

Research Article

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A full-view scenario model for urban waterlogging response in a big data environment

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Abstract: The emergence of big data is breaking the spatial and time limitations of urban waterlogging scenario description. The scenario data of different dimensions (e.g., administrative levels, sectors, granularities, and time) have become highly integrated. Accordingly, a structural and systematic model is needed to represent waterlogging scenarios for more efficient waterlogging response decision-making. In this article, a full-view urban waterlogging scenario is first defined and described from four dimensions. Next a structured representation of scenario element is given based on knowledge unit method. The full-view scenario model is then constructed by extracting the scenario correlation structures between different dimensions (called scenario nesting), i.e., inheritance nesting, feedback nesting, aggregation nesting, and selection nesting. Finally, a real-world case study in Wuhan East Lake High-tech Development Zone, China is evaluated to verify the reasonability of the full-view model. The results show that the proposed model effectively integrates scenario data from different dimensions, which helps generate the complete key scenario information for urban waterlogging decision-making. The full-view scenario model is expected to be applicable for other disasters under big data environment.

Keywords: big data, urban waterlogging, scenario-based analysis, full-view model, scenario model

1 Introduction

Urban waterlogging response varies according to disaster scenarios [1]. How to effectively recognize waterlogging scenarios has always been the basic issue of waterlogging emergency management [2]. With the significant development of Internet, Internet of Things (IoT), cloud computing, and other technologies, it has become a new mode to analyze waterlogging scenarios and make response plans based on multi-source big data [3]. In the big data environment, waterlogging scenario description has new characteristics. First is the high-frequency and real-time data collection. Through city-level IoT platform, physical sensors, video probes, and other sensing devices, the dynamic and continuous collection of scenario data has been achieved [4]. For example, drain-pipe status can be monitored in real time by using drainage sensors [5]. Second is multi-sector data interaction. With the in-depth construction of smart cities and implementation of citizen-based governance mode, the waterlogging scenario data from different administrative levels (including urban level, community level, and resident level) have been no longer isolated, but shared in a unified waterlogging data platform. For example, residents can get the information about the waterlogging depth of each waterlogging point in real time through mobile terminals [3]. The third one is the cross-border data fusion. Scenario data from meteorological, water, transportation, civil affairs, and even social media organizations are integrated through emergency platform, and then fused into new scenario data, which makes scenario description more comprehensive [6]. For example, using terrain data (acquired by satellite remote sensing) to analyze the waterlogging situation in each region, using location data (acquired through social media platforms) to predict the travel directions and routes of residents, and combining the two to analyze the travel risk of residents [7]. Fourth is multi-granularity data scaling. The data accuracy of remote sensing, IoT sensors, and other equipment is getting higher and higher, which makes the scenario data more detailed and can support the scenario description of different granularities.

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For example, according to the decision-making needs, the waterlogging scenarios of different geographical areas such as road intersections, communities, and cities can all be generated. In general, big data technology can help to realize the description of systematic, complex, and highly correlated waterlogging scenarios. Accordingly, in order to achieve the effective representation of waterlogging scenarios, it is necessary to construct the matched waterlogging scenario models to support the systematic recognition of waterlogging scenarios at the operational level [8,9].

Scholars have done a lot of research on the structured representation of waterlogging scenarios, focusing on the following aspects. First is about the composing elements of scenario. Scholars mostly take all kinds of things in the disaster system as scenario elements, and represent them by clarifying the features of the things and the relationship between them. The most typical view is to divide the scenario elements into three categories, that is, hazards, bearing bodies, and environment [10,11]. The second aspect is the correlation of scenarios of different granularities. The complexity of the scenario description increases with its degree of detail. Some scholars pay attention to the recognition of multi-granularity uncertain scenarios, and use the consistency transformation function model to deal with them to support the selection of emergency plans [12]. Third is the evolution of scenarios. In addition to recognizing the current state of disasters, deducing the future development of scenarios is another core goal of establishing scenario models [13,14], which has attracted wide attention of scholars. For example, some scholars have established a super network model for correlating different disaster scenarios, and studied the relationship between the disasters and disaster-related environment factors [15]. The fourth one is the different forms of scenario models. There are three kinds of typical forms of scenario models, including framework, ontology, and knowledge unit. Framework model is the most representative, which consists of attribute slot (represents general attribute) and attribute face (represents detailed attribute) [16]. Ontology model focuses on representing scenario elements in a standardized and unified form to eliminate the inconsistency of different organizations in describing the same scenario elements [17]. Knowledge unit model pays more attention to the complex relationship between the descriptive features of scenario elements [18,19], and emphasizes on the systematic representation of scenarios.

To sum up, the existing studies on disaster scenario models focus on the composing elements of scenarios, scenario model forms, and scenario evolution mechanisms, and pay less attention to the overall relevance of scenarios from a systematic perspective. Although the

knowledge unit model gives a good solution to describing the relationship, fewer studies have illustrated what the relationship is and how to extract it [19]. As a result, the relationship between scenario elements becomes less clear, which leads to the incomplete description of disaster scenarios, and makes it difficult to guarantee the effectiveness of scenario recognition. In the big data environment, the relationships of disaster scenarios among different levels, types, granularities, and time have become closer. In this context, based on the full-view management theory, this article first proposes the full-view framework of waterlogging disaster scenarios, which systematically describes disaster scenarios from four dimensions, i.e., scenario level, type, granularity, and time. In particular, focusing on the correlation of waterlogging scenarios at different levels, this article proposes four structures of waterlogging scenario nesting for recognizing the scenario relations based on data nesting theory, and then constructs a full-view model of waterlogging scenarios. Based on the full-view waterlogging model, this article presents an iterative algorithm for full-view waterlogging generation, which achieves the goal of generating the complete full-view scenario from partial feature data of scenario elements and then outputting it to the information management platforms at all levels to support decision-making.

2 The four-dimension full-view scenario framework of urban waterlogging

Before establishing the full-view model of waterlogging scenarios, it is necessary to distinguish the two concepts of “scenario” and “full-view scenario.” Urban waterlogging scenario is a basic description of the extent, scope, and evolution of waterlogging disasters, that is, the data and information describing the features of hazards (e.g., rainstorm), related disaster-bearing bodies (e.g., buildings and culverts), and disaster-related environment (e.g., the city water system) under particular disaster situation. Managers at different levels and organizational units in different fields are accustomed to recognize waterlogging scenarios from certain perspectives. All the descriptions are incomplete, and cannot help to recognize waterlogging scenarios comprehensively and systematically. Full-view management theory [20] considers that to get a comprehensive picture of management problems, we need to integrate data, information, knowledge, and even theory from different sources. In the big data environment, waterlogging

scenario description has had new features such as high frequency and real-time data collection, multi-sector data sharing, cross-border data fusion, and granularity scaling, which makes the full-view recognition of waterlogging scenarios a reality.

Based on the full-view management theory, this article focuses on the overall correlation of scenarios, and defines the full-view scenario as a systematic integration of waterlogging scenarios with different levels, objects, granularities, and time nodes under particular disaster situations. Specifically, this article integrates waterlogging scenarios from four dimensions (that is, scenario level, type, granularity, and time), which forms the full-view scenario framework of urban waterlogging disasters, as shown in Figure 1.

