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Resilience to natural hazards: a geographic perspective

Hongjian Zhou · Jing'ai Wang · Jinhong Wan · Huicong Jia

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Abstract Resilience is increasingly used as an approach for understanding the dynamics of natural disaster systems. This article presents the origin of resilience and provides an overview of its development to date, which draws on the wide literature on ecological science, social science, social–environmental system and natural hazards. From a geographic perspective, the model of disaster resilience of "Loss–Response" of Location (DRLRL) was created and disaster resilience was defined from three dimensional mode, which focused on the spatial, temporal scale of resilience and attributes of hazard-affected bodies. A geographic approach was put forward to measure the disaster resilience, including two properties of inherent resilience and adaptive resilience and a case study was implemented in order to validate this approach. This perspective would offer greater potential in application of resilience concept, especially in the process of integrated risk management and disaster recovery.

Keywords Resilience · Ecology · Society · Social–ecological system · Geographic perspective

1 Introduction

Natural hazards have the potential to become disasters in the absence of a proper mitigation system (Chadha et al. 2007). During the past several years, the world has witnessed some unprecedented natural disasters such as Asian Tsunami, Hurricane Katrina, and

H. Zhou (✉) · J. Wan
College of Geography and Remote Sensing Science, Beijing Normal University, No. 19, Xinjiekouwai Street, 100875 Haidian District, Beijing, China
e-mail: zhouhj_bnu@hotmail.com

J. Wang · H. Jia
Key Laboratory of Regional Geography, Beijing Normal University, 100875 Beijing, China

J. Wang
Key Laboratory of Environment Change and Natural Disaster, Ministry of Education of China, Beijing Normal University, 100875 Beijing, China

Earthquake Wenchuan China. Although some preventative measures have been taken, the reality is that future disasters cannot be prevented due to the likelihood that these events will involve unexpected forms, magnitudes, or locations. Thus, it is very important to enhance the capacity of a system to resist and recover from the disasters. Confronted with this situation, United Nations International Strategy for Disaster Reduction (UN/ISDR) put forward that "Building the Resilience of Nations and Communities to Disasters" as the Hyogo Framework for Action 2005–2015.

Resilience, broadly defined as the capacity to resist and recover from loss, is an essential concept in natural hazards research and is central to the development of disaster reduction at the local, national and international levels. Resilience is derived from the Latin word *resilio*, meaning "to jump back" (Klein et al. 2003). Originally developed as an ecological concept (Holling 1973), resilience was being applied to social systems (Adger 1997), and coupled human-environment systems (Carpenter et al. 2001; Folke 2006). The idea is to focus not merely on ecosystems per se or societies per se, but on the integrated social–ecological system (SES) (Berkes and Folke 1998; Berkes et al. 2003). It also has been adapted or re-invented for the case of short-term disasters (Tierney 1997; Bruneau et al. 2003; Rose 2004) and long-term phenomena, such as climate change (Timmerman 1981; Dovers and Handmer 1992). Despite these noteworthy efforts, we still lack a common conceptualization of resilience.

This article reviews the research on resilience in different study fields. It mainly focuses on three thematic areas: the confusion and contradiction on the meaning of the resilience; the spatial pattern of disaster resilience; and its temporal trend. A new conceptual model of disaster resilience of "Loss–Response" of Location (DRLRL), is then proposed, which clarifies many of the discrepancies found in the existing literatures. Examples of agricultural drought resilience at local scale and household-based approaches are provided throughout.

2 Divergent definitions and highly varied methodological approaches

Despite more than three decades' worth of collective research experience on the concept, resilience still means different things to people in different fields (Table 1). Many of the discrepancies in the meaning of resilience arise from different epistemological orientations and subsequent methodological practices. Fundamental conceptual differences exist, as well, visions that either focuses research on ecological systems, social systems or some combination of the two. The result is a confused lexicon of meanings and approaches to understanding resilience to external shock or natural hazards. At the very least, some form of clarification consistency in our use of resilience would be helpful if we are to advance our theoretical and practical understanding of how and what places and people are more resilient to hazards. At this juncture, one can find four distinct themes in resilience studies; resilience as a biophysical attribute, a social attribute, a social–ecological system (SES) attribute, and an attribute of specific areas.

2.1 Resilience as a biophysical attribute

The first research theme examines the resilience of biophysical or technological system. These studies are characterized by a focus on the key features of systems, such as (1) diversity, including biodiversity (Holling et al. 1995; Folke et al. 2004) and functional (response) diversity (Chapin et al. 1997; Elmqvist et al. 2003), which provide a system

Table 1 Diverse definitions of resilience

Holling (1973, 1986)	Resilience is defined as the amount of disturbance that can be sustained by a system before a change in system control or structure occurs. It could be measured by the magnitude of disturbance the system can tolerate and still persist
Timmerman (1981)	Resilience is the ability of human communities to withstand external shocks or perturbations to their infrastructure and to recover from such perturbations
Pimm (1984)	Resilience is the speed with which a system returns to its original state following a perturbation
Pimm (1984); Holling et al. (1995); Gunderson et al. (1997)	Resilience of an ecological system relates to the functioning of the system, rather than the stability of its component populations, or even the ability to maintain a steady ecological state
Wildavsky (1991)	Resilience is the capacity to cope with unanticipated dangers after they have become manifest, learning to bounce back
Dovers and Handmer (1992)	Re-active and pro-active resilience of society can be distinguished based on the major difference between ecosystems and societies (human capacity for anticipation and learning)
Holling et al. (1995)	Resilience is the buffer capacity or the ability of a system to absorb perturbation, or the magnitude of disturbance that can be absorbed before a system changes its structure by changing the variables
Adger (1997, 2000)	Social resilience could be measured through proxies of institutional change and economic structure, property rights, access to resources, and demographic change
Horne and Orr (1998)	Resilience is a fundamental quality of individuals, groups and organizations, and systems as a whole to respond productively to significant change that disrupts the expected pattern of events without engaging in an extended period of regressive behavior
Mallak (1998)	Resilience is the ability of an individual or organization to expeditiously design and implement positive adaptive behaviors matched to the immediate situation, while enduring minimal stress
Miletti (1999)	Local resiliency with regard to disasters means that a locale is able to withstand an extreme natural event without suffering devastating losses, damage, diminished productivity, or quality of life without a large amount of assistance from outside the community
Comfort (1999)	The capacity to adapt existing resources and skills to new systems and operating conditions
Miletti (1999); Geis (2000); Chen et al. (2008)	In the context of disaster management, resilience is used to describe the ability to resist or adapt to stress from hazards, and the ability to recover quickly
Adger (2000); Kimhi and Shamai (2004)	Social resilience is understood as having three properties: resistance, recovery and creativity, in which (1) resistance relates to a social entity's efforts to withstand a disturbance and its consequences, and can be understood in terms of the degree of disruption that can be accommodated without social entity undergoing long-term change; (2) Recovery relates to an entity's ability to pull through the disturbance, and can be understood in terms of the time taken for an entity to recover from a disruption. (3) Creativity is represented by a gain in resilience achieved as part of the recovery process, and it can be attained by adapting to new circumstances and learning from the disturbance experience
Carpenter et al. (2001)	The Resilience Alliance consistently refers to social-ecological systems (SES) and defines their resilience by considering three distinct dimensions: (1) the amount of disturbance a system can absorb and still remain within the same state or domain of attraction; (2) the degree to which the system is capable of self-organization; (3) the degree to which the system can build and increase the capacity for learning and adaptation

