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RESILIENCE EMERGENCY STRATEGIES FOR URBAN WATER SUPPLY SYSTEM UNDER EMERGENT WATER POLLUTION EVENTS

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Abstract

Aiming at the problem of fluctuations in the supply capacity of urban water supply systems caused by sudden water pollution incidents, an emergency strategy is proposed from the perspective of system resilience. The system resilience is defined from both economic and social aspects, and a single objective mathematical model under the constraints of limited resources is established. The CPLX software was used to solve the emergency dispatch and resource allocation plan. The simulation results show that the economic resilience of the water supply system can be improved by increasing the capacity of the backup water source; the social elasticity value of the water supply system in the rich areas is usually low; stable and continuous water supply It can improve the social resilient value of the water supply system. Finally, the relevant data of the water pollution incident in Harbin were simulated to verify the effectiveness and practicability of the model, and provide a basis for government departments to formulate relevant policies.

Key words: emergent water pollution, economic resilience, resilience strategies, social resilience, water supply system

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1. Introduction

Water is very important for all of the people in the world. It is an important guarantee for resident life. However, in recent years, frequent water pollution incidents have seriously threatened people's life and production water safety (Sfikas et al., 2015). In 2013, thousands of dead pigs appeared on the Huangpu River in Shanghai. The number of dead pigs of about 10,000 per month caused villagers to throw dead pigs directly into the river, which seriously threatened Shanghai's water quality. In 2007, the tap water in the homes of citizens in Wuxi, Jiangsu, suddenly deteriorated and was accompanied by a foul odor. The reason was that the blue-green algae of Taihu Lake broke out in advance, and the phenomenon of citizens buying mineral water appeared in Wuxi. In addition, in 2005, major water pollution incidents in Songhua River, severe water shortage in Jiaxing, and phosphorus pollution in Minjiang also caused major losses to the normal lives of residents. Therefore, the problem of sudden water pollution has become a concern of academic circles.

Sudden water pollution refers to an event caused by man-made or natural disasters, which causes the rate of deterioration of the pollutants to increase suddenly in the short term and severely harm the water ecological environment. This kind of water pollution has no fixed discharge method and way, and a large number of harmful pollutants are discharged into the water body in an instant, resulting in deterioration of water quality and affecting the effective use of water resources. (Meng and Nan, 2019; Pan and Wang, 2019; Zhang and Liu, 2016). According to the Chinese Environmental Statistics Bulletin, the number of water pollution incidents in China in recent years has increased and the harm has become greater, which is related to China's rapid economic growth and accelerated industrial development in recent years (Wu and Cao, 2018). The

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causes of water quality problems are mainly concentrated in sudden water pollution, cumulative water pollution, non-human-led pollutant leakage, and vehicle and vessel traffic accidents (Sfikas et al., 2015). The city supply water is a very important living facilities . The frequent occurrence of sudden water pollution will lead to the decline or disappearance of the supply capacity of the urban water supply system, which will have a serious impact on the lives of residents and even trigger a public crisis (Christine and Zhang,2015; Gong and Yan,2019).

The resilience of the urban water supply system is proposed in the article. Resilience has two attributes, economic and social, so resilience can be described from these two aspects. In the existing research, most scholars study the economic resilience of water supply system, and seldom conduct research from the aspect of social attributes. The research on social attributes also focuses on qualitative, Following the research above, this paper measures the social and economic resilience regarding the water supply system from a quantitative perspective, and constructs a drinking water emergency dispatch model after a water pollution incident. The simulation results show that the model can solve the temporary drinking water problem of residents. Finally, based on the data of different water pollution incidents, the economic and social resilience of each water supply system is calculated, the sensitive factors affecting these two resiliencies are given, and the strategies for improving the system resilience are proposed.

2. Literature review

The research on sudden water pollution mainly focuses on three aspects: risk analysis, early warning and forecast, and emergency management.

In terms of risk analysis, the initial research focused on a qualitative description of the harm caused.

653 cases of surface water pollution in China were cited. These pollution incidents are classified according to the time, place, and cause of occurrence. The number of chemicals involved in the accident, the number of people poisoned, and the frequency of pollution are used to assess the cumulative probability (Yao and Zhang, 2016). A fuzzy risk assessment method is used to quantify the uncertainty of the system. These uncertainties are related to environmental standards and health assessment standards. A sequential Monte Carlo model considering sudden water pollution is implemented (Li and Shi, 2019). Dong and Liu (2018) proposed a method to simulate process chamical substance changement. This method has been apply to treat sudden water pollution issues. They found that the changement of chamical substance can affect water quality. The changement process need several years.