2.1 The level dimension of waterlogging full-view scenario

In terms of the organizational system of urban disaster response, the hierarchical structure is mostly adopted. Because the goals, routes, and methods of disaster response in different administrative hierarchies are distinctive, the demand of different level decision makers for disaster scenario data is different [12]. For example, to know about the travel risk of residents in urban waterlogging, it is needed for city governors to analyze the main directions of their travel based on their location information. Compared with city governors, residents themselves pay attention to their own travel risk, and they need to combine the waterlogging situation of the destination and different roads to determine

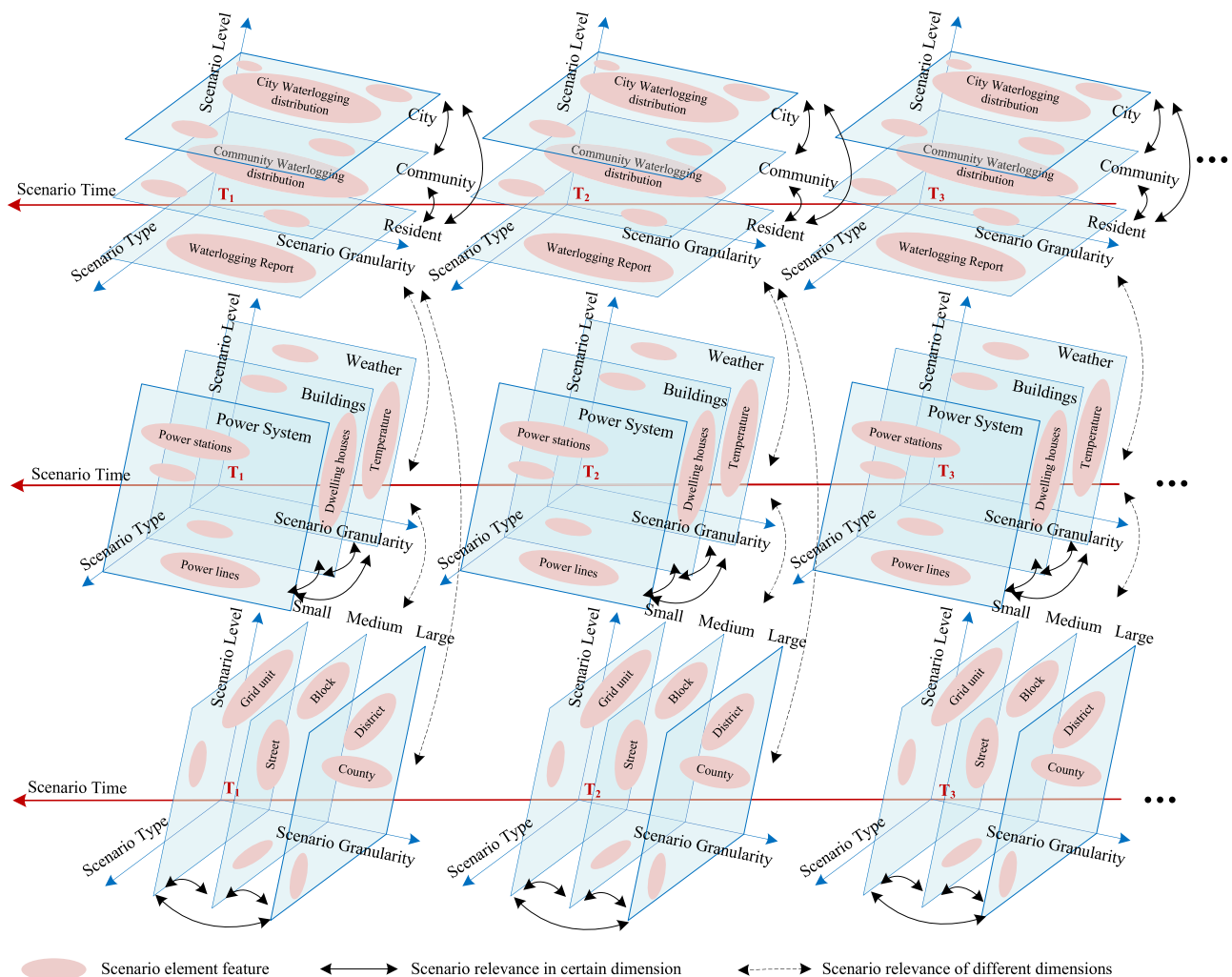


Figure 1: The four-dimension full-view scenario framework of urban waterlogging disasters.

whether to travel and the travel routes. At present, the main subject of urban safety management is shifting or has shifted from city managers to community managers or even residents, strengthening the positive role of communities and residents in waterlogging prevention and control work [21]. On the other hand, the waterlogging scenarios at different administrative levels are not independent, but interact with each other, which is reflected as the correlation between the waterlogging scenario data at different levels.

To sum up, this article defines the level of waterlogging scenario as the administrative level of waterlogging disaster response. Combining with the existing hierarchical structure of urban waterlogging response [22], this article divides the waterlogging scenarios into city level, community level, and resident level.

First is the city level scenario. Urban managers pay attention to city level waterlogging response, and the scenario includes all scenario elements related to the overall city waterlogging response and their relationships.

Second is the community level scenario. Community managers pay attention to the waterlogging response of their communities, and the scenario data involved are used to support the waterlogging response decision-making of the communities.

The third one is the resident level scenario. Residents play their active role in waterlogging response, and the scenario data involved are used to guide their own safety behavior.

2.2 The type dimension of waterlogging full-view scenario

Different waterlogging response organizations have different scenario descriptive data and analyze disasters based on the data they have, making these organizations have different perceptions of waterlogging scenarios [23,24]. For example, meteorological departments have remote sensing and meteorological data, and their scenario descriptions focus on terrain and rainfall. Water departments have the data about drainage pipe network and the water level monitoring data of rivers and lakes, and their scenario descriptions focus on the operation of various drainage facilities. Mobile operators have mobile phone signaling data, which can generate the population distribution among different areas. When waterlogging occurs, these organizations have limited data, describing actually some scenario segments from domain perspectives, rather than the full-view scenario [25]. Therefore, when representing

scenarios, these data should be integrated to help to recognize scenarios comprehensively, integrally, and systematically.

This article defines scenario type as the data category of certain waterlogging scenario. There are two kinds of common criteria for data classification, that is, data source organization (with this criterion dividing scenario data into meteorological scenario, traffic scenario, hydrological scenario, and others) or storage form (with this criterion dividing scenario data into numerical scenario, graphic and text scenario, video scenario, and others). Among them, the storage form is included in the criterion because in the context of cross-organizational integration of scenario data, the problems of multiple data sources and heterogeneity data are significant, and it is conducive to more effective scenario data management with this criterion [26].

It is worth noting that in the full-view scenario model construction, it is necessary to reduce scenario types according to actual problems. For one, the scenario data of some scenario types are not available for reasons such as data safety and privacy and the organizational coordination failing. On the other hand, if there are too many scenario types, the correlation of scenario elements will be too complex to recognize.

2.3 The granularity dimension of waterlogging full-view scenario

Scenario granularity is the detailed degree of scenario data. Obviously, the higher the detailed degree is, the smaller the granularity is, and the lower the degree of refinement, the larger the granularity [27]. Generally, scenario granularity is divided according to time or space.

The time granularity of waterlogging scenario data is reflected in the time range of scenario description. The scenario granularity is proportional to the time range. For example, for the scenario description of emergency material dispatch, large-granularity scenarios remain unchanged or change slightly in a certain time range, such as the demand resource types and resource amounts of cities [28]. Small-granularity scenarios are more real time, such as real-time road conditions, GPS, etc.

The spatial granularity of waterlogging scenario data is reflected in the spatial range of scenario description. For example, for the scenario description of a city, large-granularity scenarios correspond to larger geographical areas, such as the whole city, districts, and counties. Small-granularity scenarios are targeted at geographical grids, i.e., units with smaller geographical area. Medium-

granularity scenarios are defined between the two, which are targeted as areas such as streets and communities.

Large-granularity scenario data can generally be obtained by statistical analysis or simulation with small-granularity scenario data [12]. For example, according to the waterlogging depth and area of each geographic grid in a community, the waterlogging depth of the community is calculated by taking the average. Generally, in the real scenario description, the description effects depend on the time or spatial range corresponding to the smallest granularity scenario, and the relationship between scenarios of different granularities is also clearly described [12,29,30].

2.4 The time dimension of waterlogging full-view scenario

Scenario often changes with time. On the one hand, the status of waterlogging varies at different time nodes. For example, the water depth of waterlogging is largely affected by rainstorm intensity, which has high time dependency. On the other hand, emergency departments adopt various responses for reducing disaster effects, e.g., emergency rescue and waterlogging risk communication, which also change the waterlogging scenarios [8].