Table 1 continued

Paton et al. (2000)	Resilience describes an active process of self-righting, learned resourcefulness and growth—the ability to function psychologically at a level far greater than expected given the individual's capabilities and previous experiences
Carpenter et al. (2001)	Ecosystem resilience is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes. A resilient ecosystem can withstand shocks and rebuild itself when necessary. Resilience in social systems has the added capacity of humans to anticipate and plan for the future
UN/ISDR (2002)	The capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase this capacity for learning from past disasters for better future protection and to improve risk reduction measures
Bruneau et al. (2003)	An analysis of seismic resilience and apply the concept at four levels: (1) technical, physical systems perform when subjected to earthquake forces; (2) organizational, the ability to respond to emergencies and carry out critical functions; (3) social, the capacity to reduce the negative social consequences of loss of critical services; and (4) economic, the capacity to reduce both direct and indirect economic losses
	Resilience has four dimensions: (1) robustness, strength to withstand a given level of stress without loss of function; (2) redundancy, the extent to which elements, systems that are substitutable; and (3) resourcefulness, the capacity to identify problems, establish priorities, and mobilize resources; (4) rapidity, the capacity to meet priorities and achieve goals in a timely manner
	A resilient system has: (1) reduced probability of failures; (2) reduced consequences from failures; and (3) reduced time to recovery
Kendra and Wachtendorf (2003)	The ability to respond to singular or unique events
Cardona (2003)	The capacity of the damaged ecosystem or community to absorb negative impacts and recover from these
Pelling (2003)	The ability of an actor to cope with or adapt to hazard stress
Rockström (2003)	Strategies of social resilience building include manageable strategies, such as institutional development, land reform, land tenure, diversification, marketing, human capacity building, and unmanageable ones, such as relief food, cereal banks, social networks, virtual water imports
Rose (2004, 2007)	Resilience includes inherent resilience (ability under normal circumstances) and adaptive resilience (ability in crisis situations due to ingenuity or extra effort)
Aguirre (2006)	A resilient social entity absorbs, responds and recovers from the shock; and improvises and innovates in response to disturbances
Maguire and Hagan (2007)	In broad terms, social resilience is the capacity of a social entity (e.g., a group or community) to bounce back or respond positively to adversity
Kang et al. (2007)	Resilience is the ability of the system to recover once hazard has occurred and measure resilience by the duration of an unsatisfactory condition

with wide latitude of response to a variety of perturbations; (2) dynamics and creativity, educed from the theory of adaptive cycle (Holling 2001), make the systems more resilient by passing through the following four characteristic phases: rapid growth and exploitation, conservation, collapse or release, and renewal or reorganization (Gunderson and Holling 2001).

2.2 Resilience as a social attribute

The second group of resilience studies focuses on describing the behavioral response of communities, institutions, and economies. Resilience in social system can be examined by economic, demographic and institutional variables in both temporal and spatial fashions. Economic growth and the stability and distribution of income among populations are key factors of the economic aspects of resilience (Adger 2000). Mobility and migration are a further set of important indicators of resilience (Ruitenbeek 1996; Adger 2000). Social capital (including trust and social networks) (Enemark 2006) and social memory (including experience for dealing with change) (Olick and Robbins 1998) are essential for the capacity of systems to adapt to and shape change.

The relationships between diversity on economy (Adger 1997) and institutional rules (Ostrom 2005) and resilience were dealt with more attention. According to the research of Adger (1997), coastal economies are more diverse and have multiple niches, making them inherently more resilient than inland economies. Dependency is another notion related to the social resilience, stemming from a rural sociological perspective on communities and their interaction with risky resources (Peluso et al. 1994). Communities or individuals depending on a single resource are less resilient than ones who own many resources (Freudenburg 1992).

2.3 Resilience as a social–ecological attribute

The third group of resilience studies focuses on the resilience of social–ecological systems (SESs). Four critical factors seem to be important in building resilience in SES (Folke et al. 2003). (1) Learning to live with the change and uncertainty requires building a memory of past events, abandoning the notion of stability, expecting the unexpected, and increasing the capability to learn from crisis; (2) nurturing diversity in its various forms increases the options for coping with shocks and stresses; (3) combining different types of knowledge for learning is a particularly effective strategy for bridging scales to stimulate learning and innovation (Cash and Moser 2000); and (4) creating opportunity for self-organization and cross-scale linkages has several merit discussion: (a) strengthening community-based management (Berkes and Folke 1998), which is key to effective response and adaptation (Tompkins and Adger 2004); (b) building cross-scale management capabilities (Cash and Moser 2000; Folke et al. 2005); (c) strengthening institutional memory (Folke et al. 2005); and (d) nurturing learning organizations and adaptive co-management (Olsson et al. 2004).

2.4 Resilience as an attribute of specific area

The fourth direction is emerging that combines elements of the three but it is inherently more geographically centered. In this perspective, resilience is conceived as a biophysical, social or social–ecological attribute, but within a specific area or geographic domain. For example, local resiliency with regard to disasters means that a locale is able to withstand an extreme natural event without suffering devastating losses, damage, diminished productivity, or quality of life without a large amount of assistance from outside the community (Miletti 1999). Cutter et al. (2008) developed a disaster resilience of place (DROP) model to present the relationship between vulnerability and resilience and can be readily applied to address real problems in real places.

