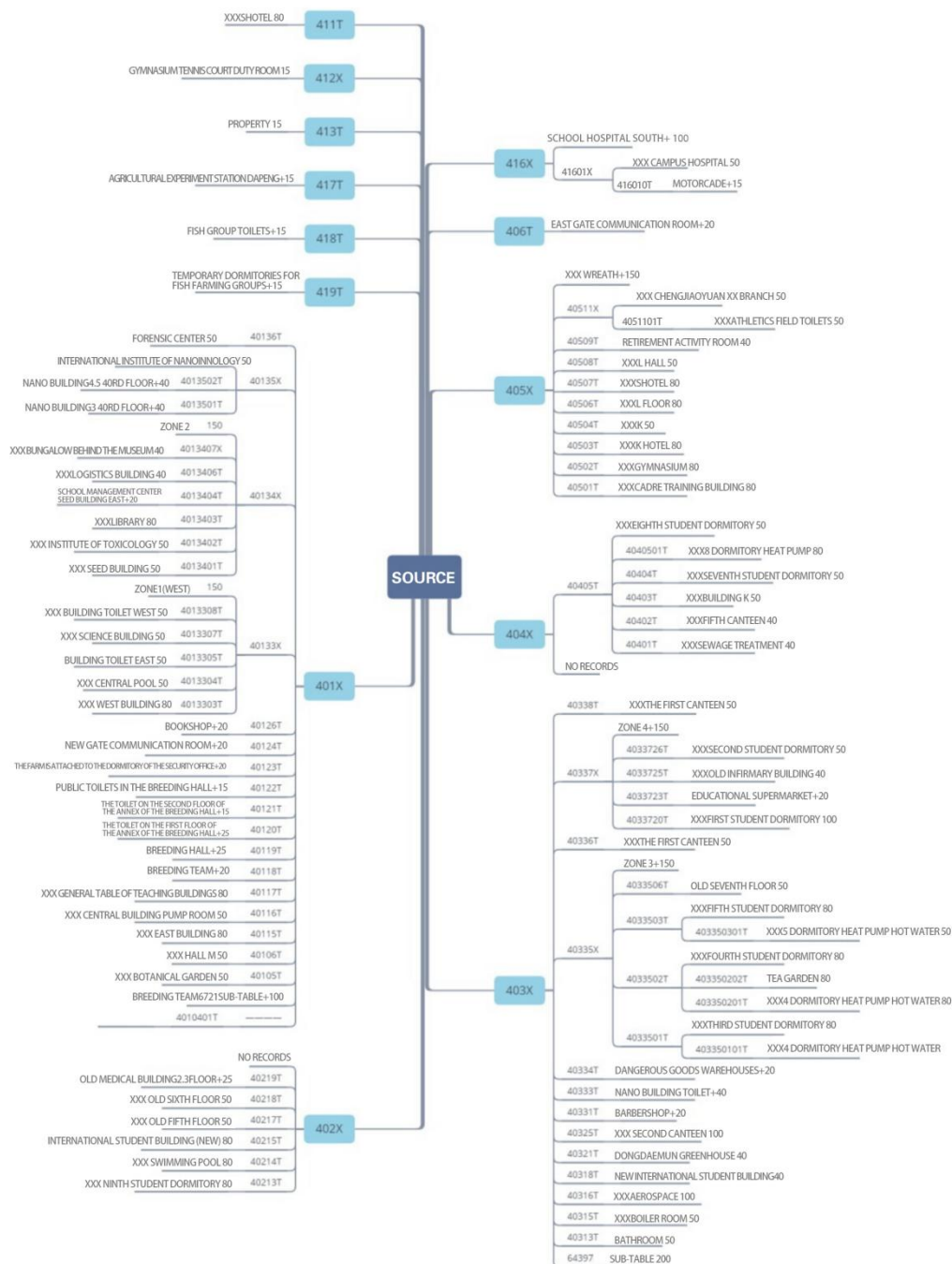


Fig. 6 hierarchical thinking map

According to the hierarchical relationship in the mind map, Y denotes the water consumption of the primary meter, X denotes the sum of the water consumption of each secondary meter, Z denotes the total water consumption of each tertiary meter, and J denotes the total water consumption of each quaternary meter, we derive the following model [2].

$$Y = X + Z + J$$

However, we used Excel to validate and found that part $X + Z + J > Y$, which is not in line with common sense, so the model has errors and is discarded.

5.3 Modeling and solving Question 3

Leakage in the water transmission network is a serious problem; in a good public water supply network, an average water loss of about 5% is negligible, and greater than 5% is considered leakage.

