

# Finding of urban rainstorm and waterlogging disasters based on microblogging data and the location-routing problem model of urban emergency logistics

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**Abstract** Due to the climate change and the rapid progress of urbanization, extreme weather disasters such as urban rainstorm and waterlogging are frequent. Therefore, how to find the waterlogging points in the presence of disasters and how to optimize the distribution of urban emergency logistics and reduce the negative impact of disasters have become a hot and difficult issue for government departments and scholars. First of all, the idea and method of using the big data of microblogging to obtain urban rainstorm and waterlogging disasters and public sentiment are put forward. In addition, this thesis constructed the location-routing problem model of urban emergency logistics in the situation of rainstorm and waterlogging disaster, and found out the dynamic emergency distribution path of Nanjing in the situation of waterlogging disaster by using NSGA-III algorithm. Research shows that the risk management of urban rainstorm and waterlogging disasters, together with social media data, is a feasible way to obtain on-site data of disasters and carry out risk assessment of disasters. At the same time, the emergency logistics location-positioning model and algorithm can provide a reference for similar disaster emergency logistics distribution network and the conclusion can provide empirical reference for cities to cope with rainstorm and waterlogging disasters.

**Keywords** Microblogging data · Urban rainstorm and waterlogging disasters · Location-routing problem · NSGA-III algorithm

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## 1 Introduction

In recent years, meteorological disasters have become increasingly frequent as a result of global warming. In the meanwhile, compared with the rapid urbanization process, the less developed water system planning and underground pipe network construction in China lead to frequent rainstorms and waterloggings, imposing a serious effect on the traffic, tourism, routine work and life, even bringing huge threats to the personal safety of inhabitants. Affected by climate and topography, the Yangtze river basin always suffers from long periods of heavy rain in summer and is one of the most effected areas with rainstorm in China.<sup>1</sup> It is even more difficult for Nanjing to escape it. Therefore, urban rainstorm waterlogging has become a common concern in all sectors of society, since it may lead to congestion and submergence of areas that are prone to be submerged. And this is why Nanjing rainstorm event is a major disaster worthy of consideration. However, the form in carrying out emergency rescue work targeted at the high-risk places. All these formidable site condition makes it difficult for governments and emergency organizations to know the detail about the disaster site and the public emotion, which also poses a difficulty been hot and difficult issues in the process of the disaster emergency management.

However, the bloom of social media big data, such as microblogging, and data mining technologies, provides a viable channel for us to know disaster details and the public emotion. China owns the most netizens in the world: by the December 2015, Chinese citizens had amounted to 731 million and the popularity rate of the Internet had reached 53.2%; phone netizens had amounted to 620 million, the percentage of which increases to 90.1%. With the enlargement of netizen scale, the usage of social platforms, like microblogging and wechat, shows a gradually rising trend, for example, Sina Weibo, launched in China in August, 2009. In 2010, four largest portal websites dedicated to the development and publicity of microbloggings, especially Sina Weibo, achieving the greatest success, with active users amounting to 50 million within 1 year in 2010. Statistics suggest that the number of microblogging messages that Chinese netizens post and forward every day are 250 million. As a kind of social tool, microblogging has become a major platform for more and more people to express personal emotions and record their life. Featured by real time and timeliness, microblogging serves as a platform for the extremely rapid spread of hot issues. Therefore, microblogging contents could be a valid source for the public opinion analysis, emotion extraction and personal opinion mining. Owing to the low efficiency of information dissemination of traditional media, in the case of waterlogging disaster brought by rainstorm, relevant departments are unable to obtain the first-hand information and elicit quick response. With strong timeliness, microblogging could be employed by the public to post disaster details once natural disaster happens, which would provide a means to extract the disaster information through social big data.

Meanwhile, with global warming and the rapid progress of urbanization in China, urban rainstorm and waterlogging disasters have become frequent, which has drawn scholars' attention to the emergency management of urban waterlogging disasters (Kaur and Singh 2016; Song and Du 2017). However, once a rainstorm disaster occurs in the city, the finding of

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<sup>1</sup> First of all, the Yangtze River region experiences frequent heavy rainstorms. As the capital of six dynasties in ancient China, the capital of Jiangsu province and one of the cities with the largest population in the Yangtze River region, Nanjing city has been suffering from heavy rainstorms for a long time. For instance, the heavy rainstorm from June, 2016 to July, 2016 imposed great influence on Nanjing. The rainfall in 10 h on June 10th broke the record of daily rainfall within a century. The heavy rainstorm did not stop until June 27th, causing many regions submerged and subway outage of multiple lines. Second, since the data of microlog and road traffic of the present paper are all from Nanjing, the paper chooses Nanjing as the case for research.

the disaster and the waterlogging points in the emergency situation and the building of the traffic emergency network are undoubtedly important theoretical and practical problems in the emergency management of the disaster.

In this paper, we focus on the extraction of microblogging disaster data and the optimization of post-disaster rescue routes. These two parts were combined skillfully to solve the problem of rapid collection and application of disaster information. When the heavy rain came and the road was cut off, the smooth flow of road traffic will be affected by waterlogging points. Using the microblogging data, the waterlogging points can be found precisely. Based on the construction of location-routing problem model and the application of the NSGA III algorithm, the new road traffic route can be redesigned timely. Then, this work of article is novel and will be of great significance to the emergency rescue of sudden disasters such as rainstorms.

The rest of the paper is as follows: the second part is the literature review; the third part is the research of finding the waterlogging points and the disasters by using microblogging data; the fourth part is the model construction; the fifth part is the simulation calculation; and the last is the summary.

## 2 Literature review

### 2.1 Disaster information extraction of microbloggings

Currently, studies on the microblogging disaster extraction mainly center on the earthquake area. Once an earthquake happens, rescue must be conducted within the shortest time in order to reduce the loss to the minimum. Due to the lack of timeliness of traditional media, it is difficult for relevant departments to control the disaster and rescue in time and accurately. Microbloggings enjoy strong timeliness. After an earthquake, the public generally post various conditions that they are facing through microblogging and other social media. By analyzing microblogging big data, disaster details could be known, including the location and casualty of the earthquake.

In recent years, the attention and interest on using microblogging big data in disaster emergency logistics are increasing. Xu et al. (2015) puts forward the concept of position microblogging. Sakaki et al. (2010) and other researchers put forward the real-time earthquake monitoring system based on the Twitter through the Bayesian Decision Method: take keywords as the evidence. In practical application, the system has successfully detected more than 80% earthquakes and forecasted earlier than the local earthquake organizations. The system can not only detect the occurrence of earthquakes, but also can estimate the location of the earthquake on account of the location information contained in the microblogging data. Choi and Bae (2015) introduced how Social Big Board, a real-time monitoring system based on the social big data, represented the disaster and its spreading trend on the map for further disaster estimation, forewarning and precaution development by analyzing earthquake-relevant contents posted on Twitter after the Haiti Earthquake happened in 2010. Yan et al. (2010) believed that microblogging contents play a vital role in extracting disaster information by analyzing the microblogging message, developing trend of various themes and propagation process through various analysis methods by the example of Yushu Earthquake in 2010.

In a word, by mining microblogging data, earthquake information could be known and it is efficient to prevent and reduce the loss that might be caused by earthquakes. And some paper about using data from Twitter and authority to analysis flooding disaster. Nevertheless,

the microblogging big data has not been applied to the emergency management research of urban rainstorm waterlogging disaster.

## 2.2 Emotion analysis of microbloggings

By mining and analyzing microbloggings contents, relevant departments could know the emotion of the public timely so that they could take corresponding measures to control the public emotion. By now some scholars have developed relevant research by taking advantage of microblogging big data. For instance, Zheng et al. (2012) raised an integrated microblogging data process method and detecting algorithm about news topics. Li et al. (2013) presented the topic propagation evolution model that could describe the fission propagation mode with immunization rate. Hou (2013) made an integrated analysis on the evolution process of the public emotion about the unexpected group events by the example of Shenfang Lindgrenite Event. Yang (2014a, b) raised the method to monitor the public emotion about the emergency on the internet on the basis of the microblogging data.

Microblogging emotion analysis is conducted through three steps: text preprocessing, emotion information extraction and emotion classification. This kind of research is quite common. For instance, Zheng (2014) came up with the concept of emotion polarity: classify the emotion polarity into positive, neutral and negative by comparing the number of positive and negative emotion vocabularies in the text. Zhou et al. (2013) put forward the method to build Chinese emotion dictionary based on the HowNet and SentiWordNet. The experiment represented that the dictionary is superior to those emotion dictionary with general polarity, which provides valid dictionary resources for emotion analysis studies. Preethi et al. (2015) introduced a generalized model that could be adopted to determine the possibility of an event happens in the future by estimating the causal relationship between the event and its corresponding emotion reaction on the basis of timeliness emotion analysis of Twitter. Take the Sandy Hurricane happened in October, 2012 as an example, Neppalli et al. (2017) visualized the hurricane-related emotions on the map based on the Twitter big data. The study showed that the public emotions are not only related to their geographical position, but also the distance range that the hurricane has affected. Although currently there are abundant studies about emotion analysis on the microblogging big data, the emotion analysis on the urban rainstorm waterlogging based on the microblogging big data are quite rare.

On the basis of the above research, the paper extracts and analyzes the Sina Weibo data during the heavy rain occurrence to further analyze the disaster information and the public emotion, select urban rainstorm waterlogging areas with high risks and provide empirical support for disaster emergency management by the example of the heavy rainfall on June 18th and July 7th in 2016.

## 2.3 Urban emergency logistics in waterlogging disasters

The decision-making in the presence of urban rainstorm disasters is a focus of attention for scholars. People like Chen et al. (2016) build an urban waterlogging disaster emergency shelter to improve the flexibility and capacity for decision making in emergency management departments; Deng et al. (2016) put forward suggestions on how Shanghai could prevent and cope with waterlogging. Hu et al. (2015) constructed the two-stage stochastic mixed integer programming model at the aim of minimizing the total cost of logistics; Su et al. (2016) presented an integrated simulation method to analyze the effects of urban rainstorm and waterlogging on traffic congestion. However, the research on how to carry out disaster relief material delivery on flooded roads after urban rainstorm and waterlogging is rare. But it is a

key issue that needs to be solved in real life as well as a difficult and hot issue that people are concerned about. Therefore, this paper, by proposing an optimization model of post-disaster material delivery and carrying out the demonstration by taking Nanjing as an example, is of great theoretical and practical significance.