In terms of early warning, as early as the 1850s, the United States Environmental Protection Agency was able to automatically monitor water quality. In detection technology, the United States uses the QUAL model, Denmark uses the MIKE software, and the Netherlands uses the SOBEK software. China only established its first water quality monitoring system in 1988. In order to respond to sudden water pollution accidents, a dynamic and early warning model (EP-risk model) based on the Internet of Things was proposed by Hou and Ge (2014). The risk level of EP is determined through the risk matrix. Ni and Liu (2010) described the basic framework of the rural drinking water safety early warning system on the basis of ComGIS, and designed a system with information collection, search, classification, and dynamic analysis and prediction functions. The design of this system can timely grasp the safety status of rural drinking water, issue early warning information, and take appropriate and necessary control measures. Amanatidou and Trikilidou (2018) studied the water quality changes of the Ilarion Reservoir in western Macedonia, Greece, and performed statistical explanations. Certain chemical parameters in the water exceed legal limits, and changes in these parameters can cause substantial changes in water quality.

Also, in terms of emergency management, the United States has established the National Security Department as its core, and has five levels of emergency response agencies: federal, state, county, city, and community; Japan has also established a comprehensive disaster emergency rescue system; Australia has established voluntary Emergency response system. Jiang and Liu (2018) studied how to increase system resilience. They proposed concept of resilience of water system.when disasters occue, some strategies was studied and the simulation analysis was performed. Taking the Liyang city of Jiangsu province as the research object, Kuang and Du (2019) used the finite difference method to establish a water pollution accident diffusion simulation analysis system with WebGIS as the core, and solved the system dynamics water quality model. They provided decision support for controlling the spread of water pollution.

This article belongs to the category of emergency management of sudden water pollution. Although there have been some articles describing the water supply system from the perspective of flexibility, few authors have measured it from both economic and social aspects. However, in this paper, we focus on the social features of the system. We believe that water supply system has economic and socal character. Quantitative technique was used to describe system features. Therefore, this article uses a quantitative method to describe city wanter system which not only has economic attributes, but also social attributes. According to the existing cases, the total cost has been minimized as the goal, and an emergency water supply plan is given, which can enhance the economic and social resilience of the urban water supply system.

3. Methodology

3.1. Water supply system resilience

Urban water systems include artificial water systems and natural water systems. The artificial water system consists of a drainage system and a water supply system. Natural water systems include rivers, wetlands, green spaces, etc (Fig. 1). The research object of this paper is urban water supply system, including water source, water pipe, water plant and water distribution network.

Resilience is first derived from Ecological perspective. In recent years, resilience has been used once to describe the characteristics of systems, such as resilient systems; it has also been introduced into urban studies, such as resilient cities. Scholars have gived concept of resilience. Various types concepts were proposed. They described resilience from different perspective. Scholars defined it as the water supply system's ability to revert to its initial state after encountering damage. When the city's water supply is terminated, rumors will appear, causing panic among residents and rushing to purchase water, causing negative social impact. Therefore, this paper defines resilience from two aspects: economic resilience and social resilience. Economic resilience is measured by the water supply satisfaction rate during a disaster (Sfikas et al., 2015).

When the system work well, it can sent the water to the residents. We can say that the funtion of the water supply is 100%. But when the residents have no water to use, system stop to work. We can say that the fuction of the system is 0.

x_0 is the system robustness and the loss of function is ($1\text{-}x_0$) (Fig. 2) . The rate of satisfaction loss is divided into two phases: the first phase ($t_1 \le t \le t_2$), the phase in which the system disaster continues to spread. The second phase ($t_2 \le t \le t_3$), the phase in which the system disaster is gradually reduced.

SL is the loss of satisfaction rate

$$SL(x,t)=\frac{\int_{t_1}^{t_2}(1-x(t))dt+\int_{t_2}^{t_3}(1-x(t))dt}{T}.$$

Usually satisfaction is between 0 and 100. The system can supply water, but not as nomal. The water is not enough for the citizens.. T is the time of decision-making cycle. $SR(x,t)=1-SL(x,t)$ represents the water supply system satisfaction. Factors that affect economic resilience are as follows: capacity of the standby water sources, contaminated water sources recovery speed, and water sources supply from other places.

Residents cannot estimate the water suspension duration when the water pollution incident occurs, because the government may not release pollution-related information in time. Therefore, it is possible that residents may hoard drinking water. The anomaly in the sales volume of drinking water can be used to describe social resilience, that is, the current sales volume exceeds the sales volume during the normal period. The daily sales volume of bottled water after the disaster is SD_d, the sales volume of daily bottled water is SD, and the abnormal amount of sales is

$$\frac{SD_d-SD}{SD}\times 100\%$$

Social resilience is:

$$SF=1-\frac{SD_d-SD}{SD}\times 100\%.$$

When the sales volume of drinking water after the disaster is not much different from the normal period, it shows that the water supply system's social resilience is greater, no severe social panic has been caused by the system, and the system's social resilience is stronger. Factors affecting social resilience include the degree of transparency of government information, the level of rumors, the nature and extent of pollution (Yao and Zhang, 2016).

