URBAN LOCAL EARTHQUAKE DISASTER RISK INDEX

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SUMMARY

For the earthquake disaster risk level, there exists imbalance among all local areas within an urban. Urban Local Earthquake Disaster Risk Index (ULEDRI) is a new methodology to reveal the imbalance of the risk faced by the whole city. Using the local areas within a city as its study units, ULEDRI will give not only the relative level of overall risks of all local areas within a city, but also the relative contribution of various factors to ULEDRI of each local area. ULEDRI involves a large amount of knowledge about earthquake disaster of various disciplines such as geology, engineering, socio-economics, and culture. The ULEDRI of a city, therefore, will be useful for its decision-makers, disaster managers, city planners, organizations and even individuals. In this paper, the features, purposes and its developing approach of ULEDRI were given and the problems concerning with its development and usefulness are pointed out and discussed. As a case study, ULEDRI of Shanghai, which is based on its central districts, was developed in this paper.

INTRODUCTION

In the course of a city's urbanization, the situation has been formed in which the characteristics of all local area within it are different from each other. These different characteristics include economic developing level, local economic structure, city function undertook by individual local area, magnitude and quality of the buildings and infrastructure system, population density and quality and so on. For example, In Shanghai, while the population density of the densest district, Nanshi, is 58233 (person/sq. km), that of the sparsest one, also located in center part, is only 15228 (person/sq. km). Additionally, there are also many different characteristics inside a city formed by nature, such as ground condition, topographic feature. All these distinct characteristics of local areas will have different effect on the disaster once an earthquake affect the city, and will make different contribution to overall disaster. In order to understand the risk faced by the whole city, it is essential to demonstrate the local features of disaster.

Urban Local Earthquake Disaster Index (ULEDRI), presented firstly in this paper, is a new methodology to understand the risk faced by a city. It expresses the earthquake risk of a city in a suitable way, and it pays much attention to the city features that will affect the disaster but often be ignored. This kind of index can compare the risk of all local area inside a city directly, and describe the relative contributions of various factors to the overall risk of each area. So, through using ULEDRI, it is possible to guide disaster management and city planning, to provide the bases for choosing the sites of many major projects, and consequently to improve the level of disaster prevention and mitigation.

This paper begins with a brief summary of EDRI, an existing approach from which ULEDRI derives. After that, the main features, anticipated usefulness of ULEDRI, together with the differences between ULEDRI and the related works are given in the following section. The general approach of developing an ULEDRI is given, along with the ULEDRI of Shanghai, presented as a case study. As conclusion, several problems concerning with the use and development of ULEDRI are pointed out and discussed.

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EDRI AND ULEDRI

Earthquake Disaster Risk Index (EDRI), from which ULEDRI derived, is a existing risk assessment approach put forward in 1997 by Dr. Rachel Davidson firstly (Davidson 1997a). Using the greater metropolitan areas worldwide as its study unit, EDRI brings together plenty of knowledge about earthquake disasters from various disciplines to form a composite index, through which the direct comparison of overall earthquake disaster risk among cities worldwide can be achieved, and the relative contributions of various factors to that overall risk can be demonstrated. A multidisciplinary and holistic approach is one of key features of EDRI, in which a framework is provided to integrate the knowledge and techniques from earth science, engineering, socio-economics, culture and politics. The disaster conception used in EDRI is a function of not only the physical impact, but also the capacity of the affected city to sustain that impact, and the implications of that impact to the city and world affairs. Another feature of EDRI is using a composite index form to express risk assessment findings, rather than the expected consequences of risk, used by traditional risk assessment approach.