To sum up, an effective scenario description should present the scenarios at different time for timely response. In this article, scenario time is proposed as a dimension of waterlogging full-view scenario, which can be defined as the time stamp of a scenario.

3 Full-view scenario modeling of urban waterlogging

It can be seen that the relationships between scenario elements of different granularities are clearly described. In addition, the correlations between scenario elements of different types are usually identified by data integration, regression analysis, and other technical means [31]. Therefore, given a scenario time, the full-view waterlogging scenario model in this article focuses on the relationships between waterlogging scenario elements at different levels. The basic theory of the model construction is as follows. First the waterlogging scenario element is structured, which consists of the features of the scenario element and their relationships. Second, based on data nesting theory, the correlation characteristics of scenario elements

at different levels are generalized and the typical structures of multi-level scenario nesting are established, including top-down inheritance nesting, bottom-up aggregation nesting, and selection nesting. Finally, based on the scenario nesting structures, the correlation relationships of scenarios of different types and those of different granularities are embedded to complete the construction of full-view waterlogging scenario model. The process is shown in Figure 2.

3.1 Structuring scenario elements

The premise of representing and recognizing scenarios is to clarify the elements of the situation [32]. Based on the existing studies [10,11], the scenario elements are defined as the disaster-related things in waterlogging disaster system, including hazards (i.e., rainstorm), disaster-bearing bodies (e.g., roads, communities, and residents), and environment (e.g., temperature and geology). Setting the domain of waterlogging scenario elements as E , which includes n scenario elements, the domain E can be expressed as follows.

$$E = \{e_1, e_2, \dots, e_n\}, \quad n > 0 \quad \forall i, j \in \{1, 2, \dots, n\}, \quad e_i \neq e_j, \quad (1)$$

where e_i and e_j represent scenario elements. There are differences in scenario elements of different scenario levels, types, and granularities. This article describes scenario elements from their features and relationships, and constructs the formal representation of scenario elements as follows.

$$e_i = (t, S_i, R_i), \quad e_i \in E, \quad (2)$$

$$R_i \subseteq S_i \times S_i, \quad (3)$$

$$s = (d_s, o_s, f_s), \quad s \in S_i, \quad (4)$$

$$r = (S_r^I, S_r^O, f_r), \quad r \in R_i, \quad S_r^I \in S_i, \quad S_r^O \in S_i, \quad (5)$$

where t indicates time stamp. The feature values of waterlogging scenarios and the relationships between the features often change with time. S_i is the feature set of waterlogging scenario element e_i . R_i is the correlation set of the features of scenario element e_i . For the feature set S_i , s is an element in it, which represents a feature of scenario element e_i . Feature s is described with its data value type d_s (e.g., number and text), its value o_s , and its value of evolution function or rule f_s (e.g., how waterlogging depth changes with time). For the correlation set R_i , r is an element in it, which represents a correlation relationship between the features. The relationship r is described with input feature set S_r^I , output feature set S_r^O ,

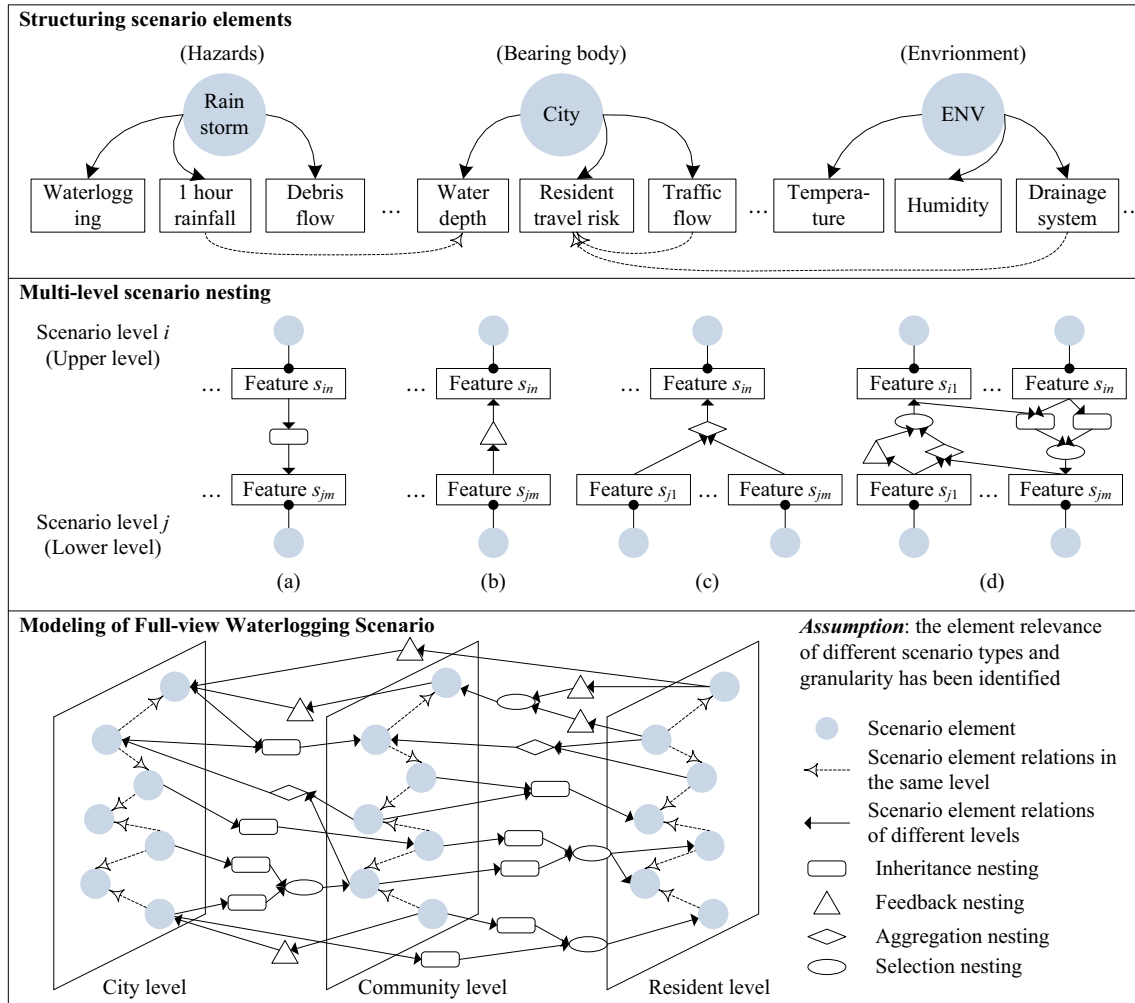


Figure 2: The basic theory of full-view waterlogging scenario modeling. (a) Inheritance nesting, (b) feedback nesting, (c) aggregation nesting, (d) selection nesting.

and the conversion relationship f_r , which can be expressed as $S_r^O = f_r(S_r^I)$.

3.2 Multi-level scenario nesting

In the field of computer science, when the attribute of a kind of data is the data with the same data structure, we call this data a nesting data [33]. Similarly, the nesting structure of waterlogging scenarios is formed when the features of the scenarios at a specific level are correlated with those at other levels. Based on existing literature and field research [12,24], there are four typical scenario nesting structures defined in this article, namely inheritance nesting, feedback nesting, aggregation nesting, and selection nesting.