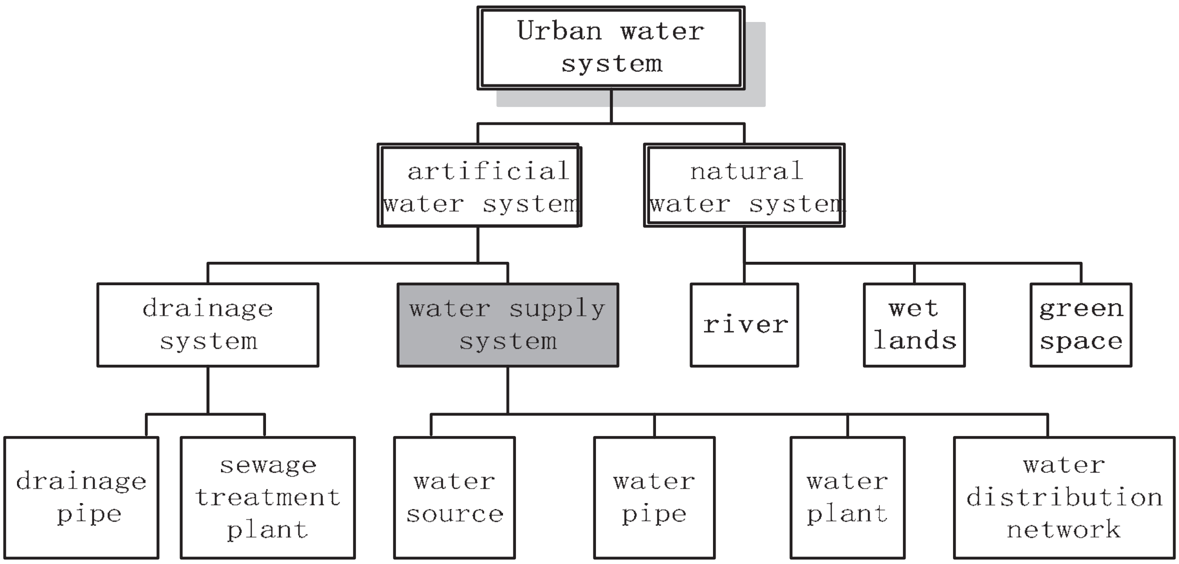

Fig. 1. Schematic diagram of urban water system

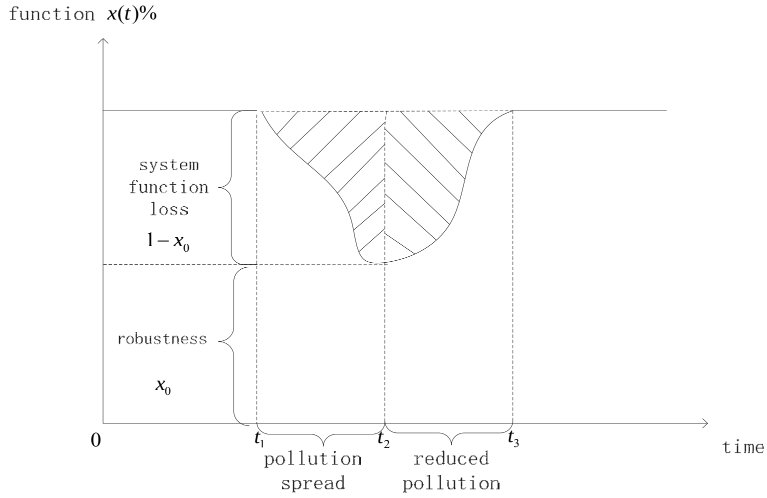

Fig. 2. Measurement of the water supply system loss rate

3.2. The water supply system resilience model

3.2.1. Problem assumptions and description

During the normal operation of the urban water supply system, the system water is supplied from the water source, and after the purification project, it is transported by the pipe network to give priority to the domestic water, and then meet the needs of fire water and building water.