Disaster relief supplies can be classified as a sort of location-routing problem. In 1970s, Cooper (1972, 1976) combined the distribution center location problem with the vehicle routing problem, and put forward the transportation-positioning problem. People like Rahman and Smith (2000) suggested that the key to solving the location-routing problem was constructing a reasonable optimization model. During the delivery of emergency supplies, the effect of the relief effort depends on the ability to deliver emergency supplies to affected areas with the minimum amount of time and minimal cost of emergency relief. People such as Li and Zhou (2014) and Moshref-Javadi and Lee (2016) constructed the rescue model aiming at spending the shortest time; people like Pranmudita et al. (2014) constructed the model with the aim of minimizing the total cost; people including Wei and Özdamar (2007), Rath and Gutjahr (2014), Wang et al. (2014), Burkart et al. (2016), Khalipourazari and Khamseh (2017), Tayal and Singh (2017), Chang et al. (2017) and Song and Du (2017) constructed multi-objective models considering a variety of mixing factors to solve the multi-objective problems.

The difficulty of research lies in how to obtain optimal or satisfactory solutions of these models. Scholars often use heuristic algorithms, among which the two-stage heuristic algorithms are used more frequently (Metzger and Zabinsky 2010; Han et al. 2011; Ahmadi et al. 2015). Some other algorithms such as simulated annealing algorithm and ant colony algorithm are also used by scholars (Jotshi et al. 2009; Yu et al. 2010; Dalfard et al. 2013; Ting and Chen 2013). Genetic algorithm is one of the most common used algorithms, but the hybrid optimization algorithm is more adopted by combining basic genetic algorithm with other algorithms due to the complex design and long running time of basic genetic algorithm (Wu et al. 2002; Wang et al. 2015; Asgari et al. 2017). For instance, by comparing and studying, scholars (Rabiee et al. 2012; Fallah-Mehdipoura et al. 2012; Bandyopadhyay and Bhattacharya. 2013; Kalaivani et al. 2013; Pasandideh et al. 2013; Pranmudita et al. 2014; Song et al. 2017) found that non-dominated sorting genetic algorithm had obvious advantages among the current multi-objective optimization algorithms; The improved NSGA-III algorithm, in particular had great advantage in running time and solution quality. Therefore, in recent years, the improved NSGA-III algorithm has been applied to the research of emergency and other multi-objective planning in many literatures (Mohapatra et al. 2015; Duan et al. 2016; Yu et al. 2017; Zhou et al. 2017; Feng et al. 2017). Based on the above considerations, the algorithm was also selected in this paper.

Based on the existing literature review, there exists very little research in which a city is taken as an example to study emergency material delivery under the circumstance of rainstorm flood disaster. As far as the researchers' vision is concerned, there has not yet been research of building the LRP model based on the disaster information obtained via the microblogging. Therefore, in the paper, information on the disasters is obtained through microblogging data for the first time, and then the paper presented the LRP model in the context of rainstorm and waterlogging disaster, and by taking Nanjing as an example, used non-dominated sorting algorithm NSGA-III to get solutions. The strategy and method of the research has enriched the existing research literature of disaster management, and the conclusion has provided an empirical reference for Nanjing to cope with the rainstorm and waterlogging disaster.

### 3 Obtainment of disaster information via microblogging data

#### 3.1 Research steps

On the basis of the Sina Weibo content, take the following three steps to extract the urban rainstorm waterlogging information from microbloggings of numerous users:

First step: data extraction and IP address translation. Take the persistent strong rainfall from the mid-June to the beginning of July in 2016 as an example, 6,385 microbloggings are extracted from June 18th to July 7th. Owing to the long time quantum, microblogging contents are divided into two parts and processed separately to specifically reflect the variation trend of waterlogging during this period in Nanjing: from June 18th to June 30th and from July 1st to July 7th. The paper will analyze the seriousness level of waterlogging in all administrative regions of Nanjing and find out areas prone to be submerged during this strong rainfall via microblogging contents. Since the IP address contained by the microblogging cannot directly reflect the administrative region of the blogger, all IP addresses are translated into physical addresses through IP address convertor. Then all microbloggings can be classified according to administrative regions for further analysis.

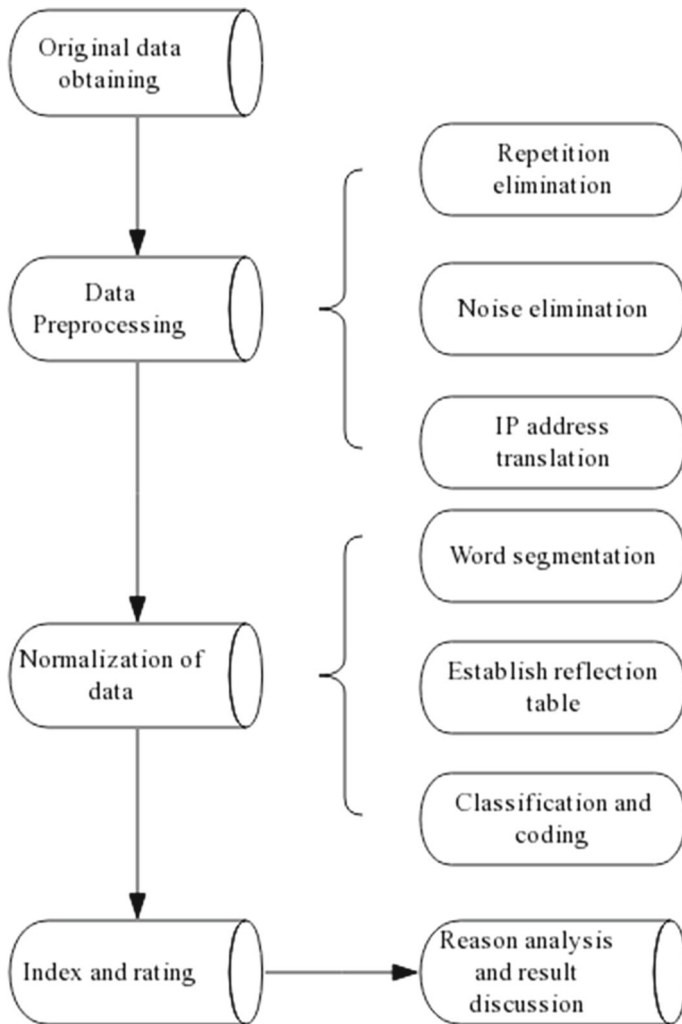
Second step: repetition and noise elimination, word segmentation and index establishment. It is necessary to eliminate the repetition and noise, segment words and establish the index because of the loud noise and plenty of invalid repetition in the original microblogging data. ICTCLAS is used for word segmentation to process microblogging contents. The result of the word segmentation is classified according to the rainfall reasons, the description about the ponding of the public, the effect of the waterlogging on traffic and the emotion reaction of the public (see the attachment Table 9 for details); the waterlogging information and emotion description are rated and coded in order to compare the strong rainfall information and emotion reaction in various administrative regions of Nanjing (see attachment Tables 10, 11 for details).

Third step: contrastive analysis of these two phases. According to the word segmentation result, for one thing, the variation trend of the waterlogging in the two phases and waterlogging differences in various administrative regions of Nanjing can be determined and areas prone to be submerged can also be found; for another, the varying regularity of the public's emotions during the urban waterlogging could be analyzed and the emotion difference of the public in various administrative regions could be achieved.

Targeting at the urban rainstorm waterlogging disaster, the paper designs the following extraction process (Fig. 1).

#### 3.2 Research methods

The present paper adopts the word segmentation to analyze the enormous microblogging text data. Words are processed by the currently universal ICTCLAS, which enjoys high accuracy and can label the part of speech and its corresponding weight and frequency of each word. The main purpose of the paper is to distinguish the disaster degree of waterlogging in all administrative regions of Nanjing. After the word segmentation, the urban rainstorm waterlogging reflecting table and disaster classification coding table could be established and then disaster values of all administrative regions could be normalized by the word frequency and weight of the strong rainfall description.



**Fig. 1** The extraction process of urban rainstorm waterlogging information based on the microblog big data

### 3.3 Empirical results

#### 3.3.1 A brief introduction about the disaster

In 2016, affected by El Nino, the rainfall in the Yangtze River basin was significantly more than that in previous years, and brought great influence to the entire river basin. Nanjing was one of the most affected cities in the rainstorm, where the rainfall was of high and sudden intensity and long duration. Nanjing began to rain from June 5th, 2016 and it nearly did not stop until the beginning July. From the mid-June to the end of June, the rain was normal, mainly thundershower and moderate rain; at the beginning of July, the rain started to be stronger, mainly moderate and torrential rain. This persistent rain refreshed the rainfall amount record of Nanjing, amounting to 441 mm on June 27th.



The persistent strong rainfall directly caused serious ponding in urban areas of Nanjing, so that the emergency office of municipal government kept raising the rating of flood prevention and emergency response. There were numerous ponding in urban areas: the depth of ponding in Nanjing University of Science and Technology amounted to 1.5 m; the rainwater submerged the garage in the Yinchengdongyuan housing estate; numerous cars were submerged; the metro station of the Mingfa Square was submerged by rainwater, the depth of ponding on the Saihongqiao Street amounted to almost 2 m, which imposed great negative influence on citizens' property safety and transportation.

From the result of word segmentation of microbloggings, people gave the following description: convective weather, convection, violent typhoon, Nepartak, plum rains, plum, and so on. Since June belongs to rainy seasons, adding to that strong convective weather and typhoon are common in summer, these two factors led to the lasting rainstorm with huge amount of rainfall. People also offered the following description about the disaster: water level rises of Qinhuaihe River; dragon water on the city wall; traffic paralysis; the Yangtze River exceeds the warning level; rapid increase of water level of Xuhe River. The disaster brought huge challenge to the city water prevention system of Nanjing.

### 3.3.2 Contrastive analysis on the waterlogging level

How to evaluate the waterlogging level in various administrative regions of Nanjing is an important issue for research. Generally, people regard disaster degree as the rating standard to measure the loss of the natural disaster. Cheng et al. (2011) put forward the synthetical disaster index (SDI), which can be used to normalize a series of disaster evaluation factors and obtain quantitative disaster evaluation index by weighted addition. Ma (2006) advocated to adopting the disaster degree rating standard of dual-factor evaluation at the early stage: the death roll and the value of the social property loss in a disaster. In the study of the disaster degree of floods, some scholars presented indicators that reflect the size of the disaster area (including the size, population and the number of counties that the disaster has affected). By three-factor analysis, Mao (2000) built the flood disaster index (including the affected area, affected population and food reduction) to evaluate the disaster degree of flood, waterlogging and flood-waterlogging disaster in Dongtinghu Region.