2.5 The relationship between resilience and vulnerability

Resilience and vulnerability are two key concepts of natural hazards studies (Klein et al. 2003), and they have gained currency in disaster work. A key question that emerges, however, concerns the relationship between them. Is resilience the opposite of vulnerability? Is resilience a factor of vulnerability? Or is it the other way around? It is not easy to provide single answers to these questions. Addressing this relationship is important in defining the meaning, implications and applications of resilience.

Vulnerability refers to the potential for loss (Cutter 1996) and more specific definitions qualify the potential for loss by factoring in the likelihood of exposures and susceptibility to damage. Etkin et al. (2004) defines vulnerability as the propensity to suffer some degree of loss from a hazardous event, whereas Turner et al. (2003) defines it as the degree to which a system is likely to experience harm due to exposure to a hazard. And it is also thought of as a susceptibility to harm, a potential for a change or transformation (Gallopín 2006). However, diverse views regarding the precise meaning of vulnerability are also evident. Some of the differences are important for the task of identifying the relationships between vulnerability and resilience.

Figure 1 attempts to contrast the vulnerability and resilience. The emphasis of disaster resilience is in the process of enhancing the capacity to resist and recover from loss caused by extreme natural events within the shortest possible time with minimal or no outside assistance. It is a process, mainly focused on the stages of in- and post-disaster (when the loss occurs) and helps to enhance the abilities of the system to resist and recover and explore policy options for dealing with hazards. It can be improved dynamically through

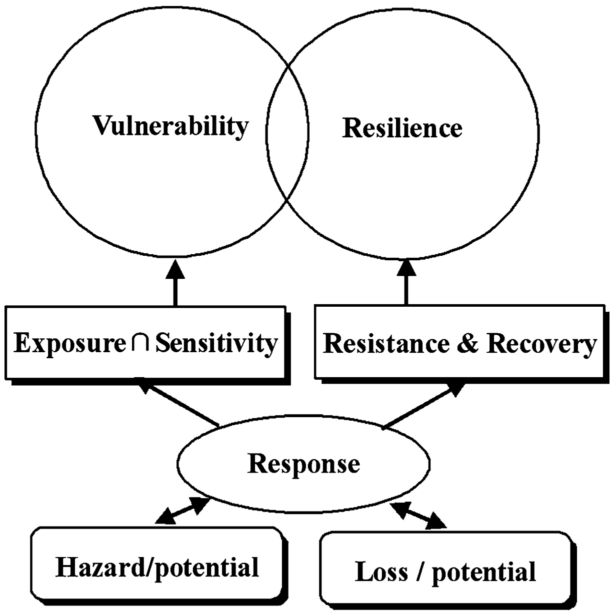

Fig. 1 The relationship between vulnerability and resilience

learning from experiences of several-time disasters and adaptation to the local geographic setting.

Vulnerability places stress on system's response to hazard or hazard potential, which determines the likelihood of loss from hazards. Exposure and sensitivity are two aspects of vulnerability and are variable with the change in structures and functions of systems suffered from hazards. But in general, the concept of vulnerability only focuses on the situation of system before disaster, and it is helpful for the preparedness for the future hazards. It is an inherent characteristic of system and it changes by moving from one place to another or reconstructed after disaster. For example, when a community moves into flooding-prone area, the vulnerability of community will become high; in contrast, when most population moves out this area, the vulnerability will become low, in which the extent of exposure to hazard plays an important role. Alteration to the types of drought-resistant crop in rainfed area will reduce vulnerability, in which the change in sensitivity of farmland is a key reason.

3 Disaster resilience from a geographic perspective

Natural disaster system consists of hazard-formative environments, hazards and hazard-affected bodies (HABs) on the earth surface (Shi 1991). It is essentially geographic in nature (Cutter 1993; Hewitt 1997). Disaster resilience is important for understanding uncertainty and reducing losses from natural hazards. It is a kind of resilience that conceptualizes the resilience of HABs to natural hazards. Due to the various types of hazards and different characteristics of HABs, it is difficult to get a general knowledge of disaster resilience in different geographic domains and temporal stages of disaster. But, there is a pressing need for measuring the disaster resilience objectively and repeatedly and enhancing the resilience in disaster-prone areas of the whole world.

Disaster resilience analysis requires assimilation of physical and socio-economic information from many sites each with a unique geographic location (Shahid and Behrawan 2008). While, at present three difficulties confront researchers in disaster resilience arena: (1) at the conceptual level, disaster resilience has not have a explicit definition from a geographic perspective; (2) at the operational level, it may be difficult to model the resilience of individual, group, and community behavior in a single framework; and (3) at the applied level, it is especially difficult to transfer the resiliency at different spatial scales. In this section, the authors query this consensus view from a geographic perspective by asking the following questions: (1) what is the disaster resilience? (2) What regions and localities are more resilient to disaster? (3) What's the temporal trend of resilience?

3.1 What is the disaster resilience?

In struggling with these issues for many years, it became necessary to clarify our thinking and understanding of disaster resilience from a geographic perspective. With a category of hazards that arose from the interaction between nature, society and technology, it was clear that many of the existing theoretical constructs were either too limiting or too diffuse to be of practical use to enhance the resilience of HABs in a specific geographic domain. In this study, we returned to be original work of Hewitt and Burton (1971) on the hazardousness of places where they attempted a multi-hazard mapping exercise to delineate a regional ecology of natural hazards events, of Cutter (1996) on the hazards of place model of vulnerability that stated the various elements interact to produce the vulnerability of specific places and the people who live there, and of Hewitt (1997) on the regions of risk expatiated that people's relations to the climate, waters, bedrock, soils, topography, wild plants and animals attached to particular places are an integral part of their security and the dangers they face, and of Cutter et al. (2008) on the disaster resilience of place model of interaction between disaster impact and absorptive capacity. Borrowing from them, the model of disaster resilience of "Loss–Response" of Location (DRLRL) was proposed in this study.

Disaster resilience can be defined as the capacity of hazard-affected bodies (HABs) to resist loss during disaster and to regenerate and reorganize after disaster in a specific area in a given period. It can be conceived as both the loss potential and the biophysical/social response, just as shown in the DRLRL model (Fig. 2).

