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# Rethinking the relationships of vulnerability, resilience, and adaptation from a disaster risk perspective

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**Abstract** Vulnerability, resilience, and adaptation are three fundamentally inter-related concepts among such research communities as global environmental/climatic change, social–ecological and disaster risk science. However, their mutual relationships are still unclear so far particularly in the field of disaster risk reduction, which to some extent blocks the reasonable risk analysis and scientific decision making. This paper performed a brief overview on the basic definitions and evolution processes of vulnerability, resilience, and adaptation, and tentatively categorized past diverse thoughts of their relationships into three modalities, such as, vulnerability preference, resilience preference, and overlapped relationships. From a "hit-damage-recovery-learning cycle" insight and based on an empirical case study, we put forward two conceptual frameworks to address the relationships of vulnerability, resilience, and adaptation within the disaster risk domain, and we further discussed their broader implications in terms of disaster risk management and social–ecological sustainability. In an attempt to bring together the analytical frameworks of vulnerability, resilience, and adaptation, this study indicates that a sustainable adaptation strategy to the unavoidable disasters or changes should not only seek to reduce the

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vulnerability of a social–ecological system, but also to foster its resilience and adaptive capacity to future uncertainties and potential risks.

**Keywords** Disaster risk reduction · Vulnerability · Resilience · Adaptation · Social–ecological sustainability

## 1 Introduction

The concepts of vulnerability, resilience, and adaptation are originally inter-related and are widely applied in global change science, especially under the framework of International Human Dimensions Program on Global Environmental Change (IHDP). There are a great number of definitions and relationship discussions regarding them, particularly in the domains of global change science and social–ecological research (e.g., Holling 1973; O'Brien et al. 2004; Adger 2006). Some studies tried to explore the basic concepts of vulnerability, resilience, and adaptation within a social–ecological system (SES) (Folke 2006; Berkes 2007) and to discuss the relationship between adaptability and vulnerability (Smit and Wandel 2006). Others attempted to address the linkages among vulnerability, resilience, and adaptive capacity (Gallopin 2006; Vogel et al. 2007) from a global change perspective. Furthermore, there have been efforts to integrate the conceptual frameworks of vulnerability, resilience, and adaptation into sustainability science within a coupled human–environment system (Turner et al. 2003; Turner 2010; Miller et al. 2010; Endfield 2012). Over the past several decades, with climate change and its attendant disasters dramatically increased, more and more scholars adopted the concepts of vulnerability, resilience, and adaptation in their disaster risk researches (Wisner et al. 2004; Birkmann 2006; Cutter et al. 2008; Zhou et al. 2010).

Although the concepts of vulnerability, resilience, and adaptation have received extensive attention among various academic fields, their mutual relationships are still unclear so far. Many questions remain. For example, why the definitions and relationships of vulnerability, resilience, and adaptation have created such a wide range of discussions in recent academic arenas? In addition to continuous concerns over them in global change science and social–ecological domain, what are the relationships of vulnerability, resilience, and adaptation in the domain of disaster risk science? And how their relationships are different from those in other fields?

Regardless the chosen focus of any specific research be that vulnerability or resilience or adaptation, this paper argues that the common goal of these research is to reduce the risk of SESs that confronted with the external stress or uncertain threat, so that a sustainable development could be maintained. From a coupled human–environment system view, vulnerability, resilience, and adaptation are all integrated concepts to characterize and understand how the system respond to and cope with changes. They are all closely linked to the overall system property (e.g., structure and function) and processes, and inherently complex and inter-related to each other. Taking disaster risk management for example, a scientific risk analysis or a robust coping strategy should be based on comprehensive understandings on the internal relationships of vulnerability, resilience, and adaptation, and their linkages with disaster risk. However, a good deal of previous attention has been given to just one or two of those interdependent three elements in formulating coping strategies to disasters, which may have undermined the efficiency and effectiveness of disaster risk management.

In this study, we attempt to frame the relationships of vulnerability (V), resilience (Re) and adaptation (A) based on a case study in northern China, in order to facilitate more reasonable risk analysis and effective disaster risk management. Following a brief overview on the basic definitions of V, Re, and A, and their evolutions to date, the past diverse understandings on their relationships are summarized and categorized by considering various academic backgrounds. We then present an empirical case study of drought disaster management to highlight the intricate human–environment interactions through concepts of V, Re, and A. Finally, based on insights derived from the literature review and case analysis, we develop two conceptual frameworks to understand the relationships of V, Re, and A within the disaster risk domain, and we further discuss their broader implications with respect to disaster risk reduction and social–ecological sustainability.