When the water pollution incident occurs suddenly, water source was polluted and water pipe network was also polluted. At this time, the emergency water supply vehicle and the alternate water source are necessary to be activated to meet the domestic water consumption demand of the residents. When the local alternate water resources cannot meet the needs of users, it is necessary to adjust the alternate water support from the neighboring provinces and cities, and at the same time, carry out emergency treatment and recovery of the contaminated water sources. Fig. 3 is a post-disaster emergency water supply system consisting of $i(i=1,2,\cdots,I)$ alternate water sources, $j(j=1,2,\cdots,J)$ emergency water supply vehicles and $k(k=1,2,\cdots,K)$ regional disaster victims. We make the following assumptions about the system:

- When the water quality testing agency finds that the water source or pipe network is contaminated, immediately close the water intake and use a backup water source and water supply truck to supply water.
- Due to the pollution on the pipe network, the emergency water supply vehicle supplies the alternate water source. When the alternate water source capacity falls below the warning level, support for water supply from the field is needed.
- The nodes are water source, water truck, and home of citizens. Water flow from source to home, counter-current is not allowed
- .Emergency water supply system has high event sensitivity.
- There are three sources of domestic water for residents: emergency water supply, supermarket purchase, and foreign water transfer support.
- Regardless of the method used, the minimum daily water consumption of residents must be met.

3.2.2. Parameter determination

evc_j is the capacity of the *j*th emergency water supply vehicle, *$j=1, 2, \ldots J$*

t_s is the time required for recovery after the water source is polluted.

t_1 is the time when water pollution occurs

t_2 is the most serious time of water pollution

t_3 is the end of water pollution and the time when the water supply returns to normal.

F_c is the total amount of water supplied by the field

L_d is the transportation distance of the foreign water supply

c_L is the unit transport cost of water supply in different place.

P_w is tap water unit price

c_g is daily average processing cost of polluted water sources

c_v is the emergency water supply vehicle unit distance transportation cost

J is the warning line for the reserve water source

L_{ik} is the distance from the i th alternate water source to the kth disaster area

L_d is the transportation distance of the foreign water supply

c_l is the unit transportation cost of the foreign water supply

w_k is the total amount of bottled water purchased by the victims in the kth region from the market.

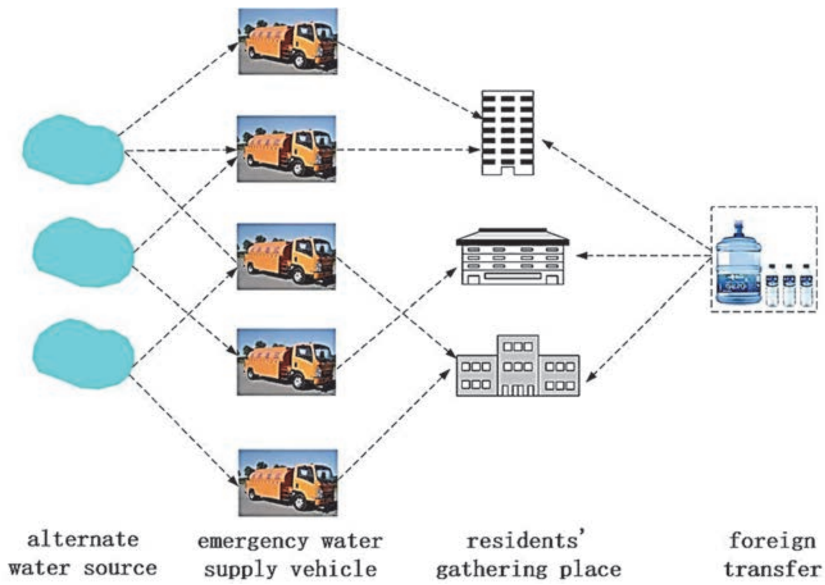

Fig. 3. Emergency water supply system after disaster

3.2.3. Decision variables

Qab_{ij} is the flow between the i th alternate water source and the j th emergency water supply vehicle.

Qbc_{jk} is the flow between the jth emergency water supply vehicle and the kth user area.

$$\varepsilon=\begin{cases}1 & \sum_{i=1}^{I} swc_i-\int_{t_1}^{t_3}x(t)dt\le J\\ 0 & \sum_{i=1}^{I} swc_i-\int_{t_1}^{t_3}x(t)dt> J\end{cases}$$

$$\sigma_{ij}=\begin{cases}1 & \text{There is transport relationship between } i \text{ and } j\\ 0 & \text{There is no transport relationship between } i \text{ and } j\end{cases}$$

$$\lambda_{jk}=\begin{cases}1 & \text{There is transport relationship between } j \text{ and } k\\ 0 & \text{There is no transport relationship between } j \text{ and } k\end{cases}$$

3.2.4. Objective functions and constraints

The total cost of the emergency rescue process $(t_1\sim t_3)$ is comprised of the following: total water cost of consumption, emergency treatment cost, emergency water vehicles transportation cost, and cost of water resources transportation.