The model of resilience in Fig. 2 is simple, but serves as useful heuristic in understanding the diverse elements that contribute to our understanding of the model of DRLRL. There is an explicit focus on locality in this conceptual framework, for it is in place that forms the fundamental unit of analysis for any disaster. Risk is the probability of harmful consequence (loss), and risks combine with resistance/relief (efforts to reduce losses such as emergency response during disaster and recovery measurements after disaster) to create an overall loss potential. Losses can be attenuated with timely resistance/relief or they can be amplified by a poor resistance/relief. On the one hand, loss potential is filtered through the social fabric (e.g., ability to respond) to determine the overall social resilience of the

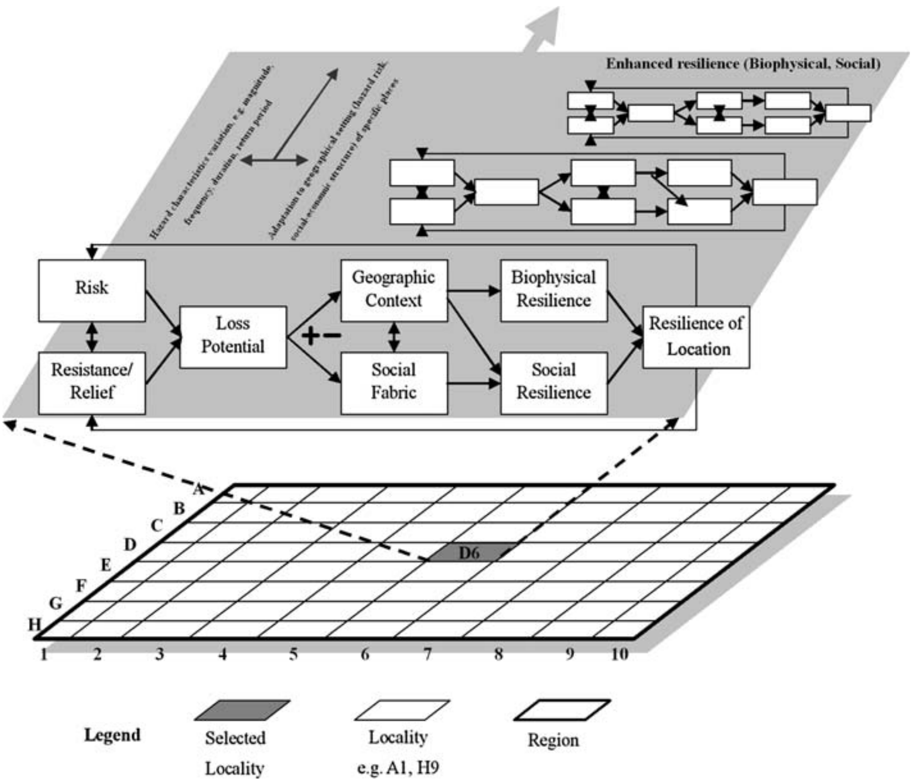

Fig. 2 The model of disaster resilience of "Loss-Response" of location (DRLRL)

locality. On the other hand, it is filtered through its geographic context (geographic setting) to determine biophysical resilience. It is the intersection and interaction of both social resilience and biophysical resilience that create the resilience of location. The resilience of location provides a feedback loop to both risk and resistance/relief, which in turn further reduces or enhances both risk and resistance/relief. Adaptation to geographical setting (hazard risk, social–economic structure, local culture) will enhance the resilience of location, although the characteristics of hazard (e.g., frequency, intensity, duration, return period, area covered, etc.) varied all along.

3.2 What regions and localities are more resilient?

The definition and model of DRLRL include three dimensions (Fig. 3): (1) Time, it can be divided into three periods: before (pre-), during (in-) and after (post-) disaster. It also can be divided into several periods according to the number of disaster, and the post-disaster period in one disaster is the pre-disaster one in the next disaster. (2) Space, it can be divided into several spatial scales according to the scope of disaster-influenced area: community, town, county, province, and country. At each scale, resilience is different due to the various attributes of the HABs. (3) Attribute, it indicates the content of the HABs, consisting of economic, institutional, social, and environmental characteristics in different localities.

Which locality is more resilient to the disaster is the theme focused on the spatial pattern of disaster resilience. It can help to deeply understand what makes some localities more resilient and how resilience can be enhanced within these areas. According to the complex adaptive systems thinking (Holling 2004), complex systems phenomena, such as natural

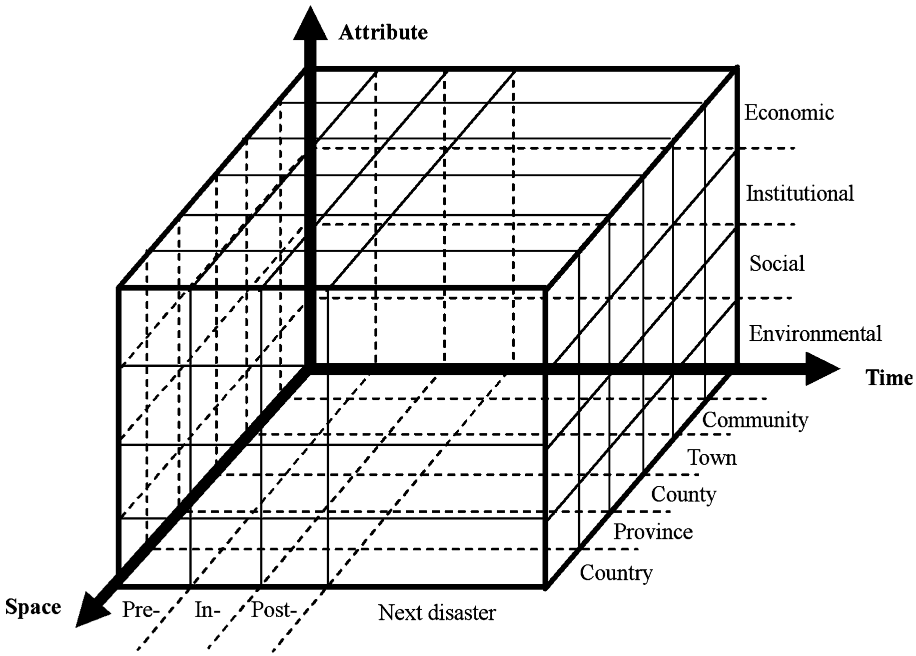

Fig. 3 Three dimensions of DRLRL model

disasters, occur at multiple spatial scales, with feedbacks across scale. Thus, no single level is the ''correct'' one for analysis. Natural disasters cannot be understood at the global level alone, just as it cannot be understood at the local level alone. Community-based monitoring and indigenous observations are also significant, because they fill in the gaps of global science and provide insights regarding local impacts and adaptations (Berkes 2002).