It can be known from the microblogging content that this torrential rain did not cause any casualties; however, the direct and indirect economic loss caused by waterlogging was unlikely to be calculated through micrblog contents. Therefore, the disaster rating of the urban rainstorm waterlogging is mainly influenced by the amount of rainfall, ponding range, ponding depth and traffic jam. Based on the previous research, the paper summarizes the following formula to calculate the disaster rating of urban rainstorm waterlogging<sup>2</sup>:

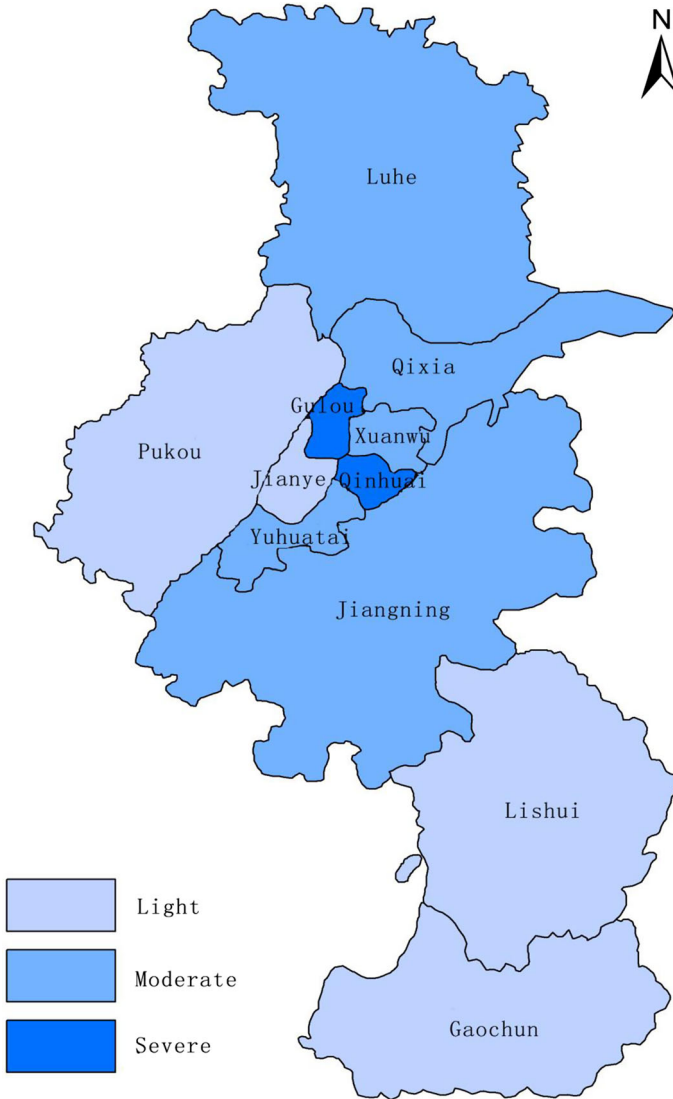
$$\text{Disaster index} = \text{ponding range} * 30\% + \text{ponding depth} * 30\% + \text{traffic jam} * 40\%$$

Based on the above formula, the value of rainstorm waterlogging disaster is quantized and classified into five ratings: low-grade, mild, ordinary, serious, grave. The results can be seen in the following two figures (Figs. 2, 3).

In the last 10 days of June, ponding in Qinhuai Region and Xuanwu Region was ordinary—even more serious than the other regions; ponding in Pukou Region, Lishui Region and Gaochun Region was mild. In the first 10 days of July, the rain became strong, mainly heavy rain, rainstorm and heavy rainstorm. Adding to the previous persistent rain, the increase of

<sup>2</sup> The disaster index came from Cheng et al. (2011) and the weights were determined by 3 rainstorm disaster experts of Jiangsu meteorological bureau.





**Fig. 2** The rainstorm waterlogging disaster from June 18th to June 30th

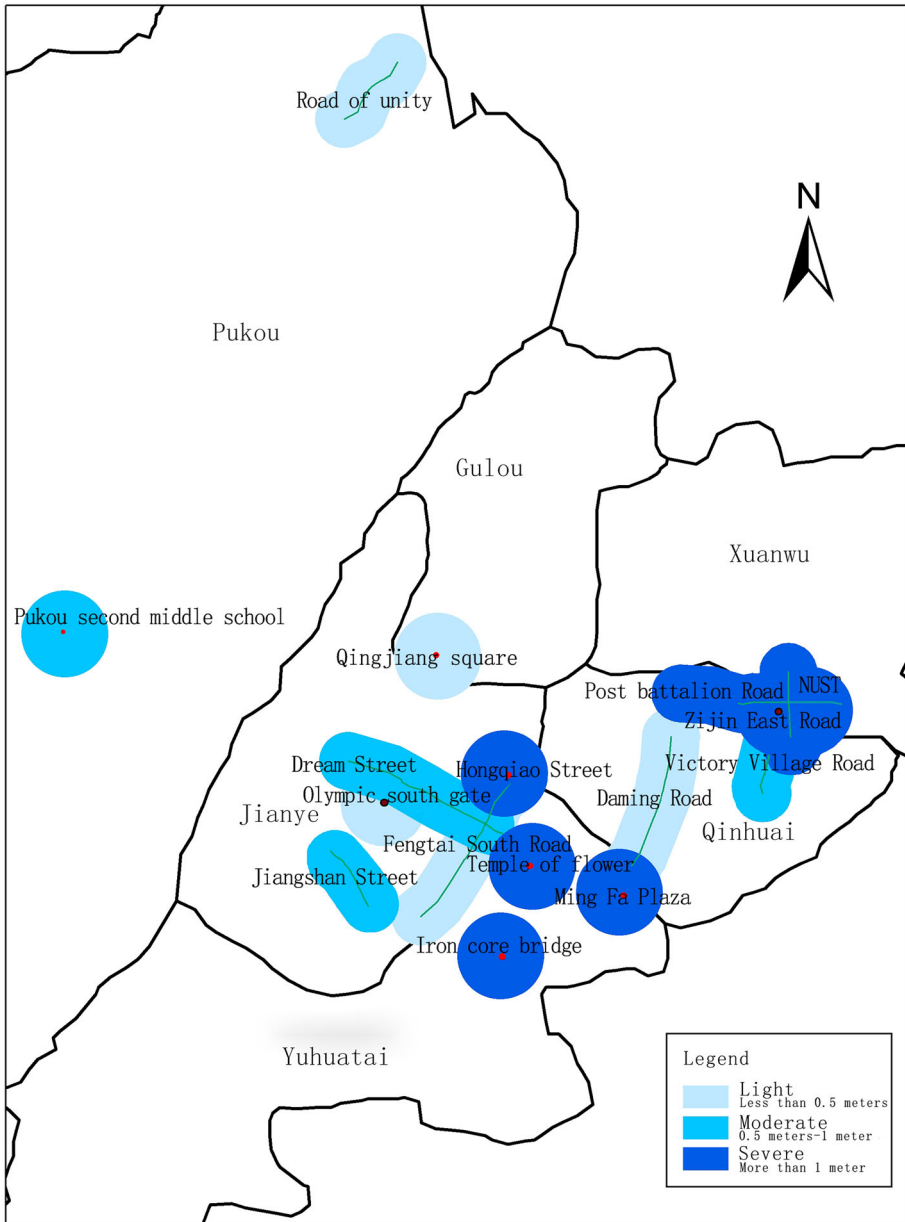
rainfall directly led to severe ponding in various administrative regions of Nanjing. There were plenty of direct descriptions about the waterlogging in contents of microbloggings. For instance, see the sea; the deepest depth of ponding amounts to 1.5 m; hundreds of cars were submerged; and so on. The ponding in Nanjing was more serious than before as whole: the ponding in Qinhuai Region, Gulou Region and Jiangning Region was grave; the ponding in Jianye Region and Yuhuatai Region was serious; the ponding in Pukou Region, Gaochun Region and Lishui region was mild. At the same time, urban places prone to be submerged can be determined by the ponding depth based on the direct description of ponding depth on specific streets in the microblogging, such as “the deepest depth of ponding was 1.5 m”,



**Fig. 3** The rainstorm waterlogging disaster from July 1st to July 7th

“the deepest depth of ponding was more than 2 m”, “the depth of ponding was from 60 to 80 cm”, and so on. Areas prone to be submerged mainly centered in Xuanwu Region, Qinhuai Region, Gulou Region, Jianye region, Yuhua Region and Pukou Region. Among these areas, the ponding in Saihongqiao Street was the most grave, with depth of 2 m; the ponding depth in Nanjing University of Science and Technology was 1.5 m; the rainwater submerged the metro station in Mingfa Square, which greatly affected the normal function of metro system.

The ponding in Qinhuai Region was the most serious. Nanjing University of Science and Technology, Zijin East Road and HoubiaoYing Road all become places prone to be



**Fig. 4** The layout of areas prone to be submerged from July 1st to July 7th

submerged. Located at the south part of Zijin Mountain, all these places were low-lying. Adding to the enormous flood from the Zijin Mountain, lots of ponding failed to discharge in time, which made the ponding worse. The layout of areas prone to be submerged is showed as follows (Fig. 4).

### 3.3.3 *The subjective emotion of the public*

After the urban rainstorm waterlogging, the emotion of the public can be estimated by analyzing contents of microbloggings, so that corresponding emergency management could be conducted on the basis of the public opinion. After the strong rain happened in June 2016 and subsequent ponding, microblogging users expressed their emotion reactions immediately, for example: “smile”, “titter”, “full of tears”, “cry”, “curse in rage”, and so on. Based on the emotion analysis on microblogging contents, the present paper divides the emotion reaction of the public into five categories: exultant, happy, ordinary, unhappy and terribly upset.

From June 18th to June 30th, the public basically had no negative emotions. Although there were some negative vocabularies, such as “tears”, “cry”, “heartbroken”, and the like, the percent of these words was quite small. Instead, there appeared some positive vocabularies like “haha”, “titter”, “smile” and “handclap”. It can be seen that there was not obvious negative emotion among the public during this phase.

From July 1st to July 7th, the public began to show strong negative emotions compared with the previous phase: “whine”, “sad”, “fear”, “full of tears” and “sorrow”. The percentage of negative vocabularies was large. There were a few positive vocabularies with low percentage. Therefore, the public expressed intense negative emotion during this phase, mainly shown as anger, panic, fear, sadness, and annoyance. The negative emotion in Qinhuai Region and Gulou Region was the most intense, rating as terribly upset; the negative emotion in Jianye Region and Xuanwu Region rating as unhappy; the negative emotion in Lishui Region and Gaochun Region was the least intense, rating as exultant.