According to the known condition analysis data, Excel is used to count the monthly water consumption changes of each water meter and analyze the areas where leakage exists, first we apply the flow rate = pipe cross-sectional area * flow rate and calculate the total annual water supply [5], resulting in the following model.

$$\frac{3.14 \cdot R^2 \cdot V_i}{4 \cdot 10000000} \cdot \frac{3600 \cdot 224 \cdot 365}{100} \quad (\text{total annual water supply})$$

Secondly, the leakage rate required by the subject is calculated by simple mathematical formula, and the leakage rate model is obtained:

$$a = \frac{A - B}{A} \cdot 100\%$$

After careful data processing, we have calculated the following table data (see water meter hierarchy table for details), as shown in Table 2:

Table 2. Annual water supply and consumption of campus water supply network

Primary meter code	Secondary meter code	Three level meter code	Four level meter code	Water meter No	User number	User name	caliber	Annual water supply	Annual water consumption
416X				3620300500	30089	School Hospital South	100	18484.3008	15470.94
	41601X			3290100100	30023	XXX School hospital	50	4621.0752	1934.21
.....									
417T				3620302800	30091	Greenhouse of agricultural test station	15	207.948384	189.79
413T				3030100102	30097	Property	15	207.948384	180.79
412X				3030100101	30096	Gymnasium tennis court duty room	15	207.948384	170.43
411T				3312800100	30004	XXXS Hotel	80	11829.9525	5784.14
406T				3620302200	30066	East Gate reception room	20	369.686016	108.69

5.4 Model establishment and solution of Question 4

For the underground water pipe concealed leakage is not easy to be found, it needs a lot of labor to detect and locate the leakage of water supply pipe. According to the calculation results of question 3, and then using Excel to select the leakage places in each area to help the school solve the existing leakage problems, after careful processing of the data, we obtained the following table (see Figure 7 for details).

Table 3. leakage of campus water supply network

User name	Caliber	Annual water supply	Annual water consumption	Leakage
School hospital south	100	18484.3008	15470.94	6%
XXX school hospital	50	4621.0752	1934.21	55%
Motorcade	15	207.948384	157.5	24%
.....				
Greenhouse of agricultural test station	15	207.948384	189.79	9%
Property	15	207.948384	180.79	13%
Gymnasium tennis court duty room	15	207.948384	170.43	18%
XXXs hotel	80	11829.9525	5784.14	51%
East Gate reception room	20	369.686016	108.69	71%

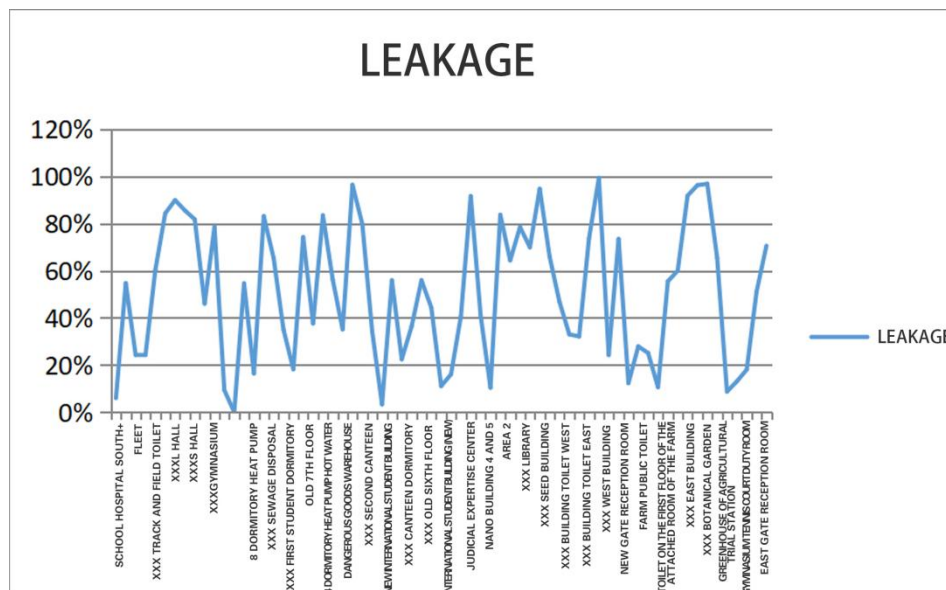


Fig.7 Leakage of the area

Figure 7 provides a visual representation of the size of the leak in each area, which facilitates maintenance.

Leakage in the water supply network not only wastes valuable water resources, but also causes large economic losses to the campus and even causes serious social problems. Keeping abreast of leaks in the campus water distribution network is one of the more important tasks in water system management. After mastering the leakage situation of the water supply network, we can adopt the optimal plan for control and maintenance management to ensure the stable operation of the campus water supply system.

Acknowledgements

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