ULEDRI, presented in this paper, applies the idea of EDRI to a different study object, and have different objectives and usefulness. Unlike EDRI, whose study unit is the greater metropolitan area, ULEDRI uses the local area within an urban, e.g. administrative district, postal area, as its unit of study. As a result of this difference between them, the objectives and usefulness of ULEDRI will differ distinctly from those of EDRI

MAIN FEATURES AND PURPOSESOF ULEDRI

In assessing urban earthquake risk, those city characteristics such as exposure and vulnerability should to be paid enough attention, cooperation among various disciplines also need to be established (Giardini et. al, 1997). In addition, in order to improve the capacity of mitigating disaster of the city as a whole and guide disaster mitigation planning, the local features of contributing factors of various local areas should be understood and exhibited. These two objectives are the primary purposes of constructing a city's ULEDRI.

Main Features

ULEDRI has the same key features as EDRI, i.e. the multidisciplinary and holistic approach, and using composite index rather than physical consequences to express disaster risk. However, Compared with EDRI, ULEDRI have the following advantages. Firstly, the social and cultural systems within a city are consistent. This kind of consistency keeps the effects of all factors on disaster risk within a uniform background, and will highlight the influences of all factors' own. For EDRI, on the other hand, because the interested cities may be located in different country, it is difficult to express the differences of social and cultural systems as some certain factors effectively. Secondly, For ULEDRI, the indicators and data have a consistent meaning and format, which is necessary to develop such an index. This condition is very difficult to meet for EDRI (Davidson, 1997a). Finally, because of its smaller study unit and consistent background, ULEDRI can consider more factors and indictors which contribute to disaster risk, consequently, more interaction of many factors.

However, the most important difference of EDRI and ULEDRI is their purposes and usefulness.

Purposes and Usefulness

ULEDRI is developed to provide the relative risk level of earthquake disaster of various local areas within an urban, and to describe the relative contributions of various factors to that overall risk of each area. Such an index has application in the following areas.

In the first place, directly compare the overall earthquake disaster risk of all local areas so that the most dangerous area can be shown. Such a comparison is useful for decision-maker and disaster administrator to know the potential distribution of disaster and to make rational use of limited resources throughout the megacity.

Second, by comparing the factors composing the ULEDRI of a given local area, the reason why this area has a high or low risk level could be revealed. The user can make decisions according to the results to decrease or remove the high risk factors. By rebuilding and reevaluating the index periodically, users can reduce the high risk factors over time, and consequently, the ability of resisting earthquake disaster of the whole city will reinforces to a great extent.

Third, in the course of city development, the city planner can refer to the index to plan the city function layout, and to guide the land use planning scientifically. For example, if a project that may cause or affect the earthquake disaster have to be built in a city, planners can consult the index to choose site for it so that the risk of the city will not increase.

Finally, Some organizations, even individuals can benefit from ULEDRI, for example, insurance companies and chain groups can use the index as they determine the insurance fee of different local area and choose sites for their branches. Citizens can refer to the index when they buy their own houses. In addition, this nonprofessional index is very simple and easy to use, so it can increase the general public's awareness of earthquake disaster prevention.

Differences Between ULEDRI and the related works

The related works dealing with the earthquake disaster of local areas within cities include loss estimation and microzonation. Both of them differ from ULEDRI distinctly.

The loss estimation expresses the earthquake disaster as absolute values of various consequences such as building damage, casualties and economic losses. Because this methodology make limited effort to consider the comprehensive effect of many factors, and each of the models for estimating damage has uncertainty associated with it (Anagnos, 1997), the results often bear lots of errors or mistakes. Furthermore, many kinds of disaster can not be described as physical consequences, e.g. city function weakening or losing, the damage of victim's mind etc. ULEDRI can overcome the above disadvantages of the loss estimation. ULEDRI is a macroscopical, composite index, which will involve the comprehensive effects of many a factor on disaster, although the interactions of several factors cannot be expressed completely. Additionally, what ULEDRI emphasizes is one kind of relative conception, and does not predict the damage states of physical exposure. Compared with the loss estimation, this new approach will get rid of the uncertainty associated with damage estimating models.

The city microzonation is to give the ground shaking level and ground conditions of small-scale area within urban in order to provide parameters to structure design. Its results can not be understood and accepted easily by decision-maker, city planner and common citizens who are nonprofessional. In microzonation, those factors that will influence the disaster degree (e.g. buildings quality, economic condition, function layout and so on) have nothing to do with it. Although the results of microzonation of a city will be used to develop its ULEDRI, the difference between them is obvious.