(1) **Inheritance nesting:** For a scenario element feature, if its value is correlated with the feature value(s) of one or more upper-level scenario elements, this nesting structure is called inheritance nesting, as shown in Figure 2(a). Inheritance nesting is mostly embodied in environmental analysis and risk analysis. For example, a community inherits scenario data such as waterlogging area and maximum waterlogging depth of each waterlogging point from the city, and identifies potential travel risks for the community residents. For the current level feature s_h^l and upper-level features $s_1^{l_w}, s_2^{l_w}, \dots, s_k^{l_w}$, if the inheritance nesting relationships exist, then the scenario nesting structure can be represented as $s_1^{l_w} \oplus s_2^{l_w} \oplus \dots \oplus s_k^{l_w} \rightarrow s_h^l$, $s_h^l \in S_m^l$, $s_1^{l_w}, s_2^{l_w}, \dots, s_k^{l_w} \in S_n^{l_w}$, where S_m^l and $S_n^{l_w}$ indicate the feature set of scenario element e_m^l at level s_l and

the feature set of scenario element $e_n^{l_w}$ at level sl_w , respectively.

- (2) Feedback nesting: For a scenario element feature, if its value is correlated with the feature value(s) of one or more lower-level scenario elements, this nesting structure is called feedback nesting, as shown in Figure 2(b). Feedback nesting appears when lower administrative units report key information for upper level scenario analysis. For example, residents can report waterlogging risk cases (e.g., road collapse and sinkholes) to water departments for timely response. For the current level feature $s_h^{l_w}$ and lower-level features $s_1^{l_t}, s_2^{l_t}, \dots, s_k^{l_t}$, if the feedback nesting relationships exist, then the scenario nesting structure can be represented as $s_1^{l_t} \vee s_2^{l_t} \vee \dots \vee s_k^{l_t} \rightarrow s_h^{l_w}, s_h^{l_w} \in S_n^{l_w}, s_1^{l_t}, s_2^{l_t}, \dots, s_k^{l_t} \in S_m^{l_t}$.
- (3) Aggregation nesting: For a scenario element feature, if its value is correlated with the feature values of multiple lower-level scenario elements, the objective feature value is obtained by the cluster analysis of the lower-level scenario features, and the nesting structure is called aggregation nesting, as shown in Figure 2(c). Aggregation nesting mostly reflects the management of upper administrative units to lower ones. For example, urban managers cluster the rescue capabilities of communities and then rationally allocate rescue resources according to the severity of waterlogging. Another example is that community managers indirectly analyze the potential travel directions of the residents in their jurisdiction according to their work or study places. For the current-level feature $s_h^{l_w}$ and lower-level features $s_1^{l_t}, s_2^{l_t}, \dots, s_k^{l_t}$, if the aggregation nesting relationships exist, then the scenario nesting structure can be represented as $s_1^{l_t} \otimes s_2^{l_t} \otimes \dots \otimes s_k^{l_t} \rightarrow s_h^{l_w}, s_h^{l_w} \in S_n^{l_w}, s_1^{l_t}, s_2^{l_t}, \dots, s_k^{l_t} \in S_m^{l_t}$.

In theory, clustering should be carried out for the feature values of all the underlying scenario elements involved. However, in reality, it is often impossible to obtain the feature values of all the scenario elements, or the actual problem does not need to cluster all feature values. At this time, the corresponding rules of scenario element selection should be formulated. For example, some communities do not have their own information platforms, and it is difficult to share the rescue capability data about their communities. However, for communities with similar basic parameters, such as the number of residents and building area, rescue capability is often similar, so only some representative communities need to be selected for clustering.

- (4) Selection nesting: In the selection nesting structure, for a scenario element feature, there are many ways of value assignment, each of which corresponds to a nesting structure (either inheritance nesting or aggregation nesting), and it is needed to select one of them to determine the value of objective scenario feature according to management requirements, as shown in Figure 2(d). Selection nesting can appear at any scenario level, including city, community, or resident level. For example, when analyzing the travel direction of residents, urban managers can not only get the data with the location data of social media platforms (resident level) through data clustering but also do that by clustering the travel direction data of the communities (community level).

3.3 Modeling of full-view waterlogging scenario

Based on scenario nesting, the relationship among waterlogging scenario elements at different levels can be established. Combining with the correlation relationship of scenarios of different granularities and those of different types (identified in advance), the full-view waterlogging scenario model can be constructed. The form of the full-view model is as follows.

$$FS = (SL, R^{SL}, SS, R^{SS}, SG, R^{SG}, ST), \quad (6)$$

$$sl_k = (E^{l_k}, R^{l_k}) \in SL, \quad r^{l_k} = (S_{r(l_k)}^I, S_{r(l_k)}^O, f_{r(l_k)}) \in R^{l_k}, \quad (7)$$

$$ss_k = (E^{s_k}, R^{s_k}) \in SS, \quad r^{s_k} = (S_{r(s_k)}^I, S_{r(s_k)}^O, f_{r(s_k)}) \in R^{s_k}, \quad (8)$$

$$sg_k = (E^{g_k}, R^{g_k}) \in SG, \quad r^{g_k} = (S_{r(g_k)}^I, S_{r(g_k)}^O, f_{r(g_k)}) \in R^{g_k}, \quad (9)$$

where $SL = \{sl_k | k = 1, 2, \dots, n^l\}$ indicates scenario level set, and n^l is the number of levels. $R^{SL} = \{R_{t,m}^{SL} | t \neq m\}$ indicates the nesting relationship set of scenario elements at different levels, $t, m \in \{1, 2, \dots, n^l\}$. $SS = \{ss_k | k = 1, 2, \dots, n^s\}$ indicates scenario type set, and n^s is the number of types. $R^{SS} = \{R_{t,m}^{SS} | t \neq m\}$ indicates the nesting relationship set of scenario elements of different types, $t, m \in \{1, 2, \dots, n^s\}$. $SG = \{sg_k | k = 1, 2, \dots, n^g\}$ indicates scenario granularity set, and n^g is the number of granularities. $R^{SG} = \{R_{t,m}^{SG} | t \neq m\}$ indicates the nesting relationship set of scenario elements of different types, $t, m \in \{1, 2, \dots, n^g\}$. $ST = \{st_k | k = 1, 2, \dots, n^t\}$ indicates scenario time set, and n^t is the number of time nodes.

This article focuses on the correlation relationships of waterlogging scenario elements at different levels, and

the correlations of scenario elements of different granularities and those of different types at the same scenario level are supplemented to the relationship set of the level. Then the full-view model is simplified as follows:

$$\widetilde{FS} = (\widetilde{SL}, \widetilde{R}^{SL}), \quad (11)$$

$$\widetilde{sl}_k = (\widetilde{E}^{l_k}, \widetilde{R}^{l_k}) \in \widetilde{SL}, \widetilde{r}^{l_k} = (\widetilde{S}_{r(l_k)}^I, \widetilde{S}_{r(l_k)}^O, \widetilde{f}_{r(l_k)}) \in \widetilde{R}^{l_k}. \quad (12)$$

For $\forall \widetilde{sl}_t, \widetilde{sl}_m \in \widetilde{SL}, t \neq m, t, m \in \{\text{city, community, resident}\}$,

$$\widetilde{R}_{t,m}^{SL} = \{\widetilde{R}_k^{t,m} | k = 1, 2, \dots, |\widetilde{E}^{l_m}|\}, \quad (13)$$

where $\widetilde{R}_k^{t,m}$ is the nesting relationship set when nesting the scenarios of level l_t to the scenario element $\widetilde{e}_k^{l_m}$ of level $\widetilde{e}_k^{l_m}$, and $|\widetilde{E}^{l_m}|$ indicates the number of scenario elements at level l_m .

$$\widetilde{R}_k^{t,m} = \{\widetilde{r}_{k'}^{t,m} | k' = 1, 2, \dots, n\}. \quad (14)$$

This equation illustrates that there are n features of scenario element $\widetilde{e}_k^{l_m}$ have nesting relationships with the scenario element features at level t .