What regions and localities are more resilient depends on the attributes of locality, in which the environmental attribute and the hazards determine the degree of disaster loss, while the social, economic, and institutional attributes of locality determine the capacity of response to loss or loss potential from extreme hazards. In general, the regions and localities that have low losses and strong response capacity are more resilient than those have high losses and weak response. The capacity of response has a more important role in the construction of more resilient regions and localities, which is often enhanced by learning and reorganizing strategies to respond to the experience of loss over time.

3.3 What's the temporal trend of resilience?

Time was identified as an important factor when considering resilience, because resilience can fluctuate over time due to the changing characteristics of HABs (Kulig and Hanson 1996), and effective resilience management required a clear understanding of the temporal stages of change.

Figure 4 shows the temporal stage of disaster resilience. In different stages of disaster, the disaster resilience expressed different attributes. (1) The inherent resilience (IR) [the ability of HABs under normal circumstances (Rose 2004)] existed in the whole process of disaster, and it began to decrease when the HABs suffered from the hazards. With the breakage of structure and degradation of function of HAB, the inherent resilience kept declining until the hazard disappears (be over), although many active measures had been taken to resist the hazard during the stage. After disaster, with the structure repaired or reconstructed, the inherent resilience began to increase. The situation of inherent resilience

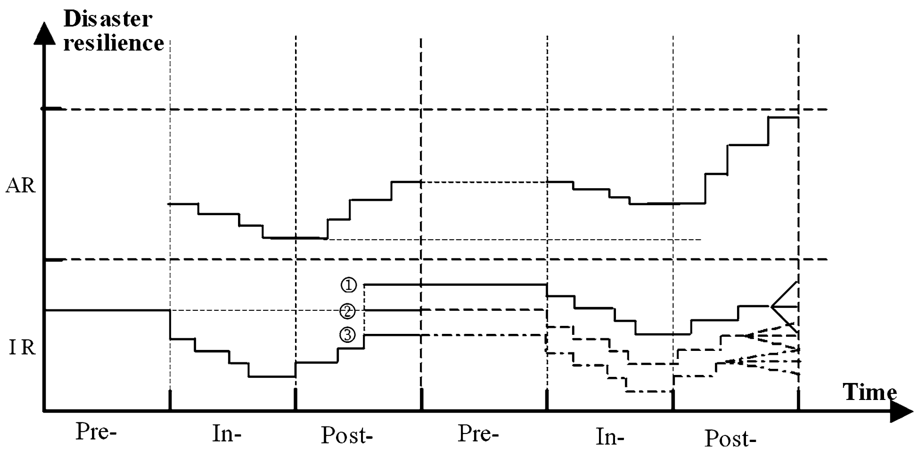

Fig. 4 The temporal stages of disaster resilience. The stage is divided into three sub-stages: pre-disaster, in-disaster and post-disaster. Disaster resilience consists of two parts: inherent resilience (*IR*), which represents the capacity of HABs under normal circumstances, depends on the structures and functions of HAB; and adaptive resilience (*AR*), represents the capacity of HABs under crisis circumstances due to ingenuity or extra effort

in post-disaster depended on the effective measures taken to recover or renew the functions; and there were three consequences of the inherent resilience: (a) the higher resilience was obtained through taking many effective measures in time; (b) the same resilience was attained through taking limited effective measures in time; and (c) the lower resilience was due to limited effective measures taken long time after the disaster. In the next disaster, the inherent resilience will fluctuate with the change of structure and function of HABs just like the previous trend, but the extent of fluctuation was different due to the intensity and duration of the hazard. (2) Adaptive resilience (AR) [the ability of HABs to adapt behavior and exercise creativity under crisis circumstances (Rose 2004)] can be measured only in stages of in- and post-disaster. It also fluctuated with the process of disaster. When the HAB suffered from the same disaster again, the decline extent of the adaptive resilience will become small and the increase extent will become large due to the enhanced capacity of the system to resist and recover from loss by learning and training or extra efforts. Adaptive resilience is not a permanent shift in a system's capacity but rather can be lost over time.

4 Case study: agricultural drought resilience in Xinghe county of northern China

Quantitative or qualitative assessment helps in understanding how various factors contribute to disaster resilience and why some localities in a region are more resilient than others. In this section, taking agricultural drought in Xinghe county of northern China as a case study, we explore spatial pattern and temporal trend of disaster resilience at community scale through the analysis of income diversification.

4.1 The study area

The Xinghe county, with an area of more than 3,518 km^2, is located on the divide between the monsoon and the non-monsoon zones in northern China, which makes the area very sensitive to climate variation (Fig. 5). In the middle of July, the summer monsoon usually

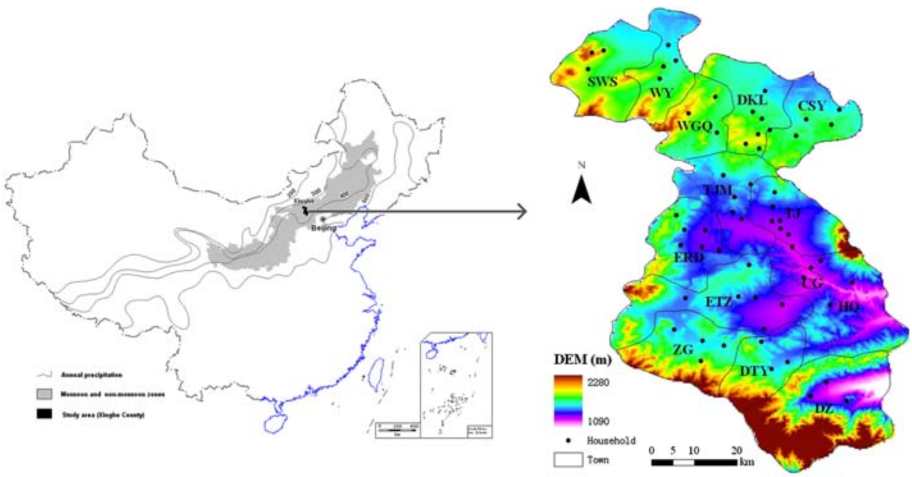

Fig. 5 The location of Xinghe county and the spatial distribution of 60 interviewed households in 13 towns

travels toward northern China and starts its retreat in the middle of August. It is during this period that the region receives most of the annual precipitation (Ding 1994). The annual precipitation is about 397 mm, while the annual evaporation is above 2,037 mm. Xinghe County is a typical drought-prone area, especially in the spring when most crops are cultivated and grown.