DEVELOPMENT OF AN ULEDRI

In the socio-economical field, the research of developing the comprehensive index has been carried out for many years (Wang, 1996), and most of the theoretical development of it has already been completed. What's more, Dr. Davidson has researched in depth the method of developing EDRI (Davidson, 1997b). The method of developing ULEDRI is almost the same as that of EDRI, but there are still some differences between them.

Developing an ULEDRI for a given city will involve the following steps. First, determine the conceptual framework of ULEDRI, in which the factors composing ULEDRI have been defined. Second, for each factor of ULEDRI, choose a set of indicators to represent it. Third, combine the indicators and factors using a certain mathematical method, before which, if the linear combination approach is used, the scaling method should be selected, and the weights of each indicator and each factor should be determined. Finally, gather and process original data, and obtain the overall ULEDRI and the disaggregated ULEDRI. Additionally, present the results of ULEDRI using various meaningful ways, and interpret them.

The following section will give a case study, in which each step of developing an ULEDRI will present in detail.

CASE STUDY

Shanghai, one of the largest cities of China, is also under the earthquake disaster. Because of its large population, dense buildings and old urban facilities, the situation of earthquake prevention in Shanghai is bad. In our case study, the ten administrative districts of Shanghai, located in its center, were used as the study units of its ULEDRI.

The Conceptual Framework

ULEDRI does not use physical consequences as the earthquake disaster risk. All kinds of physical consequences (e.g. buildings damage, casualties) and non-physical consequences (e.g. function weakening, mind impact of citizens) are included in ULEDRI through defining some kind of factors. Since the primary objective of ULEDRI is to compare the risks of all local areas, if a factor displays different characteristics in different local area, and will affect the disaster to the different extent, then this factor should be included in ULEDRI.

The factors composing ULEDRI and their components form the conception framework of ULEDRI. What Fig. 1 shows is a conceptual framework defined for Shanghai in our case study.