The emotion reactions of the public toward the urban rainstorm waterlogging in June and July can be seen in the following figures (Figs. 5, 6).

## 4 Construction of location-routing problem model

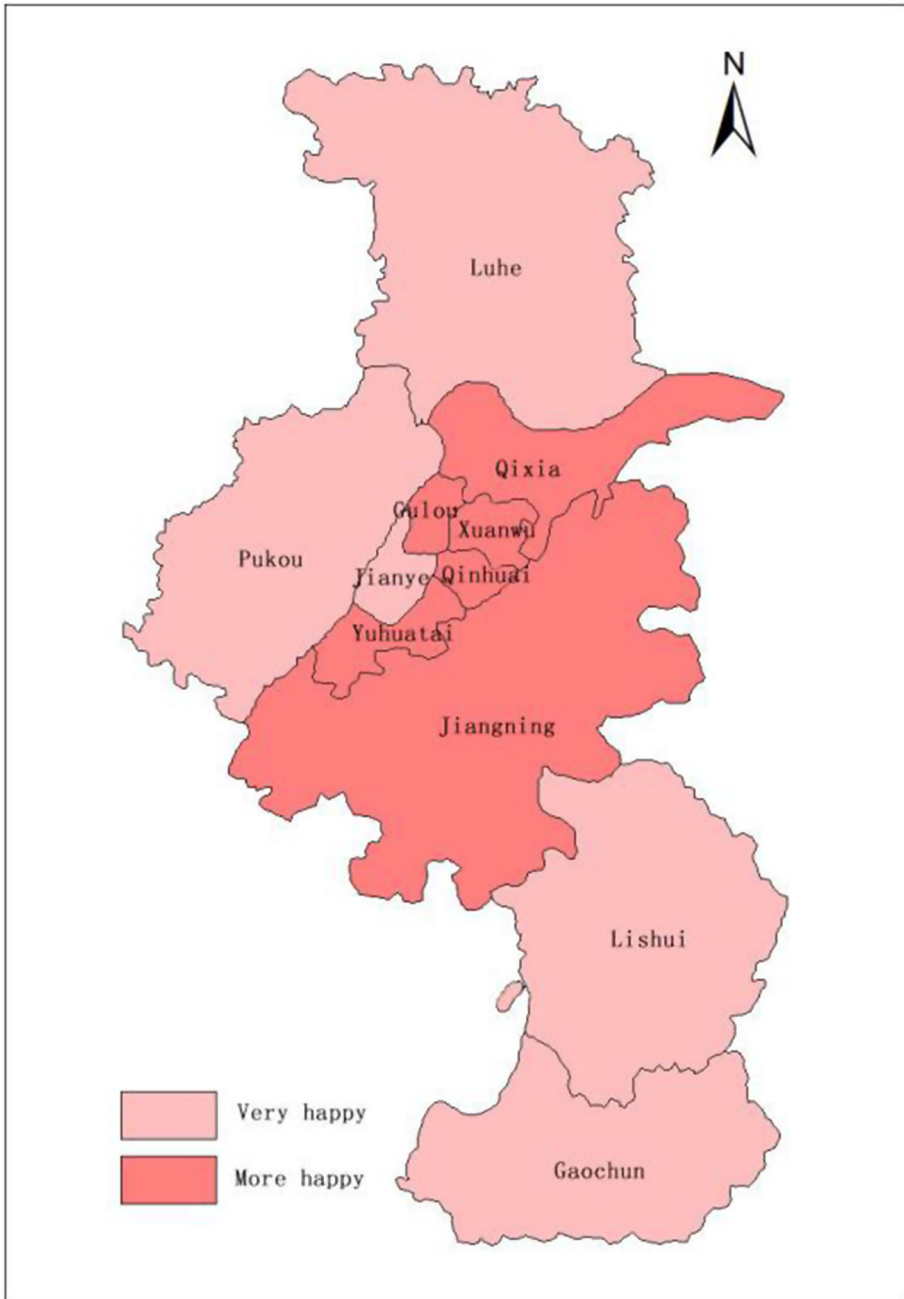
According to the disaster information obtained in the third part, the LRP model is built, and then the road traffic data of Nanjing is used to optimize the road traffic after interruption.

### 4.1 Problem description

The location-routing problem of emergency logistics after rainstorm and waterlogging disaster is described as follows. The location of emergency logistics distribution center, the construction cost and capacity, the capacity of distribution vehicle and the location of the affected point (area) of material rescue have been known. Besides, the demand for various materials can be collected and predicted by the logistics information platform. Based on the information above, the emergency distribution center needs to be determined to make sure that the total demand of the affected points on each distribution route starting from a distribution center is less than the capacity of the distribution center, and that the amount of transport supplies on a single route is less than the total capacity of all the vehicles on the route. Transportation route should be planned reasonably based on the above-all two premises with an aim of making sure the transport time is the shortest and the cost is the least in the whole transport network.

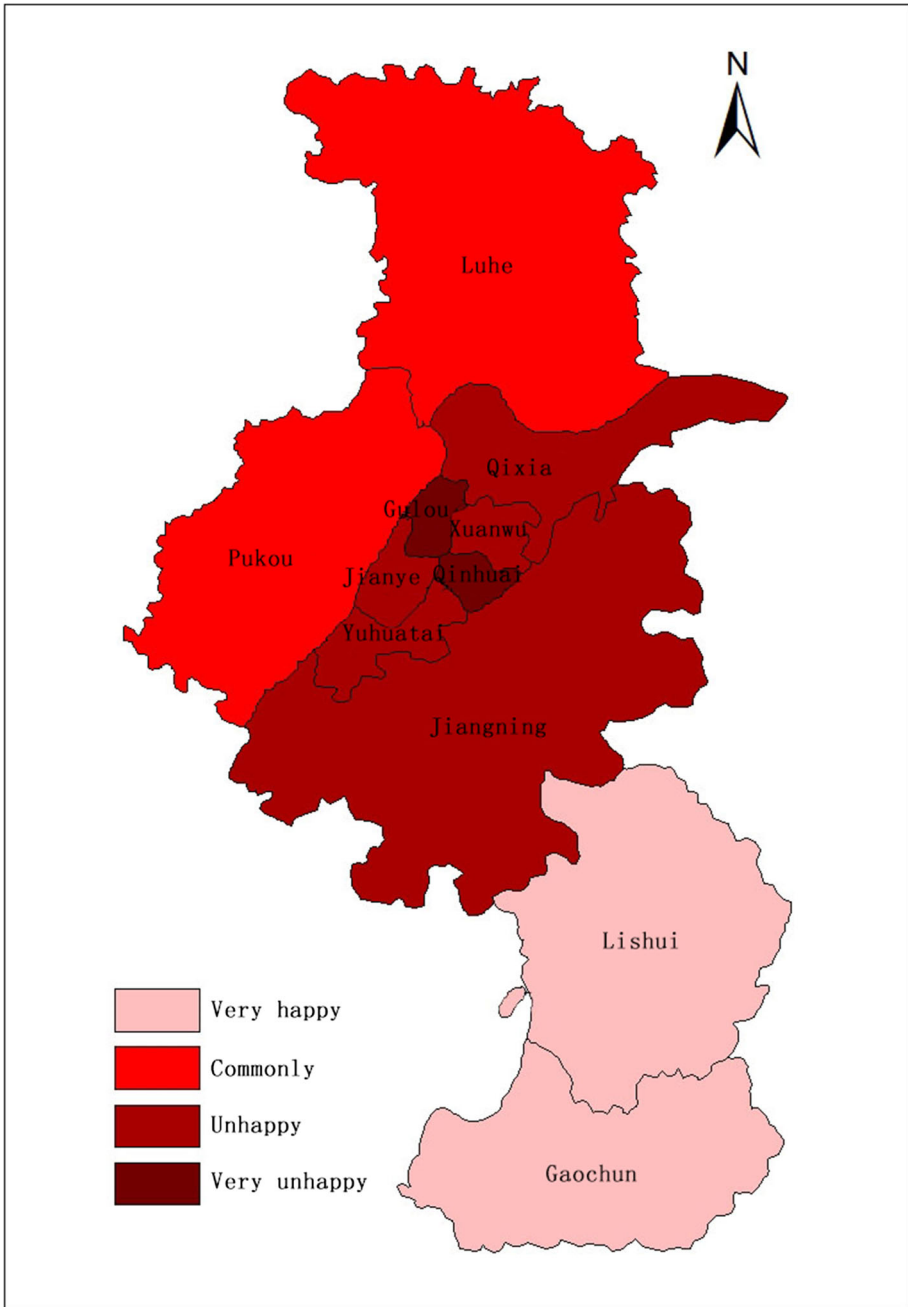
### 4.2 Basic hypotheses and symbol description

- (1) Hypothesis about the background of Web design



**Fig. 5** Emotion reactions of the public from June 18th to June 30th

In the design of the city’s logistics network, exclusive areas which the urban road network can reach are taken into consideration, and the road transport is the exclusive choice for transportation. It is assumed that the road network condition is static; however, due to the complexity of real condition, network circuitous factors are added to the model.

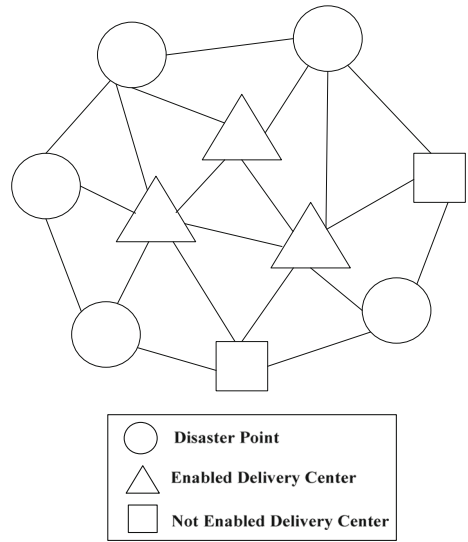


**Fig. 6** Emotion reactions of the public from July 1st to July 7th

(2) Hypothesis about distribution centers

Assume that the distribution centers are more than two and the capacity is limited and known. After waterlogging disaster, a certain number of distribution centers are started

Fig. 7 Conceptual model



for material distribution according to the demand of the affected areas; the total demand of affected points on all distribution routes from a distribution center should be less than the maximum capacity of the distribution center.