Liu et al. (2003) compiled a land-use map for the whole of China at a resolution of 1 km^2 using topographic maps and census data that depict the situation in 2000. The map shows that in 2000 26.5% of the land in Xinghe county was used for dry farming land, 32.2% for cattle herding, 33.1% for forestland, and only 4.6% for irrigated farming land. Xinghe is a typical farming-pastoral zone of northern China. The income of household is either from agricultural product or from livestock is based on the weather condition and household's location. If the household is located in the plain and has large area of farming land, especially irrigated land, the crop yield is higher than those located in the mountain. Also, the income from agricultural product is higher. In Xinghe county, TJ, CG, ERD, ETZ, HQ, and TJM are six main areas with high agricultural crop yield, while other seven towns have low crop yield but higher income from livestock.

4.2 Method for analysis of resilience

The data used to calculate the resilience of different household are from the in-depth interview in 13 towns of Xinghe county in October 2006 and April 2007. Sixty households in 13 towns were interviewed, in which 21 households in 5 towns were located in highland area in northern part of Xinghe, 18 in 3 towns located in plain area in central part, and 21 ones in 5 towns located in mountain area in southern part (Fig. 5). The questions asked in the interview can be divided into three categories: (1) the income source and the percentage of each source in the total income, (2) the measures taken to recover from the drought loss, especially the crop yield loss and economic loss, and (3) the crop planting structure, including winter wheat, corn, soybean, potato, and other crops.

The households were selected according to the following three principles: (1) representative principle ensures that the interviewees cover all different types of households, which was based on the pre-interview with the governors in all 13 towns; (2) physiognomy-based principle ensures that the households can be interviewed that located in the plain, highland, and mountain areas; (3) equation-based principle tries to interview the same number of households in each town, and in this study, 4.6 households were interviewed in each town on average. The interviewed households covered different types, different geographic areas, and they can be considered as the epitome of the town.

Diversification is the universal strategy aimed at reducing risks and increasing options in the face of hazards (Turner et al. 2003); and local economic diversification has been identified as an important policy objective for building resilience (Ullsten et al. 2004). Based on the results of Ellis (1998); Guvele (2001); Slater (2002); Elmqvist et al. (2003) and Niehof (2004) researches on the relationship between income diversity and livelihood condition, in which income diversification can reduce the vulnerability before loss occurs and provide more opportunities to recover from drought losses in- and post- disaster, two indicators were developed using the data extracted from interviews, (1) diversity index of income (DII) and (2) dependence index on agricultural income (DEI). They are calculated through the following formulas:

$$\mathrm{DII} = -\sum_{i=1}^{n} P_i \ln(P_i) \tag{1}$$

$$\mathrm{DEI} = \sum_{i=1}^{n} \left[\frac{N_i(N_i - 1)}{N(N - 1)}\right] \tag{2}$$

In Eq. 1, n denotes the number of income source; P_i, the probability of 1 Yuan/RMB (extracted from the total income) belonging to the source i.

In Eq. 2, n denotes the the number of income source; N, the total income; N_i, the total income from source i and $N_1 + N_2 + N_3 + \cdots + N_n = N$; N_i/N, the probability of 1 Yuan/RMB (extracted from the total income) belonging to the source i; $(N_i - 1)/(N - 1)$: the probability of 1 Yuan (extracted from total income exclude 1 Yuan extracted before) belonging to the source i.

The value of diversity index and dependence index in each town was the average value of all interviewed households, and Sadahiro (2000) had estimated the accuracy of count data based on the point-in-polygon method.

4.3 Spatial pattern of resilience at the town scale

The results (Fig. 6) showed that there was highest income diversification in central part of Xinghe county, with the diversity index value of 0.944, high income diversification in southern part, with the value of 0.826, low value with 0.606 in the northern part. The average number of income source for households was 2.3 in highland area, 3.2 in plain area, and 3.0 in mountain area, respectively. It indicated that the total income of households in central and southern part were more stable than those in northern part and have more opportunities to compensate the agricultural loss from non-agricultural income to

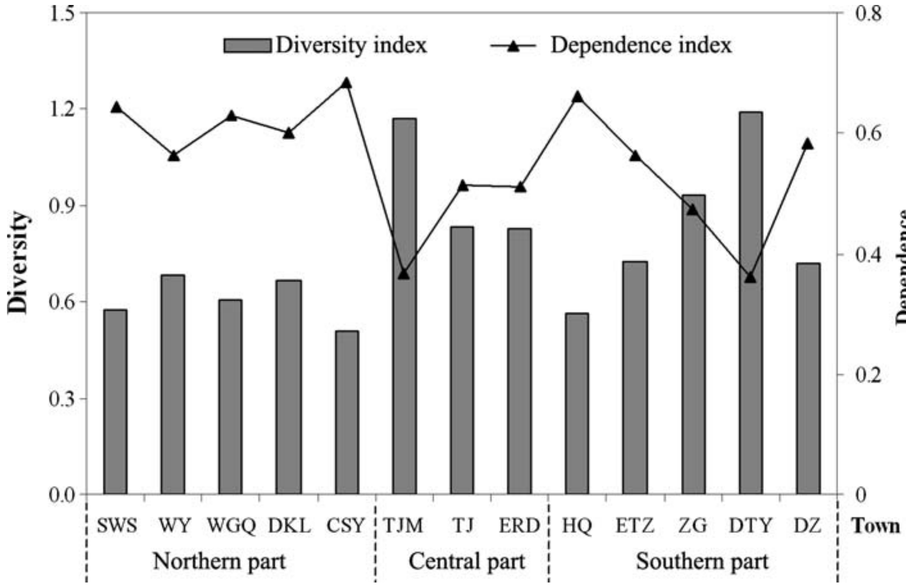

Fig. 6 Spatial distribution of the value of diversity index and dependence index among 13 towns in three parts (northern highland part, central plain part and southern mountain part) of Xinghe county

reorganize the agricultural activities. In another word, central and southern parts were more resilient than northern part.