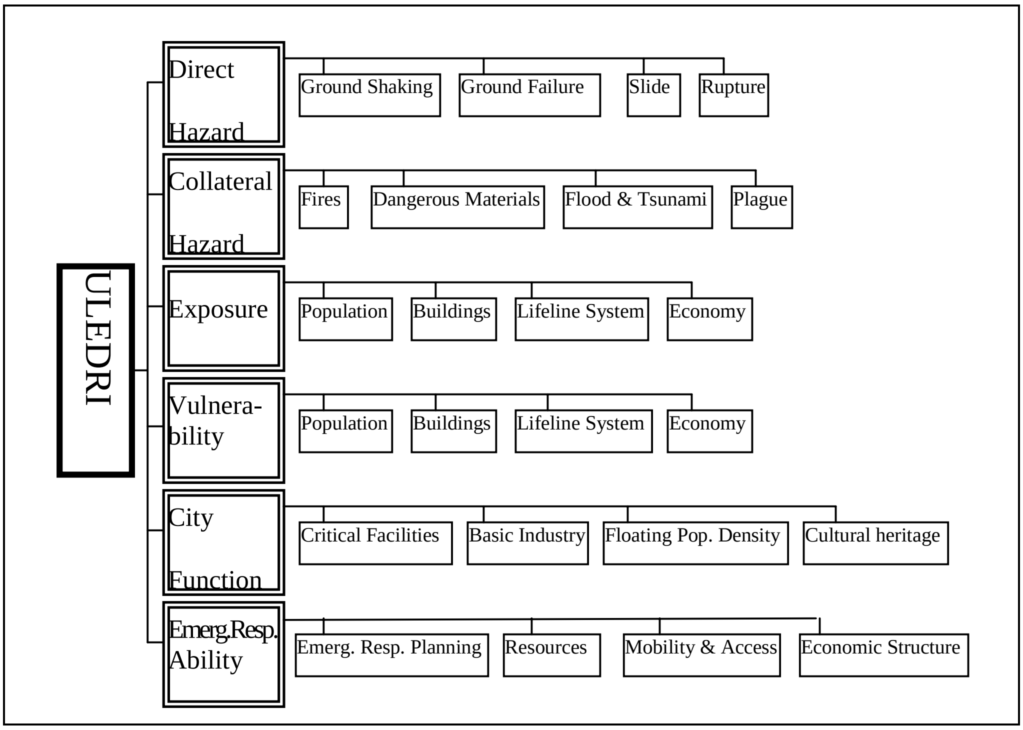

Fig. 1 Conceptual framework of ULEDRI

The following is explanation of each factor given in the conceptual framework.

Direct Hazard presents the frequency and severity of ground shaking, to which each local area will be subjected, and the probability and extent of taking place such geological damages as ground failure, slide, and rupture caused by earthquake in each local area.

Collateral Hazard describes the frequency and severity of taking place those collateral disasters such as fire, dangerous materials release, flood, tsunami and plague in each local area.

Exposure refers to all man-made facilities (e.g. buildings, infrastructure), population, economy, and the amount and type of activities associated with them in each local area, which will be affected by an earthquake.

Vulnerability describes how easily and how severely the exposure of each local area can be affected by an earthquake.

City Function represents the extent of the whole city will be affected because of the failure or weakening of some type of city functions undertaken by each local area.

Emergency Response and Recovery Ability describes the capacity of moderating all kinds of impacts caused by an earthquake through effective, organized efforts made by each local area.

Indicators Selection

Factors are only qualitative description of earthquake disaster risk, in order to compare quantitatively the overall risk among local areas, a set of measurable indicators should be selected to represent each factor. Turning the complex, qualitative factors into simple, measurable indicators will lose information inevitably. For this reason, the indicators chosen should accurately represent the factors. At the same time, data availability should be required.

Besides the above, the following conditions should be met in choosing indicators: Firstly, in order to compare the relative risk of all local areas, the indicators should be the mean rather than sum ones. Second, some indicators have different meaning over cities. Therefore, for a given city, a certain set of indicators suitable for it should be chosen. Table 1 shows the selected indicators example used in case study:

Table 1: Part of indictors used in the case study

FACTORS	FACTOR COMPONENTS	INDICATORS
Direct Hazard	Ground Shaking	1. GPA with a 10% chance of being exceeded in 50 years 2. GPV with a 10% chance of being exceeded in 50 years 3. Duration Time with a 10% chance of being exceeded in 50 years
Collateral Hazard	Fire Following Earthq.	1. Density of Wood Buildings 2. Density of Population
Exposure	Buildings	1. Density of Building 2. Rate of Building increase from 1990
Vulnerability	Population	1. Rate of population between 5-60 2. Number of persons who have professional degree or above per 10,000 3. Rate of male to female
City Function	Floating population Density	1. Scale of retail sales and catering trade 2. Scale of culture and entertainment undertakings 3. Scale of tourism sector
Emerg. Resp. & Recovery Capacity	Mobility & Access	1. Density of Road 2. Per capita public green areas 3. Capacity of access from outside the city

Combination

The ways of combining all indicators into factors and combining all factors into ULEDRI are the linear combination, just as the following:

$$\text{ULEDRI} = W_D D + W_c C + W_E E + W_v V + W_F F + W_R R$$
$$D = W_{D!} D1 + W_{D2} D2 + W_{D3} D3 + \cdots\cdots + W_{Dn} + Dn$$
$$\cdots\cdots \tag{1}$$

in which, D, C, E, V, F, R represent the six factors respectively, W refer to all weights of factors and indicators.