## 2 Overview of the origins and evolutions of V, Re, and A

In past decades, when humankinds trying to manage the extreme events such as climate-induced disasters under a deep uncertainty, our attitudes to the irreversible changes and related disaster risks have been evolved from "prevention or control" to "mitigation and vulnerability reduction" (IPCC 1995, 2001, 2007), then gradually to "adaptation and transformation" (IPCC 2012; O'Brien 2012). The terms of V, Re, and A have been broadly employed in global change science, disaster risk management, social–ecological research, and so forth. However, given the diverse focuses of different research communities on V, Re, and A, it is always a great challenge to clarify their intricate relationships within a coupled human–environment system (or SES). In view of this challenge, it may be the first step to explore the origins and evolution processes of V, Re, and A among various academic backgrounds.

### 2.1 Vulnerability

Vulnerability derives from the Latin word vulnerare (to be wounded) and describes the potential to be harmed, which means the sensitivity to a perturbation or stress (Downing et al. 1997). The IPCC reports define vulnerability as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes (IPCC 2001, 2007). Beyond that, vulnerability has been conceptualized in many ways depending on various research traditions (Table 1), yet it is developed largely in those social sciences addressing environmental risks and hazards (Kasperson and Kasperson 2005).

In recent decades, the concept of vulnerability has been broadly employed in research on global environmental/climatic change, disaster risk reduction, and social–ecological systems (Table 1). In particular, with the popularity of the human dimensions of climate change research, the focus of vulnerability has been gradually transformed from concerning the fragility of environmental system (i.e., physical vulnerability) to attaching importance to investigate the vulnerability of human society (i.e., social vulnerability). For instance, from a natural hazard perspective, Cutter et al. (2003) emphasized the social vulnerability and presented three key tenets in vulnerability research: the exposure conditions that make people or places vulnerable to extreme natural events; the societal resistance or resilience to hazards (see also Kasperson and Kasperson 2001); and the integration of potential exposures and societal resilience with a specific focus on particular regions (see also Cutter and Finch 2008). It is becoming clear that vulnerability is an

**Table 1** Some definitions of vulnerability

| Author(s) | Definitions |
|---|---|
| Downing et al. (1997) | Vulnerability means an environmental sensitivity. There are a number of factors related to vulnerability such as demographic, economic, social and technical factors, and the economic dependences |
| Kasperson and Kasperson (2001, 2005) | Vulnerability is the flip side of resilience: when a social or ecological system loses resilience, it becomes vulnerable to change that previously could be absorbed |
| IPCC (2001, 2007) | Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes |
| Turner et al. (2003) | Vulnerability is the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor |
| Cutter et al. (2003) | Social vulnerability is a measure of both the sensitivity of a population to natural hazards and its ability to respond to and recover from the impacts of hazards |
| Wisner et al. (2004) | Vulnerability means the characteristics of a group or individual in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a hazard |
| Adger (2006) | The key parameters of vulnerability are the stress to which a system is exposed, its sensitivity, and its adaptive capacity |
| Birkmann (2006) | Social vulnerability refers to the inability of people, organizations, and societies to withstand adverse impacts from multiple stressors to which they are exposed |
| UNISDR (2009) | Vulnerability, the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard |
| Zhou et al. (2010) | 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 |
| Han (2011) | Vulnerability cannot be explained solely either by exposure or response capacity (including both short-term coping and long-term adaptive capacities), but are the result of interactive change of both, or the covariance between them |

unfavorable property of SESs, which unfolds in the interaction between human and nature, and it can be reduced by enhancing preparedness and promoting social learning.

## 2.2 Resilience

Resilience, widely used by ecologists as a core concept within ecosystem (Holling 1973; Carpenter et al. 2001), is actually derived from the Latin word *resilio*, meaning ''to jump back'' (Klein et al. 2003). Among social systems, resilience is determined by the capacity of reorganizing itself and the speed of recovery. From a natural disaster insight, resilience is an essential concept broadly defined as the capacity to resist and recover from disaster losses (Zhou et al. 2010). Table 2 updates the definitions summary of resilience by Zhou et al. (2010) with additional literatures up to 2012.