The trend of value of dependence index showed an opposite direction to the diversity index (Fig. 6). The higher the value of diversity index, the lower the value of the dependence index, and the low diversity index and high agricultural income dependence index dually reduced the resilience through increasing the risk confronted with drought due to the high dependence on agricultural income and low probability of compensating loss from other incomes.

Combined with the model of resilience of location, location played an important role in the spatial differences among those towns (Fig. 7). Firstly, environmental attributes, such as climate and topography, were different due to the location, in which they determined the agricultural types, transportation and communication conditions. Secondly, the agricultural types indicated different levels of exposure and loss to drought, such as in the northern part of Xinghe, large areas of rainfed field provided lower agricultural production and higher level of hazard of drought compared with irrigated field in the central part. It was difficult for towns in northern part to get the same agricultural income as other towns. According to the interview, in the central part above 10,000 Yuan (equivalent to 1,318 dollars) was obtained in 1 year only from agricultural products, such as benne, potato and some kinds of vegetable; while in the northern part, only 1,500 Yuan could be attained from agricultural products. The poor condition of transportation led to less information obtained from outside, and many opportunities were lost potentially. It was really harder for them to get the same opportunity to participate in other industries to improve the life standard. The direct consequence of this was the lower diversity of income and higher dependency on agricultural incomes. Thirdly, diversity and dependence index influenced the resilience, so the spatial difference of resilience existed due to the location. Reasonable measures, such as land-use structure adjustment can be put forward to enhance the resilience in different location and the towns in northern parts can learn from experiences of central and southern towns.

4.4 Temporal trend of drought resilience at the town scale

Taking resilience of Tuanjie (TJ) town as a case study, firstly ten households were selected based on the above three disciplines; annual income and its sources were collected from

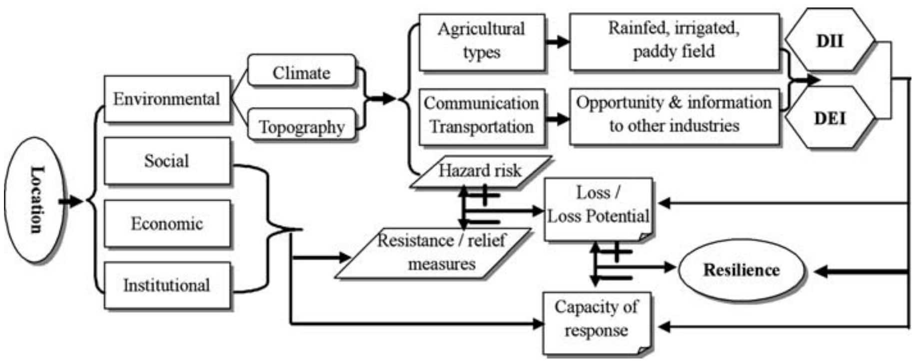

Fig. 7 The impact mechanism of location on agricultural drought resilience

yearly record (it was arranged by local government and paid them 150 Yuan y^{-1} for each household) during 1998–2005. Next, the average income diversity was calculated for ten households. Finally, the value of the town was calculated by averaging values of ten households.

The results (Fig. 8) showed that the percent of income from agricultural products fluctuated, which related with the annual rainfall variation. This mean that the agricultural production was very sensitive to the climate change, especially the rainfall; when drought occurred, the income from agricultural products decreased immediately. The income diversity index (DII) had a strong negative relationship with the rainfall from November to April in next year, especially from 1998 to 2003 [the value of correlation coefficient is −0.836, which is significant at the level of 0.01 ($N = 6$)]. That was, the household adjusted their strategies to participate in other industries to compensate the economic loss from drought. When the rainfall was enough, most of labors took part in the agricultural activities and then got the high income from agricultural products.

In this sense, the income diversity can be seen as one of the adaptive resilience of town in agricultural drought, and it can be enhanced from the experiences and lessons of frequent drought. After several times of drought, the resilience of town became stronger and had less dependence on the rainfall, which can be proved from the case study during 2004–2005 (Fig. 8).

In order to prove the enhanced resilience during 2004–2005 due to adaptive strategies, the precipitation and evaporation especially from November to April in next year (determining the water for crops cultivated and grown in spring) during 1981–2005 and the crop planting structure in TJ obtained from the household interview were calculated (Fig. 9). It shows that (1) the precipitation reached its lowest point in 1998, while the evaporation reached its highest value; and the total water supplying for crops cultivated and grown in spring in 1999 also reached its lowest value; it was significantly different from prior shock; (2) there was a significant trend in the percentage of cropped area of winter wheat, corn, soybean, potato, and others in 1998 and 2005, out of which can be concluded that there were large changes in proportions of different crops grown. The percentage of crops demanding more water, such as winter wheat, decreased from 20% in 1998 to 1% in 2005; while the potato belonged to drought-resistant crop increased from 35% to 60% in the period of 1998–2005. This was the actual evidence of learning from the extreme drought in 1998 and took adaptive strategies to reduce the vulnerability and enhance the disaster resilience.

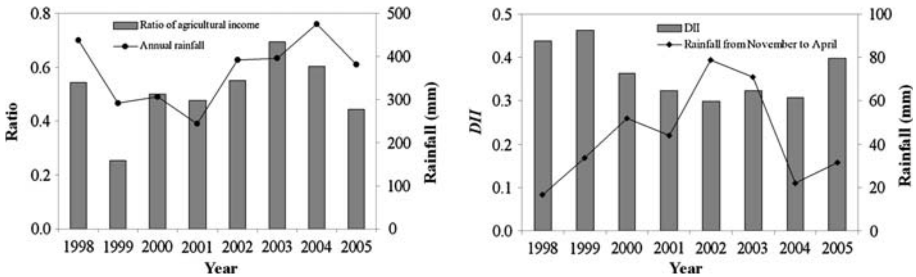

Fig. 8 The temporal change of income diversity index (DII) during 1998–2005 based on the 10 interviewed households in Xinghe county