This combination way requires scaling the original data before combination so that they are turned into compatible units of measurement. In ULEDRI, each indicator is scaled according to its mean minus two standard deviations as following:

$$X' = [X - (\bar{X} - 2S)] / S \tag{2}$$

in which, X', X represent the scaled value and original value of each indicators respectively, $\bar{X}$, S are its mean value and standard deviation respectively.
How important each factor is to overall ULEDRI and each indicator is to factor are described by weights. There are several methods to determine the weight in construction of other composite indexes, but only subjective assessment can be used in ULEDRI since the conditions needed by other approaches can not be met by ULEDRI

(Davidson, 1997b). Fig. 2 shows the weights of six factors composing ULEDRI in the developing ULEDRI for Shanghai.

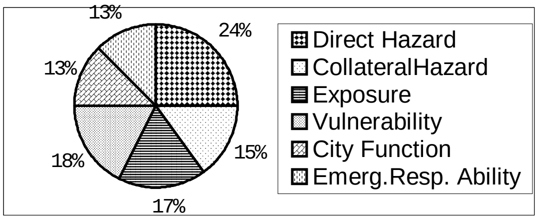

Fig .2 Weights of factors in overall ULEDRI

Gather original data for each indicator, and scale them according to Equation (2), and then multiply weights of each indicator and combine them to get the values of six factors. The final ULEDRI derive from combining the values of factors according to Equation (1).

Presentation and Interpretation

ULEDRI is not only a single representation of risk, there are lots of significant information which can be used to earthquake prevention and disaster mitigation. How to present the results of ULEDRI is critical to its applications. The following will present the results of Shanghai ULEDRI in a variety of easily understandable graphical forms, from which the usefulness of it can be demonstrated.

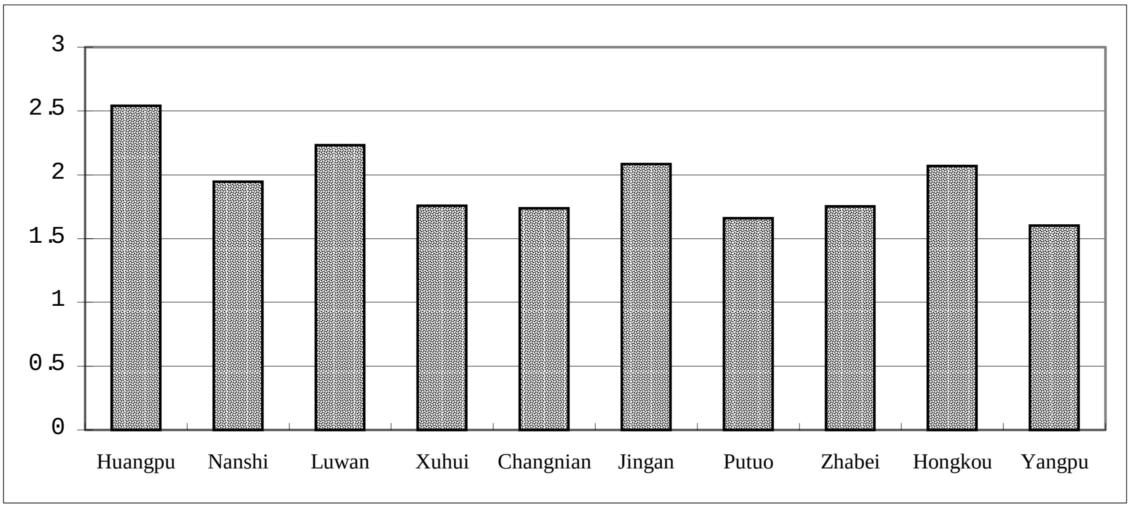

fig. 3

Fig. 3 Relative value of ULEDRI of ten districts of Shanghai

Firstly, as shown in Fig. 3, the relative values of overall ULEDRI of the ten districts can be displayed in a bar chart that can easily be used to compare the risks of all districts. From it, it can be seen that the district with the highest risk is Huangpu, which is oldest part of Shanghai, the circumambient districts such as Xuhui, Changning, Yangpu have a relative low risk because their new buildings and sparse population density.