4 Iterative algorithm of full-view waterlogging scenario generation

When generating full-view waterlogging scenarios, because of the nesting structures of the scenarios, the values of many scenario features cannot be obtained directly, but are generated by inheriting or aggregating the feature values of other scenario levels (if there are multiple value assignment methods, the selection mechanism needs to be introduced). If the feature values of other scenario levels are still not available directly, it is needed to inherit or aggregate iteratively until the feature values of all scenario elements are assigned. In order to generate a complete full-view waterlogging scenario, based on the full-view waterlogging scenario model, this section presents an iterative algorithm for full-view waterlogging scenario generation. The essence of the algorithm is to establish feature correlations of scenario elements based on the scenario nesting structures and then to iteratively derive the feature values of scenario elements based on directly available scenario data. The input and output of the scenario generation algorithm are as follows:

(1) The input of the algorithm includes the full-view model

$\widetilde{FS} = (\widetilde{SL}, \widetilde{R}^{SL})$ and the feature set $O^* = \cup_{i=1}^l O^{*(l_i)}$, where

the values of the features can be obtained directly. n^l is the number of scenario levels, and $O^{*(l_i)} = \{o_1^{*(l_i)}, o_2^{*(l_i)}, \dots, o_m^{*(l_i)}\}$ is the set of directly available feature values of scenario level l_i .

(2) The output of the algorithm is the full-view waterlogging scenario, that is, the value set of the features of scenario levels. To express the iteration process clearly, the iteration algorithm of full-view waterlogging scenario generation is illustrated as pseudo-code in C-like language as follows.

```

void Fullview_scenario_generation () {
    init FS (-); count = 0; // Inputting the full-view scenario model and initializing the number of iteration
    initialvalue ( $\cup_{i=1}^{n^l} \widetilde{E}^{l_i}, O^*$ ); // Assignment of scenario feature values obtained directly.
    for (count = 1; count <= Th; count++) { // If the number of iterations exceeds the threshold Th, the scenario nesting chain may break.
        for (i = 1; i <=  $n^l$ ; i++) { // The pointer moves to scenario level  $l_i$  (The lowest level).
            for (k = 1; k <=  $|\widetilde{E}^{l_i}|$ ; k++) { // The pointer moves to the scenario element  $\widetilde{e}_k^{l_i}$  at level  $l_i$ .
                while (t < i) { // Assignment of element  $\widetilde{e}_k^{l_i}$  according to the nesting relationships from level  $t$  to level  $i$ .
                    for (k' = 1; k' <=  $|\widetilde{R}_k^{t,i}|$ ; k'++) { // The pointer moves to k'th nesting relationship of  $\widetilde{e}_k^{l_i}$ .
                        if (emptycheck ( $\widetilde{r}_{k'}^{t,i}$ )) { // If emptycheck () = 1, null value exists in the input features.
                            break;
                        }
                        revalue ( $\widetilde{r}_{k'}^{t,i}, S_r^I, S_r^O, f_r$ ); // If the value of all input features are non-null, the value assignment will be performed.
                    } end
                } end
            } end
        } end
        if (valuecheck ( $\cup_{i=1}^{n^l} \widetilde{E}^{l_i}$ ) = 0) { // If valuecheck () = 0, the scenario features have not been all assigned.
            warning() // Warning and inputting the features that cannot be assigned successfully.
        } end
    }
}

```

5 Use case analysis

5.1 Research objects and data source

From June 30 to July 6, 2016, Wuhan suffered from heavy rainstorm and waterlogging. There were 187 sections of roads waterlogged in the whole city. East Lake High-tech Development Zone was a serious affected area. As many as 26 sections were impassable due to waterlogging. The south section of Guanggu Avenue almost ran into a river. The severe waterlogging situation aroused great attention of the management committee and widespread concern of the society. Focusing on the maximum rainfall time on July 6 (i.e., 8 a.m. when the hourly rainfall reaches 61.3 mm) as the time node, this article chooses representative research objects from three waterlogging response levels (city, community, and resident), and describes in detail the construction of full-view scenario and its specific generation process. The selected research objects of each level are shown in Figure 3.

5.1.1 City level

East Lake High-tech Development Zone was taken as the city level research object. This zone was a heavily waterlogged area in Wuhan at that time. This use case focuses on the analysis of the travel directions and travel risks of the residents in this zone. When waterlogging occurs, the location data (obtained by social media) generated by residents' movement can be used to predict the population distribution of the city in the following hours, which helps to identify the main travel directions of the residents. After

identifying the main travel directions of the residents, the scenarios of travel risks can be analyzed, which include two aspects. First, the risk of travel destination due to waterlogging, which is related to the area of waterlogging, the number of waterlogging points, and the maximum depth of waterlogging in the destination area. Second, the risk of travel route related to the waterlogging and traffic congestion on each road leading to the destination. The more serious the waterlogging and vehicle congestion are, the greater the risk of travel route is.

5.1.2 Community level

The Jiufeng New Area Community at Jiufeng Street was taken as an instance. East Lake High-tech Development Zone has jurisdiction over the community, which includes one primary school and 27 residential buildings. This use case focuses on the analysis of the residents' travel risk (including the risk of destination and that of travel route), the waterlogging situation in the community, and real-time waterlogging risk cases (e.g., serious road inundation and secondary disasters).

5.1.3 Resident level

The observation group consisted of the residents of the Jiufeng New Area Community. All the objects were under the age of 60 years and were still employed. When waterlogging occurs, community residents will plan their travel reasonably according to the waterlogging situation of the destination and the roads along the way, including the choice of transportation types and route planning.

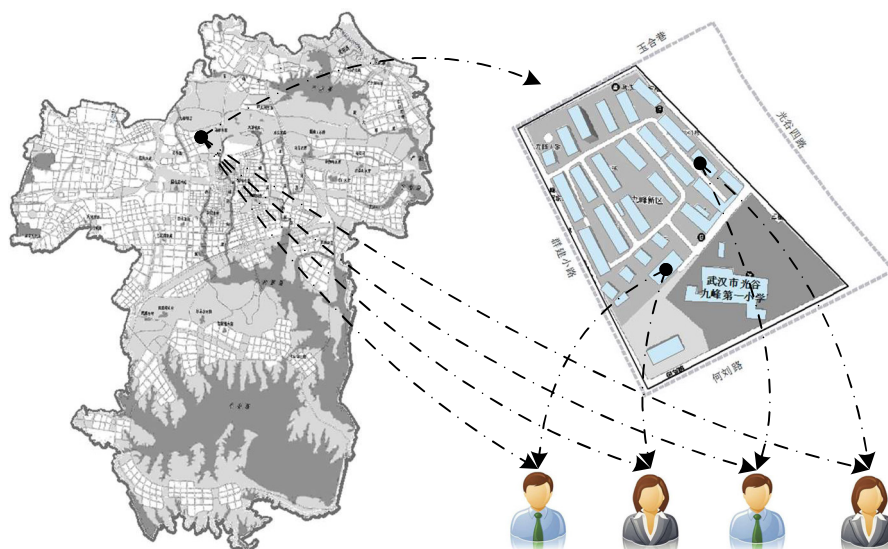


Figure 3: The selected research objects of three levels.