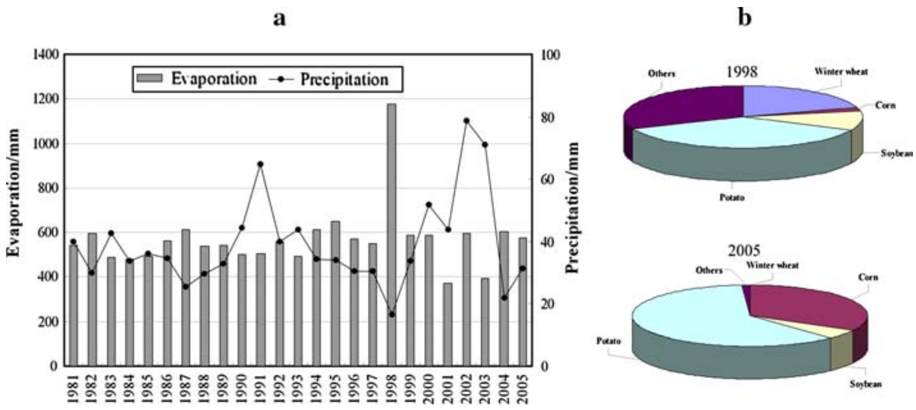

Fig. 9 The temporal change of (**a**) precipitation and evaporation from November to April during 1981–2005 and (**b**) area of the major crops (as a percentage of the total arable land) grown in TJ town in 1998 and 2005

5 Discussions

Defining and measuring disaster resilience are essential to enhance the resilience and reduce the losses from natural hazards. Many critical difficulties need to be resolved in the field of disaster resilience, such as (1) a comprehensive disaster resilience analysis framework for all types of natural hazards; and (2) a series of methods to transfer the disaster resilience at multi-spatial scales.

5.1 Obstacles for measuring disaster resilience

There are a number of obstacles that stand in the way of measuring disaster resilience. A large part of the obstacle for resilience measurement appears to be related to the complexity of HABs, including different kinds of components, the resilience at different stages and various spatial scales. Using the model of resilience of location, the complexity of HABs can be improved, because the components of HABs and spatial scale can be easily affirmed in an actual locality.

In an agricultural drought system, the HABs comprised crops, the daily life condition, and economic situation at the household scale. The content for measuring drought resilience mainly includes biophysical resilience (e.g., crops), and economic resilience. For the crop resilience, the magnitude of water resource and income diversity is the main factor that determine the extent of crop resilience before disaster. While, during the disaster the crop resilience is determined by the magnitude of available water resource and the money that can be used on the drought disaster resistance and recovery. After disaster, the crop resilience mainly focuses on the quantity and quality of seeds of crops. For the economic resilience, income diversity and percent of income from agricultural products, the opportunities for participating in other industries, the percent of income from other industries, and income from insurance are the dominant factors for the stage of pre-, in- and post-disaster, respectively. At the community scale, the contents of drought resilience measurement are different, and the factors also change correspondingly with the contents of resilience at various stages of disaster. At the local, regional and national scale, the drought resilience also is distinct with each other and it is a very complicated and versatile system due to the 3-dimensional mode of resilience.

5.2 Transformation of disaster resilience among multi-scales

There is an increasing need to building disaster resilience at different spatial scales, in which they have significant roles for local, regional, or national policy-makers. For example, building drought resilience at household scale can give a reference for households to arrange their agricultural activities, such as growing several kinds of crops, engaging in fishery or stock raising, to increase the income diversity. While building local drought resilience can help local government to make reasonable policy to improve their capacity to resist drought and recover from the loss of drought in shorter time, such as establishing more factories to increase the income of non-agricultural industry. But how to transfer the disaster resilience among different spatial scales is a difficult problem that requires more researches focused on in future.

In this study, taking drought resilience at household and town scale in Xinghe county as an example, economic resilience was measured by the income diversity index based on the statistics results of households interviewed. In each town, 4–6 households were selected under strict three principles and income diversity index was calculated for each household. Next, economic resilience of town was obtained through averaging all the households' income diversity index in a same town. But it is not the real economic resilience at town scale. In fact, at what extent that the income diversity of household influenced on the economic resilience at town scale was not determined definitely, or the income diversity of household really played an important role in the economic resilience at town scale was not known clearly because of the complex of the resilience measurement among multi-scales. It is a difficult proposition that has come under discussion only relatively recently, although the panarchy as a concept to express the cross-scale interplay among different adaptive-circle systems (Holling 1986, 2001; Gunderson and Holling 2001).

6 Conclusions

Resilience is widely being seen as a desirable property of hazard-affected bodies (HABs) in natural disaster systems, which has the equal role with the concept of vulnerability. This article presents the origin of the resilience perspective and provides an overview of its development to date, which draws on the wide literature on ecological science, social science, human-environment system and natural hazards. There is no agreeable concept of resilience due to various key points from different perspective. In this article, from a geographic perspective, we created a model of resilience of location, and defined the disaster resilience from 3-dimensional mode and paid more attention to the spatial, temporal scale of resilience, and the attributes of HABs.

Disaster resilience is essentially geographic in nature, as well as the hazards, disasters and risks (Cutter 1996). It can be explained by the interaction between the loss and biophysical, social response, in which if the response is well implemented and timely, the loss will be reduced and the resilience will be high. Disaster resilience includes two properties of inherent resilience and adaptive resilience. The former can be defined as the capacity of HAB in normal circumstances, which determined by the structure and functions of system. It will always persist before, during and after disaster, until the structure and functions were destroyed. The latter is the ability of HAB to resist and recover from loss in- and post- disaster. It related to existence of mechanisms for the evolution of novelty or learning (Gunderson 2000); thus it could be understood as dynamic resilience, and it can be enhanced by adjusting, adapting to hazards, and learning from the disasters according to the theory of the adaptive cycle (Holling 2001).

Which locality is more resilient and what is the temporal trend are important propositions in the way to measure the disaster resilience. Due to the complex of disaster systems, including the complex of HAB components, dynamic mechanism of specific resilience, and diversity of spatial scales, the model of resilience of location to study the disaster resilience can improve the complexity and the assessment of resilience can be achieved in an actual region. Next step is to assess the resilience of other types of hazard in various geographic setting, such as the flood-prone area in Dongting Lake of southern China, typhoon-prone area in Fujian Province of south-eastern China, earthquake-prone area in Sichuan-Tibet Belt in the western China, to establish the case studies database of all types of natural disasters in China. Finally, summarize a universal disaster resilience analysis framework.

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