Compared with vulnerability, the concept of resilience gives us a more practicable approach to dealing with changes. It is a profound shift from traditionally attempting to control changes in systems to a more realistic viewpoint aimed at enhancing the capacity of

**Table 2** Some definitions of resilience to date

| Author(s) | Definitions |
|---|---|
| Holling (1973) | 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 |
| Holling (1996) | 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 |
| 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; (2) Recovery relates to an entity's ability to pull through the disturbance; (3) Creativity is represented by a gain in resilience achieved as part of the recovery process, and it can be attained by learning from the disturbance experience |
| Carpenter et al. (2001) and Resilience Alliance (2009) | 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; and (3) the degree to which the system can build and increase the capacity for learning and adaptation |
| Folke et al. (2002) | The capacity to buffer perturbations, self-organize, to learn and adapt. Resilient systems contain the experience and the diversity of options needed for renewal and redevelopment. Sustainable systems need to be resilient |
| Adger (2006) | Resilience refers to the magnitude of disturbance that can be absorbed before a system changes to a radically different state as well as the capacity to self-organize and the capacity for adaptation to emerging circumstances |
| UNISDR (2009) | The ability of a system, community, or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the restoration of its essential basic structures and functions |
| Walker et al. (2009) and Folke et al. (2010) | Resilience is the capacity of socio–ecological systems (SES) to continually change and adapt yet remain within critical thresholds. Adaptability is part of resilience |
| Zhou et al. (2010) | From a geographic perspective, 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. Resilience can be classified as inherent resilience (IR) and adaptive resilience (AR) |
| Han (2011) | A resilience thinking requires not only changing the focus from modifying hazard events to reducing vulnerability, but also essential to embrace and internalize variability and uncertainty in decision making |
| IPCC (2012) | Resilience is the ability of a system to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner |

SESs to adapt to uncertainty and surprise (Adger et al. 2005). Over the past several decades, the basic definitions and application scopes of resilience have been evolved from primarily concerning the structural balance of a system gradually to concerning system functions, including its abilities of self-organizing, learning, and adaptation (Table 2). Although a generally accepted definition of resilience is still absent by now, resilience has at least three meanings (Folke et al. 2002): (1) response to disturbance; (2) capacity to self-organize; and (3) capacity to learn and adapt. In many cases, building resilience can be considered analogous to reducing vulnerability (through decreasing exposure, reducing sensitivity, or increasing adaptive capacity) (Gallopin 2006). Moreover, resilience is often illustrated as the degree to which the system can build and increase the capacity for learning and adaptation (Resilience Alliance 2009). Therefore, it is of great significance to understand the connotation of resilience by considering its linkages with vulnerability and adaptation.

### 2.3 Adaptation

Adaptation, originally a biology or ecology term, is mainly adopted by biological and social–cultural researchers in the past. It means human behaviors deviate from their original state in response to a pressure or driving effect (Winterhalder 1980). Adaptation to environmental variability has been a focus of anthropologists since the early 1900s (Denevan 1983). Adaptation is generally perceived to include adjustments in SESs in response to actual or expected environmental changes and their impacts. With the development of climate change research, more and more attention has been paid to how to facilitate people's initiative to reduce the adverse impacts of climate on SESs; therefore, adaptation becomes an important branch of climate change science.

The diversified understandings on adaptation (Table 3) are excusable due to the certain requirements in different disciplinary fields. However, "*adjustments to change"* in a system, regardless of *short-term or long-term* mentioned in the listed definitions, is the key with respect to adaptation. One of the obvious differences among these definitions is: should all kinds of adjustments be defined as adaptation, or just a certain scope of them? In other words, which kind of adjustment could be identified as an adaptation? In general, adaptation means *the process, the action, or the ability* for an individual or a system to improve their inherent genetic or behavioral characteristics in order to better adapt to changes, and it is often accomplished through social learning. Adaptation includes *both moderating harm and exploiting beneficial opportunities* (Table 3), which consists of both minimizing the adverse effects and maximizing its potential opportunities in response to the untamable disturbance. The concept of adaptation highlights the notion of "instead of trying to control nature, society needs to learn to live more compatible with the natural occurrence of disasters" (White 1974), which means an idea transformation from trying to control changes to a more realistic perspective aimed at enhancing the adaptive capacity of SESs to future uncertainties.

## 3 Various framing on the relationships of V, Re, and A

This section summarizes some main understandings on the relationships of V, Re, and A and tentatively categorizes them into three kinds of modalities. The first modality is named as a "vulnerability preference," which is emphasized by both the climate change and disaster risk researchers. This preference tends to integrate the components of resilience