The sum of the external support water cost and the local water cost gives the total cost, which is $\int_{t_1}^{t_3}x(t)dt+\varepsilon F_c$. When water pollution occus, purification drinking water is very important and the cost is $c_g(t_3-t_1)$. The transportation cost of the emergency water supply truck is $\sum_{i=1}^{I}\sum_{j=1}^{K}\sigma_{ij}L_{ik}c_v$. The total cost of transporting water in the field is $\varepsilon L_d c_l$。

When water pollution occurs, the objective function and constraints of the resident water emergency dispatch model are shown in Eqs. (1-5):

$$\min\left\{\int_{t_1}^{t_3}x(t)dt+\varepsilon F_c+c_g(t_3-t_1)+\sum_{i=1}^{I}\sum_{j=1}^{K}\sigma_{ij}L_{ik}c_v+\varepsilon L_d c_l\right\} \tag{1}$$

s.t.

$$\int_{t_1}^{t_3}x(t)dt\le\sum_{i=1}^{I}swc_i+\varepsilon F_c \tag{2}$$

$$80\le\frac{\int_{t_1}^{t_3}x(t)dt}{\sum_{k=1}^{K}C_k}+\sum_{k=1}^{K}\frac{w_k}{C_k}\le 130 \tag{3}$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}Qab_{ij}\sigma_{ij}=\sum_{j=1}^{J}\sum_{k=1}^{K}Qbc_{jk}\lambda_{jk} \tag{4}$$

$$Qab_{ij},Qbc_{jk}\ge 0\ ;\ \varepsilon,\sigma_{ij},\lambda_{jk}\ge 0 \tag{5}$$

In the constraint condition, $\int_{t_1}^{t_3}x(t)dt\le\sum_{i=1}^{I}swc_i+\varepsilon F_c$ indicates that the capacity of the backup water source and the amount of water supported by the field must meet the total water demand of the residents.

$80\le\frac{\int_{t_1}^{t_3}x(t)dt}{\sum_{k=1}^{K}C_k}+\sum_{k=1}^{K}\frac{w_k}{C_k}\le 130$ indicates that the daily water consumption of residents should meet the standard of normal drinking water per capita, which is 80-130 (L/person/d).

$$\sum_{i=1}^{I}\sum_{j=1}^{J}Qab_{ij}\sigma_{ij}=\sum_{j=1}^{J}\sum_{k=1}^{K}Qbc_{jk}\lambda_{jk}$$

is network traffic balancing. (Eq. 5) is a non-zero constraint.

4. Results

On November 13, 2005, an explosion occurred in the No. 1 workshop of the Biphenyl Plant of Jilin Petrochemical Company. As of November 14, the same year, 5 people were killed, 1 was missing, and nearly 70 were injured. After the explosion, about 100 tons of toxic substance went into the Songhua River, causing serious pollution of the river water and affecting the lives of millions of residents along the coast. The explosion caused an 80-km-long pollution zone on the Songhua River, consisting mainly of benzene and nitrobenzene. The pollution zone passed through Harbin, which experienced a four-day water outage and was an industrial disaster. On November 21, 2005, the Harbin Municipal Government issued a notice to the society that the city's water supply will be suspended for 4 days and that the municipal water supply network will be overhauled.

Since then, the public suspects that the water cuts are related to the earthquake. On November 22 of the same year, the Harbin Municipal Government issued two consecutive announcements confirming that the explosion of the upstream chemical plant caused water pollution in the Songhua River . This river located in northeast of China . It is the drinking water source of the city. Common people conjectured cause of accident. Next day, the government told citizens real reasons of pollution due to the explosion accident at the bisbenzene (Chemical Name) plant of PetroChina Jilin Petrochemical Company (Fig. 4).

Fig. 4. Location of polluted Songhua River in China

Citizens of Haerbin drink water of Songhua River. It is a main wanter source of the province .After the pollution incident, Harbin began to construct the Mopan Mountain water source as the main water source for urban water supply in Harbin. This article applies the model built in Part 4 to Harbin water pollution accidents, provides elastic strategies for emergency water supply, and calculates the economic and social resilience of the Harbin water supply system.

4.1. Initial conditions and assumptions

After the Songhua River pollution occurred, Harbin immediately closed the water supply operation facilities to prevent toxic water from entering the pipeline. At the same time, the uncontaminated standby water source was immediately opened to provide emergency water supply for residents' lives. In 2005, the city administered 8 districts, 7 counties, and hosted 2 county-level cities. Due to the different geographical locations of various districts in the city, the reserve water supply capacity of each district is also different. The city needs to make overall arrangements to allocate from areas with abundant water resources to areas with less water resources. Fig. 5 is the distribution of reserve water source capacity in each district of Harbin.