(3) Hypothesis about transport vehicles

Assume that the vehicles are of the same size and have limited capacity and that the same vehicle can be used to deliver different demand materials; the transport vehicle starts from a distribution center and returns to it after distributing to all the affected points on a route to wait for the next round of delivery. For the sake of simplification, the transport vehicles on each route are considered as a whole, and the total demand of the route is determined before allocating specific number of vehicles; the vehicle load on a route should be greater than or equal to the total demand of all affected points on the route.

(4) Hypothesis about affected points

According to real situation, although the demand of affected points can be predicted by corresponding logistics information system, it is not accurate. Therefore, the material demand of affected points can be signified by triangular fuzzy numbers and be transformed into real numbers in the interval  $[0, 1]$  by function in operations (Fig. 7).

The established model symbols are illustrated below:

(1) Collection setting

- $P$  Distribution CENTER COLLECTION,  $P = \{1, 2, \dots, p\}$ ;
- $Q$  Affected points collection,  $Q = \{p+1, p+2, \dots, p+q\}$ ;
- $R$  Node collection,  $R = P \cup Q = \{1, 2, \dots, p+q\}$ ;
- $V$  Vehicle collection,  $V = \{1, 2, \dots, k\}$

(2) Parameter setting

- $F_i$  Construction cost of material distribution center  $i, i \in P$ ;
- $\delta_i$  Maximum storage capacity of  $i, i \in P$ ;
- $n_k$  Maximum carrying capacity of vehicle  $k, k \in V$ ;



- $C_k$  Fixed use cost of vehicle  $k, k \in V$ ;
- $d_{ij}$  Distance between  $i$  and  $j, i, j \in R$ ;
- $v_k$  The average travel speed of vehicle  $k, k \in V$ ;
- $c_{ijk}$  The transportation cost of per unit distance of vehicle  $k$  from  $i$  to  $j, i, j \in R, k \in V$ ;
- $\partial_{ij}$  The circuitous factor of node  $i$  to node  $j, \omega_{ij} \geq 1, i, j \in R, \text{ when } i, j \in R, \partial_{ij} = 0$ ;
- $MT_j$  The time limit for the delivery of goods to affected point  $j, j \in Q$ ;
- $T_{jk}$  The time when vehicle  $k$  reaches node  $j, j \in R, \text{ when } j \in P, T_{jk} = 0$ ;
- $t_{ijk}$  The time vehicle  $k$  takes from node  $i$  to node  $j, i, j \in R, k \in V, t_{ijk} = d_{ij}/v_k$ ;
- $\tilde{D}_j$  The demand of affected point  $j$  is expressed by triangular fuzzy numbers  $\tilde{D}_j (\alpha_j, \beta_j, \gamma_j)$ ;  $\alpha_j, \beta_j$  and  $\gamma_j$  can be collected by the emergency logistics information system under the circumstance of disaster;
- $p_1$  Confidence coefficient limited by emergency vehicle capacity,  $p_1 \in [0, 1]$ ;
- $p_2$  Confidence coefficient limited by distribution center,  $p_2 \in [0, 1]$

(3) Variable setting

- When emergency distribution center  $i (i \in P)$  is started,  $x_i = 1$ , or else  $x_i = 0$ ;
- When delivery vehicle  $k$  is called from emergency distribution center  $I (i \in P, k \in V)$ ,  $y_{ik} = 1$ , or else  $y_{ik} = 0$ ;
- When the delivery vehicle drives from node  $i$  to node  $j (i \neq j, i \in P, k \in V)$ ,  $z_{ijk} = 1$ , or else  $z_{ijk} = 0$ .

4.3 Model establishing

Objective functions:

$$\min Z_1 = \sum_{i \in Q} \sum_{k \in V} MT_{ik} \tag{1}$$

$$\min Z_2 = \sum_{i \in P} F_i x_i + \sum_{i \in R} \sum_{j \in R} \sum_{k \in V} c_{ijk} \partial_{ij} d_{ij} z_{ijk} + \sum_{i \in Q} \sum_{k \in V} c_j y_{ik} \tag{2}$$

Constraint conditions:

$$V_1 \left( \sum_{i \in R} \sum_{j \in Q} z_{ijk} \tilde{D}_j \leq n_k \right) \geq p_1, \quad \forall k \in V \tag{3}$$

$$V_2 \left( \sum_{i \in R} \sum_{j \in Q} \sum_{k \in V} y_{ik} z_{ijk} \tilde{D}_j \leq \delta_l x_l \right) \geq p_2, \quad \forall l \in P \tag{4}$$

$$T_{jk} = T_{ik} + t_{ijk} z_{ijk}, \quad \forall i, j \in R, \forall k \in V \tag{5}$$

$$MT_j \geq T_{jk}, \quad \forall j \in Q, \forall k \in V \tag{6}$$

$$\sum_{j \in Q} \sum_{k \in V} z_{ijk} - x_i \geq 0, \text{ when } x_i = 1 \text{ and } \forall i \in P \tag{7}$$

$$\sum_{j \in Q} z_{ijk} - x_i \leq 0, \text{ when } x_i = 0 \text{ and } \forall i \in R, \forall k \in V \tag{8}$$

$$\sum_{j \in R} z_{ijk} - \sum_{j \in R} z_{jik} = 0, \quad \forall i \in R, \forall k \in V \tag{9}$$

$$\sum_{k \in V} z_{ijk} = 0, \quad \forall i, j \in P \tag{10}$$

$$\sum_{i \in R} \sum_{k \in V} z_{ijk} > 0, \quad \forall j \in R \tag{11}$$

$$x_i = \{0, 1\}, \quad \forall i \in P \tag{12}$$

$$y_{ik} = \{0, 1\}, \quad \forall i \in P, \forall k \in V \tag{13}$$

$$z_{ijk} = \{0, 1\}, \quad \forall i, j \in R, \forall k \in V \tag{14}$$

Objective functions (1) and (2) are the general goals of the LRP model.

In the main objective function, (1) represents the total amount of time of delivering all materials, but the time of returning to the distribution center is not included. (2) represents the total cost of emergency rescue including the construction cost of the emergency distribution center and the cost of transport vehicles. The constraint condition (3) ensures that the demand of the affected point is not greater than the probability of the vehicle capacity but is not less than the given probability  $P_1$ . Condition (4) ensures that the demand of affected points is not greater than the probability of the capacity of the emergency distribution center and not less than the given probability  $P_2$ . Condition (5) gives explanation for  $T_{jk}$ . Condition (6) ensures that the time that the vehicle actually reaches the affected point is less than the specified time limit. Condition (7) ensures that the distribution center must deliver supplies to the affected areas after started. Condition (8) ensures that the distribution center does not deliver supplies without being started. Condition (9) ensures that the vehicle starting from a distribution center eventually returns to it. Condition (10) ensures that there is no more than one emergency distribution center on an independent rescue route. Condition (11) ensures that every affected point can get supplies. Conditions (12), (13) and (14) are integer variables, which stipulate the value of the variable is zero or one.

Constraint conditions (3) and (4) contain the triangular fuzzy number  $\tilde{D}_j$ , which needs to be processed by real numbers. Suppose the demand of affected point  $j$  to be  $\tilde{D}_j (\alpha_j, \beta_j, \gamma_j)$ , the remaining capacity of transport vehicle  $k$  after delivering to be  $\Delta \tilde{A}_k$ , and the remaining capacity of distribution center  $i$  after serving all the affected points within to be  $\Delta \tilde{\Omega}_i$ .  $\Delta \tilde{A}_k$  and  $\Delta \tilde{\Omega}_i$  are both triangular fuzzy numbers, namely,

$$\begin{aligned} \Delta \tilde{A}_k &= (\Delta A_{k1}, \Delta A_{k2}, \Delta A_{k3}) \\ &= \left( n_k - \sum_{l \in R} \sum_{j \in Q} z_{ljk} \gamma_j, n_k - \sum_{l \in R} \sum_{j \in Q} z_{ljk} \beta_j, n_k - \sum_{l \in R} \sum_{j \in Q} z_{ljk} \alpha_j \right) \end{aligned} \tag{15}$$

$$\begin{aligned} \Delta \tilde{\Omega}_i &= (\Delta \Omega_{i1}, \Delta \Omega_{i2}, \Delta \Omega_{i3}) \\ &= \left( \delta_i x_i - \sum_{l \in R} \sum_{j \in Q} \sum_{k \in V} z_{ljk} \gamma_j, \delta_i x_i - \sum_{l \in R} \sum_{j \in Q} \sum_{k \in V} z_{ljk} \beta_j, \delta_i x_i - \sum_{l \in R} \sum_{j \in Q} \sum_{k \in V} z_{ljk} \alpha_j \right) \end{aligned} \tag{16}$$

and:

$$V_1 (\Delta \tilde{A}_k \geq 0) = \begin{cases} 1, & \Delta A_{k2} > 0 \\ \frac{\Delta A_{k3}}{\Delta A_{k3} - \Delta A_{k2}}, & \Delta A_{k2} \leq 0 \leq \Delta A_{k3} \\ 0, & \Delta A_{k3} < 0 \end{cases} \tag{17}$$

$$V_2 \left( \Delta \tilde{\Omega}_i \geq 0 \right) = \begin{cases} 1, & \Delta \Omega_{k2} > 0 \\ \frac{\Delta \Omega_{k3}}{\Delta \Omega_{k3} - \Delta \Omega_{k2}}, & \Delta \Omega_{k2} \leq 0 \leq \Delta \Omega_{k3} \\ 0, & \Delta \Omega_{k3} < 0 \end{cases}, \tag{18}$$

By the above transformation, constraint conditions (3) and (4) are respectively equivalent to:

$$V_1 \left( \Delta \tilde{\Lambda}_k \geq 0 \right) \geq p_1, \quad \forall k \in V \tag{19}$$

$$V_2 \left( \Delta \tilde{\Omega}_i \geq 0 \right) \geq p_2, \quad \forall l \in P \tag{20}$$

## 5 Stimulation application

### 5.1 Algorithm

Non-dominated sorting genetic algorithm NSGA, based on the optimality concept of Pareto, was proposed by Srinivas and Deb (1995). Deb et al. (2000) proposed the improved algorithm NSGA-II, which expanded the sample space, by introducing the elite strategy and reduced the computational complexity of the algorithm by using rapid non-dominated sorting method. The steps are taken as follows.