Secondly, For each district, the disaggregated ULEDRI can be presented as a pie chart though which the relative importance of the six contributing factors to overall ULEDRI can be revealed clearly. As shown in Fig. 4, the high risk of Huangpu is due primarily to the fact that Hauangpu have relative high hazard, poor vulnerability and the most important city function, although it has the best Emergence response capacity.

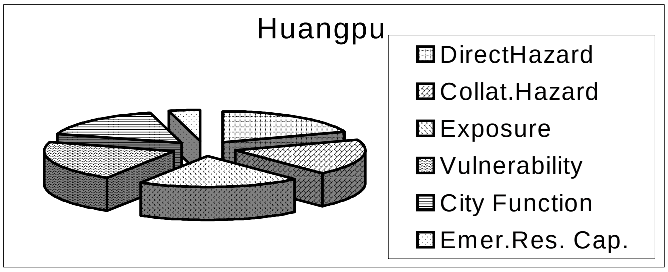

Fig. 4 Relative contributions of six factors to ULEDRI of Huangpu

Thirdly, For each contributing factor, the distribution of it within the whole city can be shown as Fig. 5. For example, It can be seen from it that for the direct hazard, the highest value is in Hongkou, the lowest in Nanshi. While for the risk caused by city function, the highest is in Huangpu, the lowest in Yangpu.

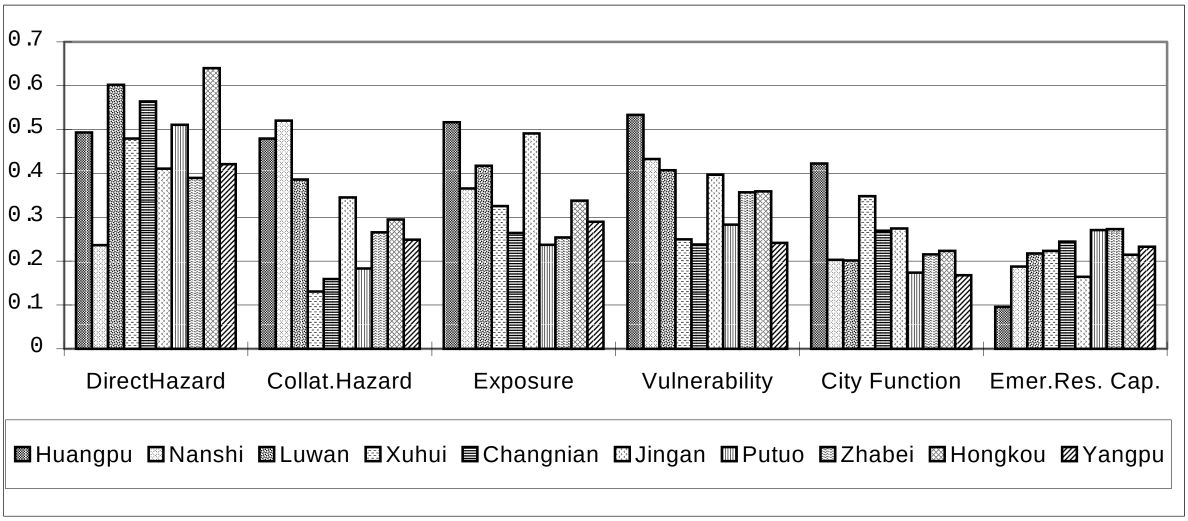

Fig. 5 Distributions of six factors in ten districts of Shanghai

Finally, as shown Fig. 6, all the information of ULEDRI exhibited above can also be integrated in only one graph called ULEDRI map, in which the size of each pie located at a given district represent the overall ULEDRI of that distract, and the slices inside of each pie chart describes relative contributions of six factors to its overall ULEDRI.