It can be seen from the figure that the dark blue part is located in the south of the city, indicating that this area has the most abundant backup water sources. Light blue is located in the central and northern parts of the city, and the water storage in these two areas is lower than in the south. The lightest blue is located in the west of the city, indicating that the area has the least spare water sources. The central and western regions are rich areas, each of which has a small area and is the central area of Harbin. Because the initial data obtained in this example is limited, only 8 dictions in the city are measured. This area is shown in the circled area in Fig. 5.

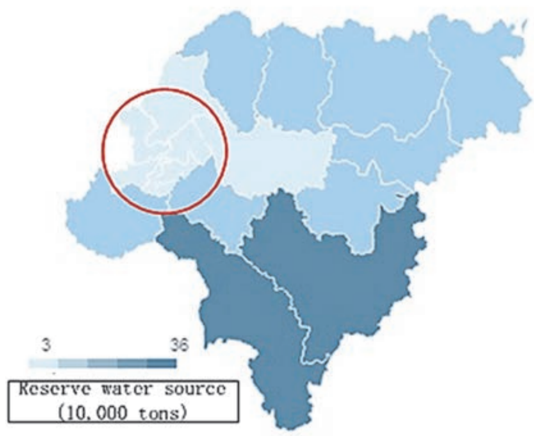

Fig. 5. Distribution of reserve water sources in Harbin

Due to the wide scope of water pollution, Harbin opened 386 spare water source wells. These spare water source wells have not been used for many years, and the Ministry of Health needs to test them on seven major pollution indicators before they can be used. Harbin Water Supply Group needs to ensure 36,000 cubic meters of emergency drinking water every day. The local water supply cannot meet the needs of residents. Harbin has transferred 18,000 tons of bottled water from Qiqihar, Mudanjiang, Jiamusi, Suihua, Daqing, Jixi, Wuchang and other cities. Shenyang has also urgently assisted 600 tons of drinking water in Harbin. The daily demand for drinking water in Harbin is 18,600 tons. After the accident, citizens snapped up 16,000 tons of mineral water on the market as a reserve, which is equivalent to the mineral water daily supply for 100 days in Harbin.

There are some vehicles. Many trucks were used to transport water for citizens. Residents use buckets to take water home. These vehicles first went to the reserve water source to fetch water, and then sent them to residential areas. After arriving at the residential area, these water supply vehicles are the temporary water collection points for the residents. When there is no water in the trucks, the trucks went back to the water source to get water. Ereryday vehicles shuttled between water collection points and water source.–Residents' temporary water points are shown in Fig. 6. Due to the limited emergency supply capacity, it only supplies residents' domestic water, excluding production water. In order to verify the validity of the model, this paper only selects the small-scale emergency dispatching data of Nangang District of Harbin for calculation, in order to obtain the emergency dispatching plan. There are 3 spare water source wells in the area, 5 emergency water supply vehicles, and about 500,000 affected residents. Nangang District received Jilin area assistance water amount of 50 thousand tons, and the distance from Jilin area is about 260 kilometers.

4.2. Simulation results and analysis

By inputting initial data into the model, simulation results are obtained. Through the solution of the model, the emergency dispatching scheme of the emergency water supply vehicle between the alternate water source and the disaster area is obtained. See Table 1 and Fig.7. The minimum total cost of emergency rescue is 9874534 Yuan RMB.

4.3. The resilience value of the water supply network

Since the emergency rescue of water pollution in Harbin is organized by districts, the economic and social elasticity of the emergency water supply system in each district can be calculated through the reserve water source capacity, water supply satisfaction rate and supermarket mineral water sales profile in each district. This article selects the reserve water source capacity, sales volume of bottled water in supermarkets, emergency residents' water supply and water supply gap in eight districts in Harbin. The water supply satisfaction rate, economic and social elasticity values of each district are calculated separately. The specific results are shown in Table 2.

Fig. 6. Location of Harbin temporary water supply point

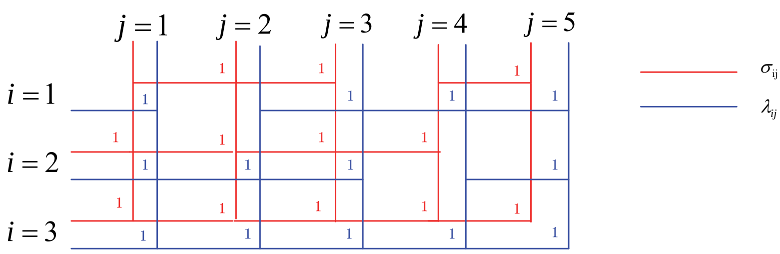

Fig. 7. Simulation calculation results（二）

Table 1. Simulation calculation results（一）(Objective function value: 9874534yuan) Qab_{ij}