- (1) Supposing that there is a population A of size N, after applying genetic operators (selection, recombination and mutation) to which, population B of size N is obtained. Population C of size 2N can be obtained by combining population A and B.
- (2) Rank population C in a non-dominant way to obtain individuals of non-dominant layers 1, 2, 3 ..., and add all the individuals in order to set D of the next generation until the size of set D is larger than N. Record the non-dominant layer as L, and then select K individuals from layer L to make the sum of K and all of the previous layer individuals equal to N.
- (3) Operation of function standard quantization  
 First, calculate the minimum on each target dimension i in M objective functions to obtain the corresponding minimum  $z_i$  of the goal i. The set of  $z_i$  is the ideal point set, perform quantitative operations on which and the formula is:  $f'_i(x) = f_i(x) - z_i^{\min}$ . Then seek for the extreme point by traversing each objective function with  $ASF(X, W) = \text{MAX}_{i=1:m} \frac{f'_i(x)}{W_i}$  to obtain individuals of the minimum ASF, which are the extreme points. Based on the specific function values of these points, the intercepts on the corresponding axes are calculated and recorded as  $a_i$ . Finally, the normalization operation is carried out according to the following formula:  $f_i^n(x) = \frac{f'_i(x)}{a_i}$ .
- (4) Associating individuals with reference points  
 The corresponding divisory reference points are obtained with recursive method to construct the vector quantity of the reference points. The individual of each population is then traversed to find the nearest reference point for each population and meanwhile record the information of reference points and the corresponding shortest distance.
- (5) Selecting the sub-generation and deleting reference points  
 After non-dominated sorting, assume that from the first non-dominated layer to layer L the total number of members of a population is larger than population size N, and then define  $St+1$  as a collection that contains all the individuals in L.  $St+1$  needs to be screened because its number is larger than the pre-set number of members of the population. First, traverse each reference point to view the times that it is cited by  $St+$

1 except layer  $L$ , and then find out the reference point with the least cited times, which is the one that is associated with least amount of population individuals, and record the cited times as  $p_i$ . Next, the following points need to be discussed. (1) Assuming  $p_i = 0$ , if individuals in layer 1, 2, ...,  $L$  are associated with the vector quantity of the reference point, find out the point of the shortest distance and extract and then add it to the selected next population, setting  $p_i = p_i + 1$ ; otherwise, delete the vector quantity of the reference point. (2) If  $p_i > 0$ , select the reference point of the shortest distance. The program does not end until the size of population becomes  $N$ .

## 5.2 Application background analysis

In 2016, affected by El Nino, the rainfall in the Yangtze River basin was significantly more than that in previous years, and the water level was much higher than the annual average. Since June 27, there had been a wide range of continuous heavy rain in areas along and southwest parts of the middle and lower reaches of the Yangtze River, which had stricken 2.772 million people from Jiang Su and other 10 provinces (municipalities directly under the central government), 37 cities (autonomous prefecture) and 133 counties (cities or areas). The rainstorm caused 14 dead and 20 missing as well as direct economic loss of 3.14 billion yuan. Nanjing was one of the most affected cities in the rainstorm, where the rainfall was of high and sudden intensity and long duration. The precipitation in many areas including the main urban area, Gaochun and Lishui all surpassed the peak of the same period in history. By July 7, the rainfall in the main urban area reached 235.5 mm. At least dozens of sections of road were encountered with traffic interruption because of serious seep in urban area; subway line 3 was forced to shut down for water inflow; the water surface in serious waterlogging stricken areas even drew close to the height of traffic light. Water flowed backward in parts of the road, which had caused serious threat to people's life and property. Under this circumstance, how to carry out the distribution of emergency supplies became an important problem to be solved urgently.

## 5.3 Data collecting and dealing

Assume under the rainstorm waterlogging disaster, each candidate distribution center has been established. The only question is to decide which centers are to be started supposing that the distribution center has enough supplies to meet the demand of the whole city.

### (1) Demand data of the affected areas

After severe rainstorm and waterlogging, the number of people affected by the disaster determines the amount of supplies. The higher the population intensity is, the greater the demand for supplies is. The eleven districts of Nanjing were selected as the affected areas, and the regional permanent population, administrative area and population density were shown in Table 1.

According to the density of affected population and the number of resident population as well as the actual data, the demand for all sorts of materials that the affected areas of Nanjing needed in rainstorm could be predicted. Rainstorms typically occur during summer, so the supplies needed are food, water, tents and emergency medicine. Referring to Yang Yang's design (2014), considering both the minimum and maximum amount of these items per person needed per day and the number of the resident population of each district, the demand for all sorts of materials that the affected points in each area needed were figured out as shown in Table 2.

**Table 1** Data of population and area of district in Nanjing

No.	Area code	Resident population (10 thousand)	Affected population <sup>a</sup> (10 thousand)	Administrative area (sq. km)	Population density (people/sq. km)
1	Xuanwu District A	65.24	1.30	75.46	8645.64
2	Qinhuai District B	102.24	2.04	49.11	20,818.57
3	Jianye District C	45.45	0.91	81.75	5559.63
4	Gulou District D	127.56	2.55	54.18	23,543.74
5	Pukou District E	74.94	1.50	910.51	823.06
6	Qixia District F	67.98	1.36	395.38	1719.36
7	Yuhuatai District G	42.69	0.85	132.39	3224.56
8	Jiangning District H	119.14	2.38	1563.33	762.09
9	Liuhe District I	93.44	1.87	1471.00	635.21
10	Lishui District J	42.44	0.85	1063.68	398.99
11	Gaochun District K	42.47	0.85	790.23	537.44

(1) <sup>a</sup>Referring to Yang Yang's method, 2% of the resident population is selected as the proportion of the affected people. (2) Data source: *Nanjing Statistical Yearbook—2016*

## (2) Data of emergency distribution center

According to the actual situation of Nanjing, the five districts of Qinhuai, Gulou, Jianye, Pukou and Jiangning were selected to build candidate emergency distribution centers. Old urban areas of Nanjing including Qinhuai and Gulou district, owing to its large resident population and outdated planning of drainage systems, the occurrence of water-logging is really frequent. Jianye district, which is near the Yangtze River and located in the west of Qinhuai River, was low-lying and the pressure on drainage system was high. However, it has developed into the vice center of Nanjing. Pukou and Jiangning districts, respectively located at the core of the north and south of Nanjing, can radiate the surrounding areas. The commissioning cost and inventory capacity of the candidate emergency distribution centers are assumed data, and the location is where each district government lies. The specific data are shown in Table 3.

It is assumed that the location of each distribution center and the affected point is determined, as shown in Fig. 8. Code A–K corresponds to the affected points of eleven districts.

According to Baidu map, the shortest practical distance between points is figured out by kilometer, among which, 1–5 in Table 4 are the corresponding candidate emergency distribution centers in Table 3. Since there is only one distribution center per route, it is assumed that the distance between each distribution center is finite. The data of distance between each node is shown in Table 4.

According to the actual situation of Nanjing, other parameters are set. The average speed of the vehicle is set as  $v_k = 50$  km/h, the driving cost of unit distance as  $c_{ijk} = 10.5$  yuan/km,

**Table 2** Supplies demand of the affected areas (tons)

No.	Area	Supplies demand			
		Food	Water	Tents	Emergency medicine
1	Qinhuai District	(28.2, 33.6, 37.5)	(40.3, 45.1, 48.6)	(11.2, 13.5, 15.4)	(8.3, 9.1, 11.6)
2	Jianye District	(42.4, 58.2, 63.5)	(60.3, 64.7, 67.8)	(25.6, 27.2, 30.8)	(13.5, 16.4, 18.4)
3	Gulou District	(11.5, 12.5, 13.1)	(12.0, 13.5, 16.9)	(6.8, 7.6, 8.3)	(4.9, 5.4, 6.0)
4	Pukou District	(58.9, 62.3, 67.1)	(71.2, 74.5, 77.6)	(31.2, 33.5, 36.8)	(16.4, 18.6, 21.5)
5	Qixia District	(31.3, 36.4, 40.2)	(43.7, 47.8, 51.2)	(12.9, 15.7, 17.3)	(10.6, 11.5, 12.8)
6	Yuhuatai District	(29.2, 35.1, 38.6)	(41.9, 46.3, 49.7)	(11.8, 14.3, 16.2)	(9.2, 10.1, 12.0)
7	Jiangning District	(9.1, 11.2, 13.0)	(10.3, 12.5, 15.1)	(5.5, 6.2, 7.4)	(3.6, 4.2, 5.1)
8	Liuhe District	(56.4, 59.8, 64.2)	(68.3, 72.5, 76.7)	(29.6, 22.1, 35.8)	(15.5, 17.3, 20.9)
9	Lishui District	(37.8, 42.7, 46.3)	(46.7, 50.4, 53.5)	(15.4, 17.8, 19.1)	(11.8, 13.2, 15.3)
10	Gaochun District	(9.8, 10.2, 11.0)	(10.9, 12.7, 15.3)	(6.0, 6.8, 7.7)	(4.1, 4.8, 5.5)
11	Qinhuai District	(10.1, 10.5, 11.3)	(11.2, 12.9, 16.0)	(6.3, 7.2, 7.9)	(4.4, 5.0, 5.8)

**Table 3** Data of candidate emergency logistics distribution center

No.	Location of distribution center	Commissioning cost (Yuan)	Inventory capacity (tons)
1	Qinhuai District	48,000	620
2	Gulou District	55,000	490
3	Jianye District	40,000	520
4	Pukou District	38,000	500
5	Jiangning District	42,000	620

vehicle carrying load as  $n_k = 20$  tons, fixed using cost of vehicle as  $C_k = 450$ . And set  $p_1 = 0.88, p_2 = 0.85, \partial_{ij} = 1.2$ .