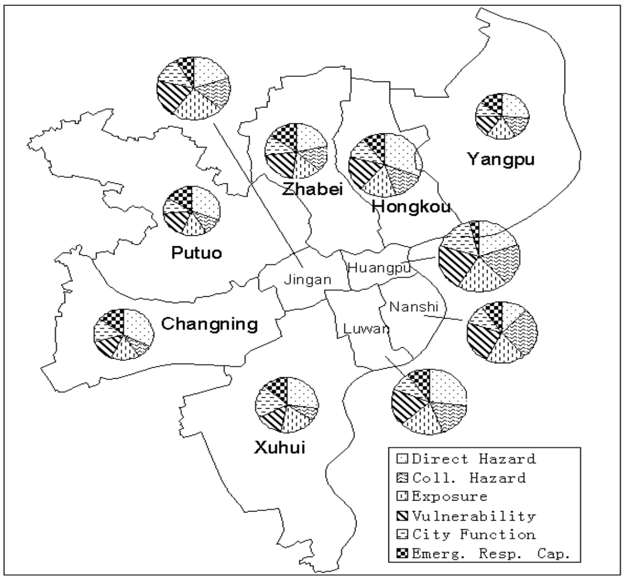

Fig. 6 ULEDRI map of Shanghai

DISCUSSIONS AND CONCLUSION

For the developing approach and usefulness of ULEDRI, there are several problems that worth discussing in detail.

In the first place, how big the study unit of ULEDRI, i.e. each local area, should be in developing a megacity's ULEDRI? This is a tough question. On the one hand, the study unit can not be too large. If the unit is too large, the benefits of constructing ULEDRI will lose because the differences of local characteristics exhibit only within limited area (e.g. within a district or less). If the study unit is a very large one, e.g. two or more districts, the data used by all indicators in ULEDRI will be the mean values of a large area. As a result, the distinctions of the city characteristics among all local areas can not exhibit in the results of ULEDRI, let alone its function of directing city planning and land use planning. On the other hand, the study unit can not too small. Although the fact that the smaller the study unit is, the more precisely ULEDRI will show the differences of disaster risk level among local areas, and the more helpfully it will direct city planning, some of the theoretical bases, on which the determination of factor and selection of indicators are depended on, have a common assumption, i.e. they must be used in a macroscopical circumstance. Furthermore, some indicators have statistic sense, and only suitable to the macroscopical situation. In addition, data gathering will become a very laborious task for smaller study unit.

Secondly, how to determine the weights of each factor and indicator in developing ULEDRI? In determining the weights, the following two constraints should be paid enough attention to: At first, for a given city, its particular settings should be took into account, and a set of weight suitable to one city can not apply to another one without changes. This is because each city has its own characteristics that have different influences on risk. For example, the ground condition of one city is very bad, and the liquefaction will take place in a very large extent. While the probability of liquefaction for another city is very little. At this case, the weights of liquefaction of these two cities should be different. Additionally, In determining the weight of a indictor, besides the contribution this indicator will take in disaster risk, the range of this kind of indictors among all local areas must also play a important role. For example, it is no doubt that ground shaking level should take a great contribution to ULEDRI, if the range of ground shaking level of all local areas is very little, however, it is reasonable that its weight should be decrease somewhat.

Thirdly, how to collect and process data? Developing such an index will need a great volume of data, and the data will involve many a sector. As a result, data gathering will be a painstaking work. What's more, the criteria and formats of all data vary from sector to sector, indicator to indicator, the pre-procession of data, therefore, also will be laborious. For instance, if the study unit of ULEDRI is selected as administrative district of the city, then, the data needed must also be collected as district-based. Some data such as liquefying areas and ground shaking units, however, do not use district as their basic unit. At this case, the original data should be pre-processed by all kind of approach (e.g. OVERLAY function of GIS) so that all data is in a consistent format.

In conclusion, the earthquake disaster risk faced by a megacity can not be understood completely and easily by traditional methodology. ULEDRI is a new approach that attempts to exhibit the risk from a different perspective. Not only the professional (e.g. disaster managers, engineers), but also the nonprofessional (e.g. city planners and insurance companies) can use such an index to achieve their joint objective, i.e. remove the earthquake disaster risk faced by a city.

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