	Qab_{ij} *(ton)*						Qbc_{jk} *(ton)*				
	$j=1$	$j=2$	$j=3$	$j=4$	$j=5$		$j=1$	$j=2$	$j=3$	$j=4$	$j=5$
$i = 1$	69	15	53	0	65	$i = 1$	52	0	36	38	55
$i = 2$	46	63	37	42	0	$i = 2$	63	49	32	0	19
$i = 3$	0	12	49	36	39	$i = 3$	13	50	41	67	21

Table 2. Parameter values of various water supply systems in Harbin

District	*Area (square kilometers)*	*Population (10,000 people)*	*Water supply satisfaction rate (%)*	*Economic resilience (%)*	*Social resilience (%)*	*Reserve water source (10.000 tons)*
Songbei	736	16	82	82	81.30	4.7
Daoli	479	67	88	88	69.20	7.1
Nangang	183	93	84.30	84.30	71.50	5.4
Daowai	257	69	86.70	86.70	72.40	6.8
Xiangfang	209	33	90	90	71.40	7.7
Power	131	36	93	93	86.40	8.9
Bungalow	94	16	91	91	88.10	7.6
Hulan	2186	55	80	80	89.70	3.2

Fig. 8 shows the area, population, social resilience, and economic resilience of various districts in Harbin. It can be seen that the economic resilience data and the social resilience data are not evenly distributed in each district, and there is no obvious law between the districts. It can be seen from the economic resilience map that the water supply system in Daoli District and Power District has higher economic resilience because the two areas are small and the population is at a medium level. It is difficult to use spare water sources for water supply and the water supply satisfaction rate. The higher the economic resilience value.

It can be seen from the social resilience map that the social resilience values of water supply systems in DL District, NG District, DW District, XF District and other places are low(we use first letter of each word to represent this area). The reason for this analysis is that these districts are downtown areas of Harbin and are rich urban areas. The sales of bottled water in these urban supermarkets are large, and residents are willing to hoard drinking water, which results in an abnormally large amount of bottled water sales in these areas, so the social resilience of the water supply system is low.

As can be seen from Fig. 8a-d represent the trend graphs of the area, population, economic elasticity, and social elasticity of each district in Harbin. As can be seen from Figs. 8c-d, the data distribution of economic elasticity and social elasticity in each area is not uniform, and there is no obvious difference between the areas.

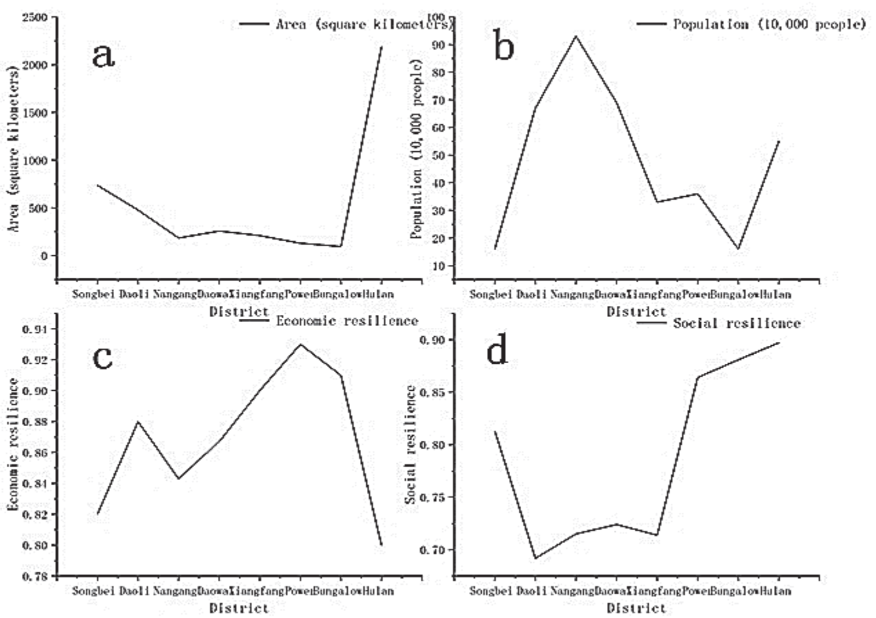

Fig. 8. Area (a), population (b), the value of economic resilience (c), the value of social resilience(d)

It can be seen from Fig. 8c that the water supply system in Daoli District, Power District and other places has high economic elasticity, because these two districts are small in size and the population is at a medium level. High, so the value of economic elasticity is also high. It can be seen from Fig. 8d that the social elasticity value of the water supply system in four areas(which contains DL,NG,DW,XF) are low. Other areas are higher than these areas.The reason for the analysis is that these districts are in the center of Harbin and are affluent urban areas. Sales data show that the sales of drinking water in supermarkets have increased significantly, indicating that residents are panic and need to stock up drinking water. These data also show that the social resilience of the system in these areas is low. Fig. 9 describes the relationship between the economic resilience value of the system and the number of standby water sources.