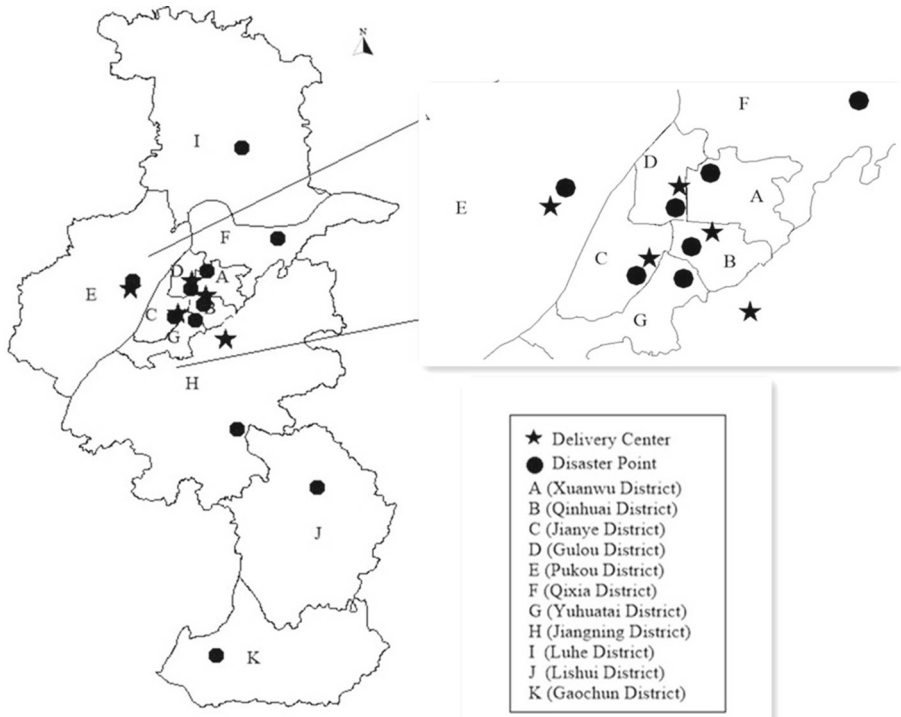
### 5.4 Solution to model application

1. First, assume that all routes are accessible. The shortest time is the main objective function, so the calculation result of the shortest time is the final result. With Java programming, after the iteration of 10,000 times, the time required for delivery was 1.974 h and the total cost was 175,294.75 yuan. The emergency distribution center, route

**Table 4** Distances between each node

No.	1	2	3	4	5	A	B	C	D	E	F	G	H	I	J	K
1	0	∞	∞	∞	∞	12.6	8.8	10.1	2.8	20.2	21.9	7.2	33.1	61.4	53.6	107.6
2	∞	0	∞	∞	∞	6.2	2.2	10.1	5.0	17.8	22.0	11.1	37.3	59.0	62.6	116.6
3	∞	∞	0	∞	∞	14.4	7.3	1.3	7.8	16.3	32.4	6.1	33.0	57.5	55.0	109.0
4	∞	∞	∞	0	∞	21.7	18.1	15.3	17.6	1.1	37.4	18.6	45.9	42.3	67.6	121.6
5	∞	∞	∞	∞	0	20.1	10.7	14.4	16.3	26.7	28.8	8.5	22.9	67.9	44.7	98.7
A	12.6	6.2	14.4	21.7	20.1	0	4.0	15.9	1.2	23.1	18.2	13.1	39.2	40.0	58.2	98.1
B	8.8	2.2	7.3	18.1	10.7	4.0	0	8.6	2.8	18.3	24.2	4.4	30.4	51.2	54.1	89.4
C	10.1	10.1	1.3	15.3	14.4	15.9	8.6	0	8.0	15.0	31.0	6.7	31.6	50.8	53.7	91.0
D	2.8	5.0	7.8	17.6	16.3	1.2	2.8	8.0	0	16.0	24.6	8.7	35.7	46.8	57.4	94.6
E	20.2	17.8	16.3	1.1	26.7	23.1	18.3	15.0	16.0	0	38.2	19.8	46.0	41.2	67.4	104.6
F	21.9	22.0	32.4	37.4	28.8	18.2	24.2	31.0	24.6	38.2	0	28.2	50.6	35.1	65.1	120.1
G	7.2	11.1	6.1	18.6	8.5	13.1	4.4	6.7	8.7	19.8	28.2	0	27.8	56.2	49.1	86.3
H	33.1	37.3	33.0	45.9	22.9	39.2	30.4	31.6	35.7	46.0	50.6	27.8	0	75.7	23.6	61.0
I	61.4	59.0	57.5	42.3	67.9	40.0	51.2	50.8	46.8	41.2	35.1	56.2	75.7	0	94.2	146.1
J	53.6	62.6	55.0	67.6	44.7	58.2	54.1	53.7	57.4	67.4	65.1	49.1	23.6	94.2	0	54.0
K	107.6	116.6	109.0	121.6	98.7	98.1	89.4	91.0	94.6	104.6	120.1	86.3	61.0	146.1	54.0	0





**Fig. 8** Location of distribution center and affected points

**Table 5** Emergency distribution centers and route arrangement

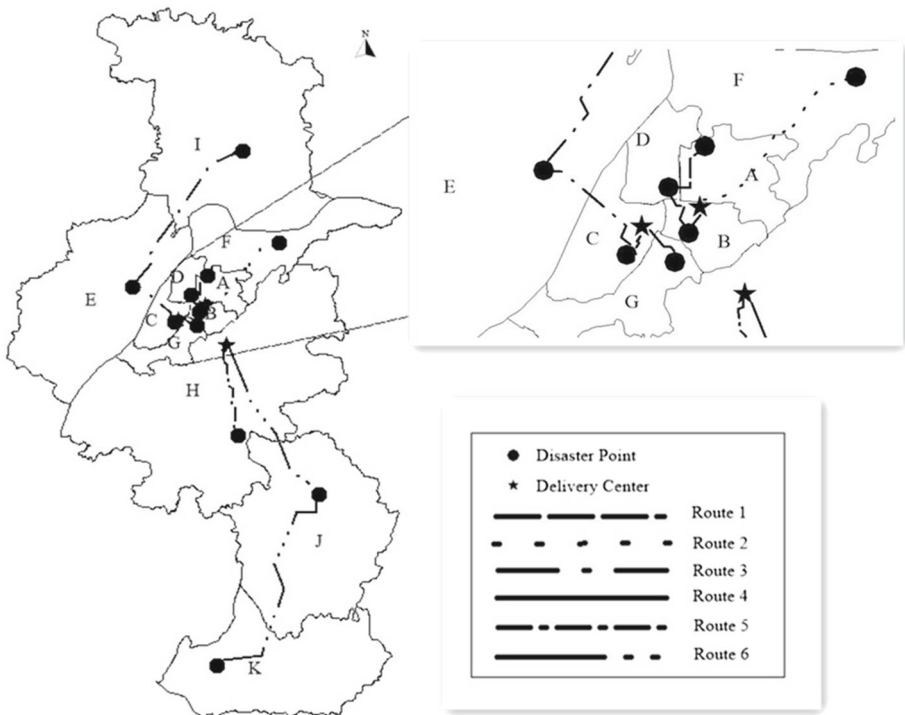
Emergency distribution centers	Route arrangement
Qinhuai District <sup>①</sup>	Route 1: ① → Qinhuai District → Gulou District → Xuanwu District
Jianye District <sup>②</sup>	Route 2: ① → Xixia District
Jiangning District <sup>③</sup>	Route 3: ② → Jianye District → Pukou District → Liuhe District
	Route 4: ② → Yuhuatai District
	Route 5: ③ → Jiangning District
	Route 6: ③ → Lishui District → Gaochun District

arrangement as well as the maximum material demand and the needed relief vehicles of each route are shown in Tables 5 and 6.

The unloading time of vehicles after reaching the affected points should be taken into consideration. If there are multiple affected points on a route, the relief vehicles required on this route are the sum of the vehicles needed for these affected points. For instance, on route 6, five vehicles are issued from the distribution center of Jiangning district, of which two stop and are unloaded at the affected point of Lishui district, and the other three continue to transport to Gaochun district. The route arrangement is shown in Fig. 9 below.

**Table 6** Distributed materials and vehicles required on each route

Route	Maximum material demand (tons)	Relief vehicle required
Route 1	496.6	27
Route 2	116.5	6
Route 3	300.0	17
Route 4	40.6	3
Route 5	197.6	10
Route 6	80.5	5



**Fig. 9** Route arrangement without route interrupts

(2) According to the actual situation analyzed above, the old urban areas of Nanjing such as Qinhuai and Gulou districts are vulnerable to waterlogging. It is assumed that the road between the affected point of Qinhuai district and the affected point of Gulou district is interrupted by the south road, which causes the road between the two affected points is not directly accessible, so the route needs to be re-planned and re-calculated. The time needed for the delivery is 1.974 h, and the total cost is 19,0566.7 yuan, which is 1,5271.95 yuan more than the cost of the initial calculation. The emergency distribution center, route arrangement as well as the maximum material demand and required relief vehicles of each route are shown in Tables 7 and 8. The route arrangement is shown in Fig. 10 below.

**Table 7** Emergency distribution centers and route arrangement

Emergency distribution centers	Route arrangement
Gulou District①	Route 1: ① → Affected points in Gulou District Route 2: ① → Affected points in Jianye District Route 3: ① → Affected points in Yuhuatai District Route 4: ① → Affected points in Xixia District
Qinhuai District②	Route 5: ② → Affected points in Qinhuai District → affected points in Xuanwu District Route 6: ② → Affected points in Pukou District → affected points in Liuhe District
Jiangning District③	Route 7: ③ → Affected points in Jiangning District Route 8: ③ → Affected points in Lishui District → affected points in Gaochun District

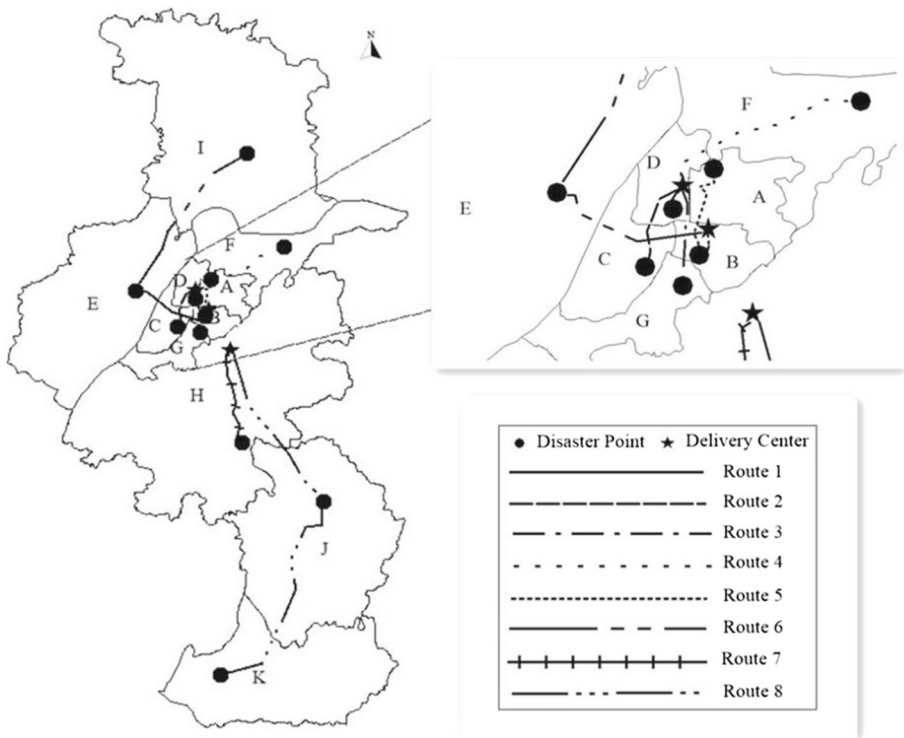
**Table 8** Distributed materials and required vehicle