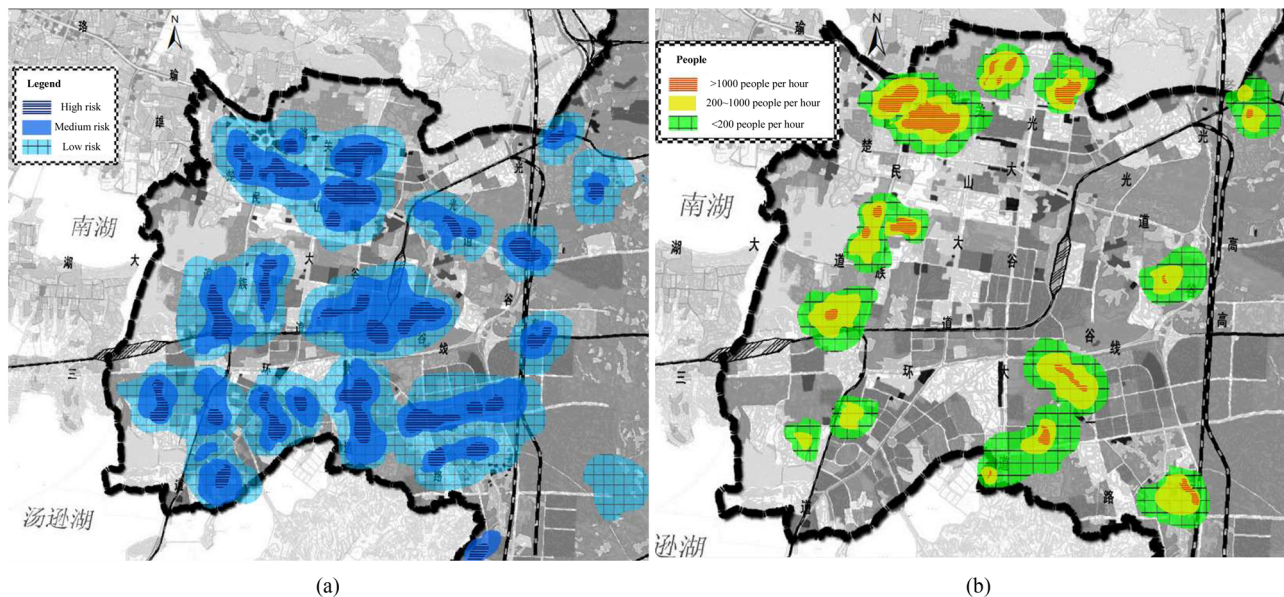


Figure 4: The scenario generation result at city level (risk of travel destination). (a) The risk of different regions, (b) people distribution in the following several hours.

Among them, the choice of transportation types (walking, bicycle, personal motor vehicle, public transport, etc.) depends on factors such as work places, work types, and whether having cars. This article considers the residents who have a car, need to travel to work, and need to drive to destinations far from the community as an example to analyze.

The data used in this article and their sources are illustrated as follows.

- (1) Rainfall data: The rainfall data in this article are provided by the Water Bureau of East Lake High-tech Development Zone in Wuhan.
- (2) Drainage system data: The data of drainage system are based on the data of drainage network provided by the Water Bureau of East Lake High-tech Development Zone in Wuhan. The data include the distribution of drainage pipe network and the data table of pipe diameters.
- (3) Elevation data: In this article, the elevation data are based on 30 m Digital Elevation Model data downloaded openly by the Geospatial Data Cloud Platform of Chinese Academy of Sciences, which provide data support for calculating the rainfall in each geographic grid.
- (4) Remote sensing image: This article downloads the high resolution remote sensing image of East Lake High-tech Development Zone through Google Earth. The image level is 18 (100 m). The road distribution, lakes, rivers, green spaces, and other data are extracted. Then, the data are modified by comparing with the water system data provided by the Water Bureau of

East Lake High-tech Development Zone. Finally, the data are imported into ArcGIS software.

- (5) Traffic data: Traffic data are provided by the traffic department of East Lake High-tech Development Zone of Wuhan Public Security Bureau, including traffic flow data of main roads and waterlogging conditions of road sections.
- (6) Demographic data: This kind of data includes resident location data and community resident data. Among them, resident location data are obtained by processing the text and location data of social media platform, which are used to identify the actual movements of the residents. Community resident data include the employers, work addresses of the residents in Jiufeng New Area Community, which are provided by the community management department of Jiufeng New Area Community to determine the potential movements of the residents.

5.2 Scenario element representation of different levels

Considering the information demands of decision makers at different levels for recognizing waterlogging scenarios, the scenario types and scenario granularities are reasonably selected to construct waterlogging scenarios at three levels, that is, city, community, and resident. The elements and their features of waterlogging scenarios at all levels are listed in Table 1. There are correlations between the features

Table 1: Scenario elements at different levels

$\bar{S}_k^l$ (Level)	$\bar{e}_k^{lm}$ (Element)	Element type	$\bar{S}_k^{lm}$ (Features of the scenario elements)
City	Rainstorm	Hazard	{1 h rainfall, 6 h rainfall, and 24 h rainfall}
	Grid unit	Bearing body	{Depth of waterlogging, drainage pipe diameter, and 1 h drainage amount}
	Selected region	Bearing body	{Number of waterlogging grids, waterlogging area, maximum waterlogging depth, and risk degree}
	Road	Bearing body	{1 h traffic flow, number of waterlogging grids, waterlogging length, maximum waterlogging depth, and risk degree}
	City	Bearing body	{Travel direction of the residents (null), destination risk (null), route risk (null)}
Community	Water level	Environment	{Water level of river, water level of lake, and water level of reservoir}
	Resident	Bearing body	{Company/School, address of company/school, age, and travel direction}
	Road	Bearing body	{Number of waterlogging grids (null), maximum waterlogging depth (null), and risky or not (null)}
	Community	Bearing body	{Number of waterlogging grids (null), waterlogging area (null), maximum waterlogging depth (null), travel direction of the residents (null), destination risk (null), route risk (null), and real-time waterlogging risk cases (null)}
	Resident	Bearing body	{Position, current risk (null), route plan, destination risk (null), route risk (null), and reported waterlogging risk cases}

of scenario elements at the same level. For example, the discharge of each geographic grid is determined by the diameter of the drainage pipe and the elevation. The specific correlations are shown in Table 2. It is noted that not all scenario feature values can be obtained directly, such as the travel direction of the residents at the city level and the number of waterlogging grids at the community level. The assignment of these values depend on the feature values of waterlogging scenario elements at other levels, and it is needed to build scenario nesting relationships to obtain the values.

5.3 Construction of full-view model

Referring to the big data analysis modes of existing literature [25,26], combining with the field investigation of

East Lake High-tech Development Zone, we extract the correlations among the features of different levels of scenarios, establish the nesting patterns of cross-level waterlogging scenarios, and complete the construction of the full-view waterlogging scenario model. Some instances of the nesting patterns are shown in Table 3.

5.4 Iterative generation of full-view scenario

According to the multi-level nesting correlations of waterlogging scenarios in the last section, following the iteration algorithm of full-view scenario generation given in Section 3.4, the value assignment of waterlogging scenario features at different levels can be realized. The feature values of scenario elements at city level are exported to the big data platform of East Lake High-tech Development

Table 2: (Instances of) the correlations of features of scenario elements at the same level

$\bar{R}^{lk}$	$\bar{r}_i^{lk}$	$\bar{S}_{r(l_k)}^l$	$\bar{S}_{r(l_k)}^o$	$\bar{f}_{r(l_k)}$
City	$\bar{r}_{grid\ unit}^{l_{city}}$	{Drainage pipe diameter (D) and ground elevation (E)}	{1 h drainage amount (V)}	$E + 4V \frac{\partial V}{\partial D^2} + 4g \frac{\partial V}{\partial D^2} = -gD^2 S_f$
	$\bar{r}_{grid\ unit}^{l_{city}}$	{1 h rainfall (F) and 1 h drainage amount (V)}	{Depth of waterlogging (H)}	$H = \alpha F - V$
	$\bar{r}_{selected\ region}^{l_{city}}$	{Number of waterlogging grids (N), waterlogging area (S_1), and maximum waterlogging depth (M_1)}	{Risk degree (R_1)}	$R_1 = M_1 \cdot (S_1/N)$
Community	$\bar{r}_{Community}^{l_{com}}$	{Travel direction of the residents (O_2)}	{Destination risk (R_2)}	$R_2 = R_1 Des(O_2)$
Resident	$\bar{r}_{Resident}^{l_{com}}$	{Route plan (P)}	{Destination risk (R_3)}	$R_3 = R_1 Des(P)$

Note: S_f is the friction pressure chop, g is the gravitational acceleration, α is an adjustment coefficient considering surface runoff, and $Des(O_2/P)$ is a function which generates the corresponding destination of O_2 or P .