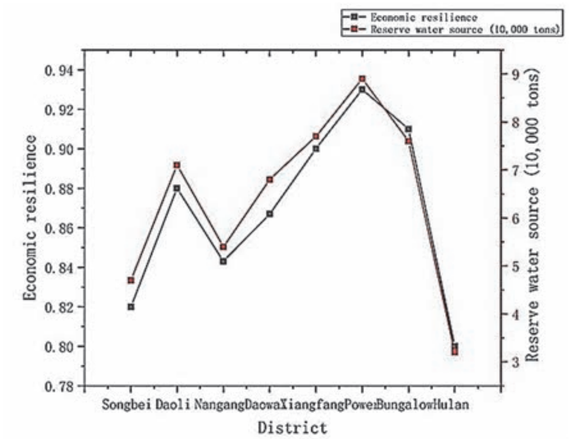

Fig. 9. Comparison of economic resilience and reserve water sources in Harbin

It can be seen from the broken line that the trend of the amount of standby water source and economic resilience is basically the same: when the standby water source increases, the economic resilience value also increases; when the standby water source decreases, the economic resilience value also decreases.

Analyzing the reasons it results that, when there is a large reserve of water resources in a certain area, the water supply satisfaction rate of residents in this area will increase accordingly, so the economic resilience value of the water supply system is also high. Therefore, we conclude that increasing the amount of reserve water in a certain region can increase value of economic. In other words , when there are lots of standby water sources, system can recover supply function as soon as possible.

In Fig. 10 , value of economic and social resilience are given. Upper half of the figure is economic resilience and the other half is social resilience. Economic resilience is higher than socila.there are four areas have low social value which we can see from picture. Why there are obvious differences of social resilience between areas? The reason is that the residents of these areas have a relatively rich life, and the sales volume of bottled water in supermarkets is much higher than the daily sales volume of bottled water. And the residents of Songbei District, Power District, Bungalow District and Hulan District live at a medium level, and sales of bottled water are not high. The social resilience of the system can be improved by improving residents' water supply satisfaction and government information disclosure.

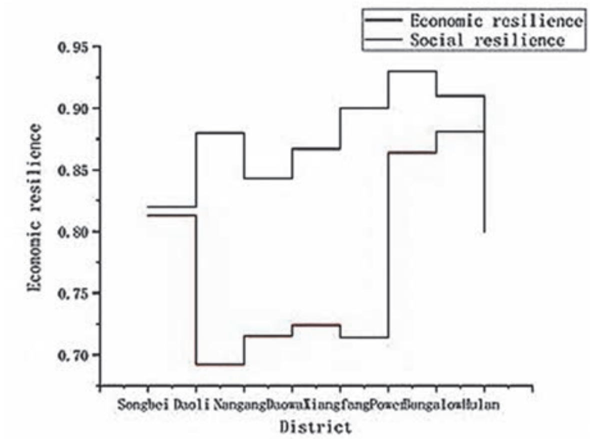

Fig. 10. Ladder diagram of economic resilience and social resilience of water supply system in Harbin

5. Conclusions

This paper studies the emergency strategy of water supply system in the event of sudden water pollution. From a quantitative perspective, the system's economic resilience and social resilience are proposed, and the functional relationship between the water supply satisfaction rate, the abnormal rate of bottled water sales, and the economic resilience and social resilience are given. Emergency dispatching model.

The integer programming model was solved with CPLX software. Finally, the case simulation proved that the model can effectively solve the emergency dispatch and resource allocation problems in sudden water pollution.

(1) An emergency dispatching model was constructed and the model was simulated using real data from Harbin Nangang District. The dispatching scheme and path are obtained in the case of 3 backup water sources and 5 emergency water supply vehicles. The simulation results can minimize the total cost of emergency dispatch, the travel path of emergency water supply vehicles is short, and the satisfaction rate of residents' water consumption reaches 84.3%.

This model can be extended, for example, to apply to more water sources and emergency water supply vehicles.

(2) The resilience values of 8 districts in Harbin were calculated.

Using values such as water supply satisfaction and the number of backup water sources, the economic and social elasticity values of the water supply system in 8 districts of Harbin were calculated. The calculation results tell us that the increase in the capacity of the standby water source can increase the economic elasticity of the water supply system. the social resilience in affluent areas is usually low; it can be achieved by increasing the satisfaction rate of residents' water supply, government information disclosure, and market bottling level Stabilize the supply to improve the social resilience of the water supply system.

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