Route	Maximum material demand (tons)	Required relief vehicles
Route 1	203.0	11
Route 2	44.3	3
Route 3	40.6	3
Route 4	116.5	6
Route 5	293.6	16
Route 6	255.7	14
Route 7	197.6	10
Route 8	80.5	5

## 6 Conclusion

The present paper introduces the process and methods to analyze the urban rainstorm waterlogging and its corresponding emotions of the public on the basis of microblogging big data. First of all, eliminate the repetitive contents of original microbloggings, translate all IP addresses into physical location and classify all microbloggings according to administrative regions of Nanjing. Second, Segment words and label the part of speech of each word of all microbloggings by ICTCLAS. Third, establish the urban rainstorm waterlogging reflecting table and waterlogging disaster and subjective emotion classification coding table. Last but not least, divide microbloggings of all administrative regions into two phases: from June 18th to June 30th and from July 1st to July 7th, extract the rainstorm waterlogging and emotion vocabularies and calculate their percentages separately to determine the disaster degree of waterlogging and the emotion reaction of the public in various administrative regions of Nanjing. On the ground of descriptions about the ponding depth of a certain location that frequently appeared in microbloggings, areas prone to be submerged during rainstorm can be determined by classifying the depth of ponding.

With the waterlogging points in the presence of disasters found in the first part, the re-optimization is made to develop traffic road. This paper constructed the location-routing problem model of urban emergency logistics in the situation of rainstorm and waterlogging



**Fig. 10** Route arrangement with route interrupts

disaster, and by taking Nanjing as an example, found out the dynamic emergency distribution path of Nanjing in the situation of waterlogging disaster with NSGA-III algorithm. Meanwhile, assuming that the route between Gulou and Qinhuai is interrupted, the paper re-planned and re-calculated the distributing route. The feasibility of the location-routing problem model was verified in the case.

However, what needs to be noted is that the design of the location-routing problem model contains many hypotheses such as distribution centers are fixed, route network are closed, and that a vehicle can only running between the distribution center and its destination. However, in reality, there exists temporary distribution centers, much wider road network and changeable parameter values, therefore, the orientation of future research be targeted on how to make the model more realistic.

Finally, with the approaching big data and rapid development of big data analysis technologies, microblogging and other social media will gradually become an important source of disaster information extraction due to its timeliness, huge data amount and abundant contents. These information could timely provide the location of disaster areas, the material requirements and the damaged routes. So they are of importance for disaster relief, especially for the delivery of emergency relief supplies and planning of transportation routes. In the future, there are also lots of problems about disaster management that could combine with the big data analysis technologies to develop the ability and level of disaster relief.

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## Appendix

See Tables 9, 10 and 11.

**Table 9** Urban rainstorm waterlogging reflecting table

Category	Description vocabulary
Reasons of rain	Convective weather, convective strong typhoon, Nepartak, plum rain and plum
Ponding	Spill, ponding, serious ponding, easily to form ponding, rise, submerge, get submerged, flood, sea, seascape, waterlogging, waterlog, fill, metro station filled with water, cars submerged into water, city surrounded by water, deluge, 30 mm higher than the line, warning, excessive rain, flood resistance, be drowned, travel far away across the sea, boundless seas, rubber dinghy canoe and kayak, kayak, raft, 235 m higher than the warning level, depth, swim, sharp rise of water level, rapid rise, universal rise, swift rise, wall collapse, serious ponding in low-lying sections, the height of ponding arrives at the waist, row the door plank, take a boat, rowing, row the friend-ship, inundation, a world of waters, wade, roaring waves, drainage, flood mode, become a sea, sea, ship, from driver to captain, feel powerless and frustrated, flood discharge, flood disaster, ocean, crop failure, submerged crop, collapsed road, the Jungle Book, filled with rain, the rapid rise of the water level of brook, deep ponding, 1-m ponding, road ponding, buy a boat, become Venice the City of Water, water filled in the pathway, half shank submerged into water, the deepest ponding amounts to 15 cm, soak, dragon water on the city wall, 0.42 m higher than the warning level, 0.06 m higher than the warning level, ponding fails to discharge within short time, household appliances soaked into rainwater, the ponding area amounts to roughly 200 m, large-scale ponding, approximately 1-m ponding, over twenty persistent ponding areas, hundreds of cars submerged, house becomes an isolated island, ponding reaches the thigh, the deepest ponding reaches 0.7 m, thirty-two sections prone to ponding, ponding fills into the basement and the deepest ponding reaches the waist
Traffic	Congestion, traffic jam, bad traffic jam, refund, ferry suspension, enlarging train distance, late, late for work, road blocking, traffic paralysis, block up, paralysis, fault in Tianlongsi section, train outage, line 3 repair, line 3 outage, stop, connection, slow down, slow-moving, behind the schedule time, flight canceled, delay, metro faults, road congestion and road closure
Rain conditions	Extraordinary rainstorm, rainstorm, shower, thunderstorm, downpour, heavy rain, roaring waves, thundershower, rain falls in torrents, small to moderate rain, stormy weather, moderate rain, windy and rainy, raining dogs and cats, tempest, overcast and rainy, occasional drizzles, thunderstorm rainfall, small rain, moderate rain, sunny rain, plum rains, pouring, thunderstorm rain, time brings a great change to the world, break in full fury, downpour, gurgle, break in full fury and thunderstorm wind and cloudburst

**Table 9** continued

Category	Description vocabulary
Emotion reactions	<p>Anger: anger, rage, curse in rage, indignantly resent, furious, resentment, angry and sulky</p> <p>Worry: worried, grievance, sad, sadness, chagrin, pitiful, struggle, unhappy, depressed, worry about, anxious, anxiety, alas, nervous and disturbed</p> <p>Sadness: sad, tragedy, tears, cry, want to cry, purr, cry, grieved, pain, feel sad, anguished, injury, unfortunate, breakdown, miserable, weep, hurt, whine, disappoint, heartbroken, uncomfortable, alas and desolate</p> <p>Fear: frighten to death, in shock, terrifying, be afraid of, horrific, horrible, scare, frightening and threaten</p> <p>Panic: surprise, wake due to fear, wow and astonish</p> <p>Annoyance: annoyance, irritable, go crazy, impatient, distressed, bewilderment, hurry, fluster, gloomy, bother and repression</p> <p>Chillax: cool, ho ho and ho</p> <p>Others: love dearly, faint, embarrassed, ache, smile, laugh, too happy, tired, likes, haha and joyful</p> <p>Emoticons:[roll eyes], [lacrimation], [sweating], [tearful], [control], [tears of laugh], [bye–bye], [hopeless], [stunned], [candle], [hum], [haha], [fist], [titter], [smile], [raining], [sunshine], [Meowth], [smirk], [lightning], [shy], [make a wish], [pick nose], [surprised], [thinking], [gluttonous], [good], [shut up], [thunderbolt], [chuckle], [heart], [microphone], [enjoy oneself], [onlooker], [laughingly], [cute], [love you], [handshake], [sun], [music], [flower], [coming], [yeah], [recommend], [handclap], [rose], [hee hee], [why], [nothing], [wink], [great], [screw you], [oh yeah], [speechless], [bravo], [bow], [prove wrong], [despise], [disappoint] and [curl lips]</p>

**Table 10** Waterlogging rating coding table

Code category	Rating	Description
The rainfall amount	1	Small to moderate rain, sunny rain, shower, overcast and rainy,, occasional drizzles, small rain, thundershower and plum rains
	2	Rainstorm, thunderstorm, heavy rain, moderate rain, windy and rainy and tempest
	3	Downpour, roaring waves, rain falls in torrents, stormy weather, raining dogs and cats, thunderstorm rainfall, pouring, cloudburst, thunderstorm rain, time brings a great change to the world, break in full fury, downpour, gurgle, break in full fury and thunderstorm wind
Traffic	1	No description
	2	Congestion, traffic jam, late, late for work, enlarging train distance, block up, slow down, slow-moving, behind the schedule time, delay, connection, road blocking and fault in Tianlongsi section
	3	Bad traffic jam, ferry suspension, refund, traffic paralysis, paralysis, train outage, stop, flight canceled, subway faults, road closure, line 3 outage and line 3 repair
Ponding range	1	No description
	2	Sea, seascape, rowing, row the door plank, take a boat and road ponding

**Table 10** continued

Code category	Rating	Description
	3	Travel far away across the sea, a world of waters, feel powerless and frustrated, ocean, over twenty persistent ponding areas, the ponding area amounts to roughly 200 m and hundreds of cars submerged
Ponding depth	1	0.5 m and below
	2	0.5–1 m
	3	1 m and above

**Table 11** Subjective emotion rating coding table

Rating	Description
1	Surprise, wake due to fear, wow, astonish, cool, ho ho, ho, [roll eyes], [sweating], [control], [stunned], [hum], [haha], [fist], [titter], [smile], [sunshine], [Meowth], [smirk], [lightning], [shy], [make a wish], [pick nose], [surprised], [thinking], [gluttonous], [good], [shut up], [thunderbolt], [chuckle], [heart], [microphone], [enjoy oneself], [onlooker], [laughingly], [cute], [love you], [shake hands], [sun], [music], [flower], [coming], [yeah], [recommend], [handclap], [rose], [hee hee], [oh yeah], [speechless] and [bravo]
2	Annoyance, irritable, go crazy, impatient, distressed, bewilderment, hurry, fluster, gloomy, bother, repression, alas, nervous, disturbed, worried, grievance, sad, sadness, chagrin, pitiful, struggle, unhappy, depressed, worry about, anxious, anxiety, [tears of laugh], [bye–bye], [raining], [despise] and [curl lips]
3	Sad, tragedy, tears, cry, want to cry, purr, cry, grieved, pain, feel sad, anguished, injury, unfortunate, breakdown, miserable, weep, hurt, whine, disappoint, heartbroken, uncomfortable, alas, desolate, love dearly, ache, [hopeless], frighten to death, in shock, terrifying, be afraid of, horrific, horrible, scare, frightening, threaten, [lacrimation], [tearful], [candle], [bow], [disappoint] and [screw you]

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