Table 3: (Instances of) the waterlogging scenario nesting patterns in the use case

$\tilde{R}_{t,m}^{SL}$	$\tilde{e}_k^{Im}$	$\tilde{S}_r^O$	$\tilde{S}_r^I$	Nesting type	Nesting method
$\tilde{R}_{city,com}^{SL}$	Community	Travel direction of the residents (O_1)	{(City) travel direction of the residents (O_1) and position (PO)}	Selection	Computing the confidence levels of clustering and choosing nesting pattern with the highest confidence
	Waterlogging area (S_2)	Waterlogging area (M_1)	{(Selected region) Waterlogging area (S_1)}	Inheritance	At the city level, setting the community as the selected region to generate the waterlogging area
$\tilde{R}_{city,res}^{SL}$	Road	Maximum waterlogging depth (M_2)	{Maximum waterlogging depth (M_1)}	Inheritance	At the city level, setting the community road as the input to generate the maximum waterlogging depth
	Resident	Destination risk (R_3)	{(City) risk degree (R_1)}	Inheritance	$R_3 = R_1 Des (P)$
$\tilde{R}_{res,city}^{SL}$	City	Travel direction of the residents (O_1)	{Position (PO)}	Aggregation	Clustering position (PO) to generate the main travel directions of residents
	Community	Real-time waterlogging risk cases (WC)	{Reported waterlogging risk cases (RC)}	Feedback	Residents report waterlogging risk cases to communities

Zone, and the feature values of the scenario elements at community level are exported to the information system of Jiufeng New Area Community. The feature values of the scenario elements at resident level are transferred to the mobile terminals. Finally, the full-view waterlogging scenario for the three level decision makers is formed. To visualize the results of full-view scenario generation, the full-view scenario is expressed through the geographic information platform. The granularity of waterlogging scenario expression is adjusted reasonably and the final results are shown in Figures 4–8.

5.5 Result analysis and validation

With the help of virtual geographic information system provided by ArcGIS, the use case integrates waterlogging scenario data of different types and granularities, constructs a full-view waterlogging model for three levels, that is, city (Wuhan East Lake High-tech Development Zone), community (Jiufeng New Area Community), and resident, and realizes the instantiation of the full-view model with the iteration algorithm of full-view scenario generation. This section analyzes the results of full-view scenario generation.

- (1) The scenario generation result at city level: We analyze the result in terms of the risk of travel destination and the risk of travel routes. To analyze the travel destination risk, the risk of different regions shown in Figure 4(a) and the people distribution in the following several hours shown in Figure 4(b) are generated. Comparing the two figures, we can find that some places have a large number of gathered people and serious waterlogging (such as Guanggu Square, Luoyu Road, Central-South University for Nationalities, Guanggu Avenue, and surrounding areas) and thus exist higher risk. It is necessary to give these information back to the public in time and suggest that they adjust their travel plans. To analyze the travel route risk, the traffic flow data of each road are generated. Compared with the risk of different regions shown in Figure 5, we can find that some roads have heavy traffic and serious waterlogging (such as the Luoyu Road, the part of National Avenue close to the Luoyu Road, the part of National Avenue close to the Third City Loop, the part of Gaoxin Avenue close to the Third City Loop, and the part of Guanggu Avenue close to the intersection with Luoyu Road). For these roads, the traffic control should be strengthened. Those city-level results are highly consistent with the governmental disaster survey reports.

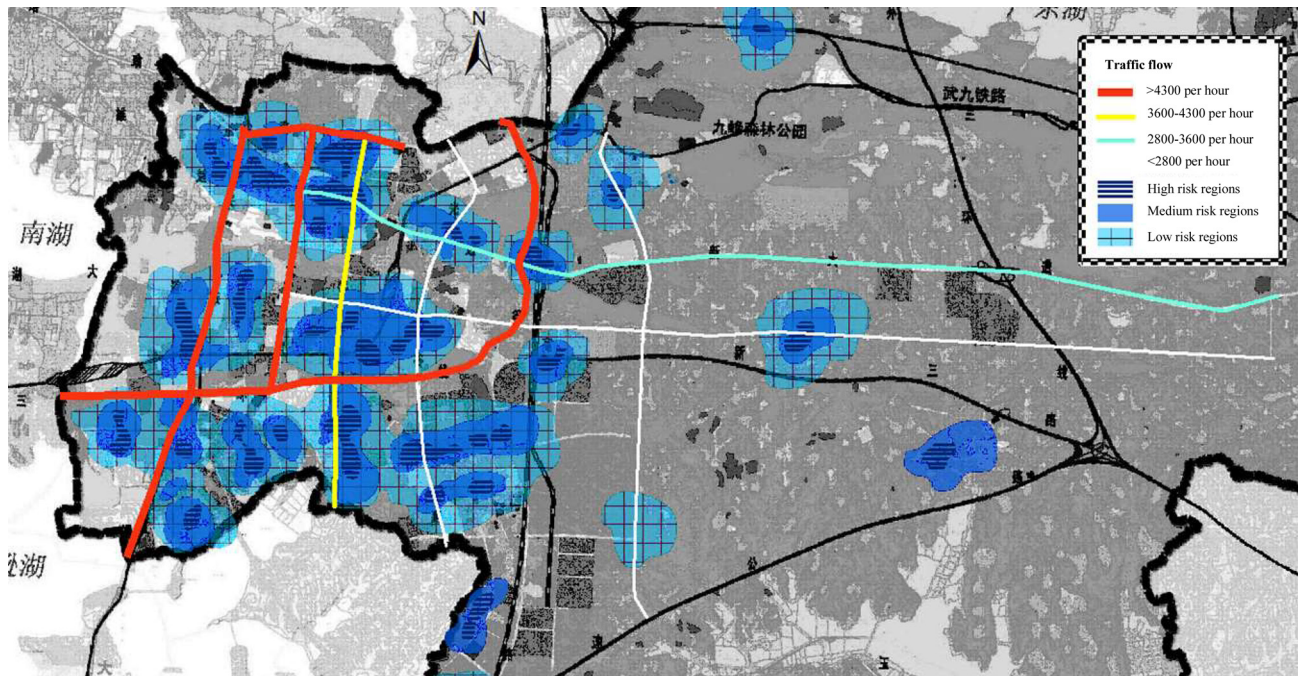


Figure 5: The scenario generation result at city level (risk of travel routes).

- (2) The scenario generation result at community level: At the beginning of 2018, the Wuhan Government built a city-wide event report platform that is called “Wuhan

Micro Neighborhood.” A sample page of the platform is shown in Figure 6. Through this platform, the residents of Jiufeng New Area Community can report

武汉微邻里 “Wuhan Micro Neighborhood”

群众报事 “Case report by citizens”

企业报事 “Case report by organizations”

报事名称: 道路淹没 “Case title: Road inundation”

报事内容: 光谷大道... “Case content: GuangGu Avenue...”

点击录入 “Input by voice”

图片 “Figures”

案件定位 “Case position”

湖北省武汉市江夏区 “JiangXia District, Wuhan, Hubei”

居民 “Residents”

网格员 “Community workers”

社区干部 “Community officials”

街道干部 “Street officials”

Figure 6: The scenario generation result at community level with translations (real-time waterlogging risk cases).

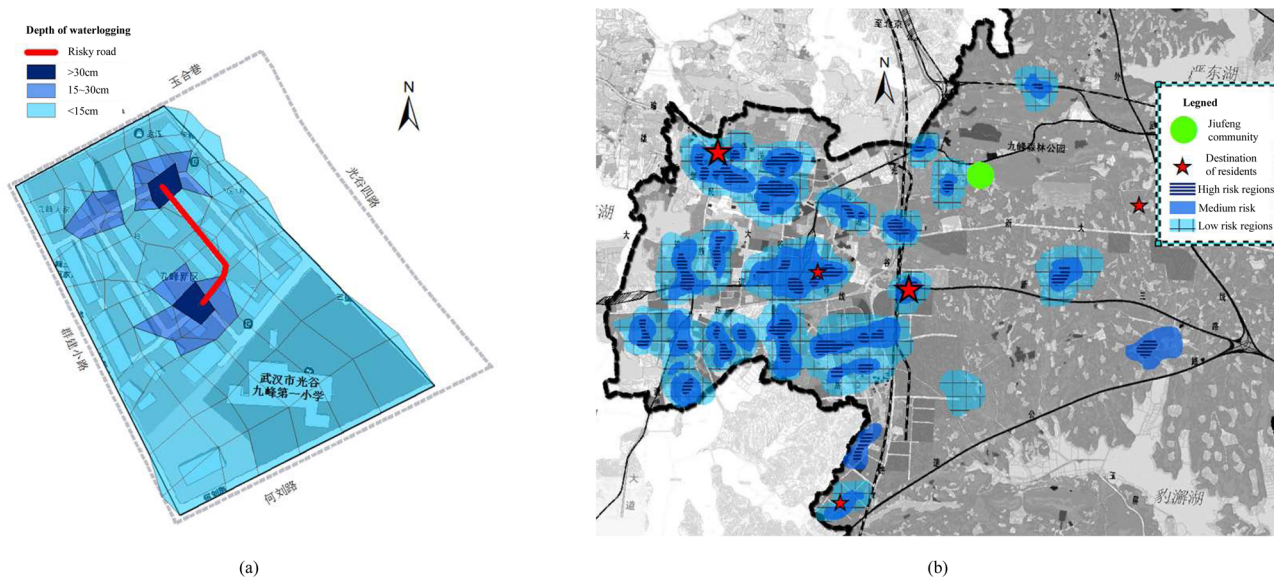


Figure 7: The scenario generation result at community level (waterlogging situation and travel destination risk). (a) Waterlogging situation of the community, (b) travel destination risk of the community residents.

real-time waterlogging risk cases (e.g., road collapse and sinkholes) to the community for timely response. According to the survey in this community, residents are really helpful in city waterlogging scenario recognition and emergency response. This real-time case report mechanism has also greatly reduced the demands

for emergency workers. Up to now, this platform has accumulated more than 12,000 case records, involving secondary disasters, serious water inundation, infrastructure damage, and trapped residents. In terms of waterlogging situation, the generation result is shown in Figure 7(a). We can find that there are three

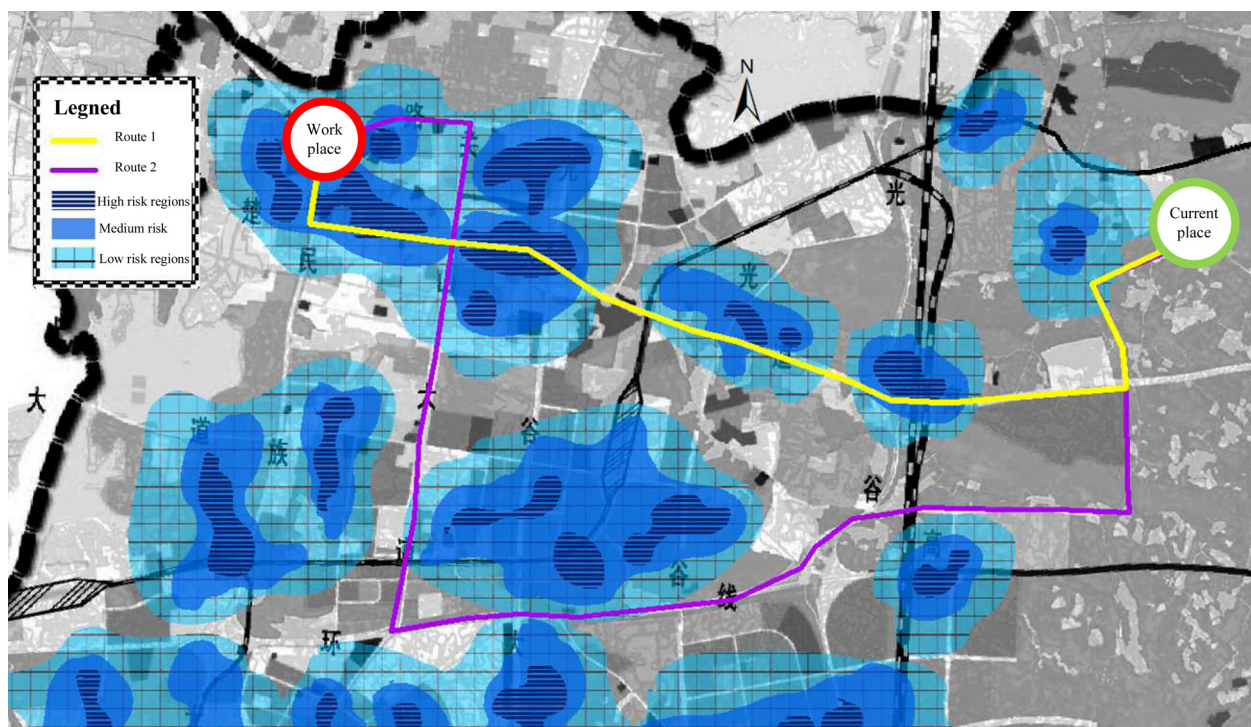


Figure 8: The scenario generation result at resident level.

intersections with serious waterlogging, and two of them have brought about some road sections being blocked. This result has been proved to be consistent with the historical situation through practical surveys. To analyze travel risk of residents, the generation result is shown in Figure 7(b). We can find that travel directions are mainly around Guanggu Square and Xiyuan Park, but there is serious waterlogging in the two places. Therefore, it is necessary to communicate the potential risks to the residents in time. Although this result is hard to be validated, the risk analysis method has been highly praised by the community managers, and relevant measures have been adopted to carry out the destination risk analysis and communication.

- (3) The scenario generation result at resident level: This article considers the residents who have a car, need to travel to work, and need to drive to destinations far from the community as an example to analyze the scenario generation result. According to the demographic data and historical cases of Jiufeng New Area Community, the number of this kind of residents is the largest, and the analysis can be highly representative. According to the result of scenario generation shown in Figure 8, if such residents drive according to the shortest route (route 1), the waterlogging along the route is serious and the risk relatively pretty high. Compared with route 1, although route 2 is longer, the waterlogging is not serious, and the mobile terminals will recommend residents to choose this route for travel. This route planning method has also been adopted by the Jiufeng New Area Community, and is expected to be integrated to the “Wuhan Micro Neighborhood” platform.

6 Conclusion

In the big data environment, scenarios of different levels, types, and granularities are more closely related. Clarifying the global and holistic relationships of waterlogging scenarios has been the key to effectively recognize waterlogging scenarios, and further make response plans. In view of the deficiencies of existing waterlogging scenario models in describing the relationships between elements, a full-view scenario model of waterlogging disaster is proposed to provide operational support for systematic recognition of waterlogging scenarios. The use case part shows that the construction of full-view waterlogging model provides effective information for various levels of decision makers to cope with waterlogging, avoids the disorder of scenario information, and improves the response efficiency. On the other hand, waterlogging scenarios of different levels,

types, granularities, and time nodes are not independent of each other, but mutually supportive. By establishing the four type nesting structures of scenarios, scenario elements in different dimensions are connected, which facilitates more precise scenario recognition and emergency response. In addition, although this article focused on urban waterlogging disasters due to limited available data, the full-view scenario model is expected to be applicable for other disasters by extracting the key scenario elements and their associations.

Future studies of full-view scenario model could explore two aspects. First, future work should include other disasters or cities with different characteristics for a more comprehensive and effective full-view model. Second, future studies are encouraged to explore the interactions between cities for collaborative scenario recognition and emergency response based on the full-view scenario model. It can be seen that big data has played more and more important role in disaster management. Researchers should make greater efforts in mining the value behind these big data resources.

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Data availability statement: The drainage network data, geological data, water system data, traffic data and demographic data are proprietary or confidential in nature and may be provided only with restrictions. Other data of this study are available from the corresponding author upon reasonable request. All related models appear in the published article.

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