**Table 3** Some definitions of adaptation

| Author(s) | Definitions |
|---|---|
| Burton et al. (1978) | Adaptation refers to the process, measures, or structural change in order to reduce or offset the potential disasters associated with climate change, or the use of the opportunities brought about by climate change, which include reducing the vulnerability of social, regional, or activities on climate change and its variability |
| Stakhiv (1993) | The term adaptation means any adjustment, whether passive, reactive or anticipatory, that is proposed as a means for ameliorating the anticipated adverse consequences associated with climate change |
| Smith (1996) | Adaptation to climate change includes all adjustments in behavior or economic structure that reduce the vulnerability of society to changes in the climate system |
| Smit et al. (2000) | Adaptation refers to the adjustments of ecological–social–economic system for the actual or foreseeable climate stimulate their effects or impacts |
| Adger et al. (2003) | Adaptation to climate change is the adjustment of a system to moderate the impacts of climate change, to take advantages of new opportunities, or to cope with the consequences |
| Brooks (2003) and Young et al. (2005) | Adaptation means adjustments in a system's behavior and characteristics that enhance its ability to cope with external stresses. Adaptation will allow a system to reduce the risk associated with these hazards by reducing its social vulnerability |
| Walker et al. (2004, 2009) | Adaptability, a manifestation of adaptation, has been defined as "the capacity of actors in a system to influence resilience" |
| Adger (2006) | Adaptations include changes in the rules and governance of disaster risk, change in organizations, and promotion of self-mobilization in civil society and private corporations |
| UNISDR (2009) | The adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities |
| Folke et al. (2010) | Adaptability is part of resilience. It represents the capacity to adjust responses to changing external drivers and internal processes and thereby allow for development along the current trajectory |
| McLaughlin (2011) | Adaptation to climate is the process through which people reduce the adverse effects of climate on their health and well-being, and take advantage of the opportunities that their climatic environment provides. The term adaptation means any adjustment whether passive, reactive, or anticipatory |
| IPCC (2012) | In the context of climate change, adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities |

and adaptation into the framework of vulnerability. The second is called "resilience preference," which considers vulnerability and adaptation as parts of resilience. This branch has largely been adopted in social–ecological research by a famous academic community "*Resilience Alliance.*" The third modality named "overlapped relationships" believes that the connotation of V, Re, and A is overlapped rather than mutual contained. Current diversified understandings on their relationships indicate that any single concept of V, Re, or A should not be over emphasized separately from the others, but need to be understood based on an integral consideration of the three elements.

### 3.1 Vulnerability preference

Traditionally, vulnerability has been viewed as a function of three interactive components: exposure, sensitivity, and adaptive capacity (IPCC 2001). Recently, there is a viewpoint that takes vulnerability as the most basic and inclusive attribute of a SES encountered an external disturbance or hazard. This kind of standpoint believes that such concepts as exposure, sensitivity, resilience, and adaptation should be included into the analytical framework of vulnerability (Fig. 1) (Marshall et al. 2009). Gallopin (2006) summarized the major conceptual relations among the three concepts of vulnerability, resilience, and adaptive capacity, which integrates the components of resilience and adaptive capacity into a response capacity under a vulnerability framework (Fig. 2). In this context, adaptability should be incorporated into vulnerability (O'Brien et al. 2004), which affects a system's vulnerability through modulating exposure and sensitivity. Also, this kind of understanding suggests that reducing vulnerability to hazards is one of the fundamental approaches to disaster risk mitigation.

### 3.2 Resilience preference

"Resilience preference" defined here has been faithfully adhered by a famous academic group *Resilience Alliance*, which is a multidisciplinary international research consortium seeking to provide novel solutions to managing resilience and coping with changes, uncertainty, and surprise in complex SESs (see www.resalliance.org). Despite the resilience thinking mostly addresses the dynamics and development of complex SESs (Folke et al. 2010), it is also an important concept used in disaster risk domain. For example, ''Building the resilience of nations and communities to disasters'' was put forward by the UNISDR (*United Nations International Strategy for Disaster Reduction)* as a key initiative under the Hyogo Framework for Action 2005–2015 (UNISDR 2010).

Resilience can generally be defined as a response capacity to interferences or changes, which includes short-term coping capacity and long-term adaptive capacity (Folke et al. 2002; Walker et al. 2004). Resilience reflects the degree to which a complex adaptive system is capable of self-organization and the degree to which the system can build capacity for learning and adaptation (Adger et al. 2005). Vulnerability is the flip side of resilience: when a social or ecological system loses resilience, it becomes vulnerable to changes that previously could be absorbed (Kasperson and Kasperson 2001). A resilient system is the one that has developed capacities to help absorb future shocks and stresses so as to maintain its essential structures and functions. It is clear that the "resilience preference" tries to incorporate the principles of vulnerability and adaptation into a new analytical framework of resilience thinking. In this respect, enhancing resilience is the key to reducing the risk of a SES that confronted with external stresses or hazards.

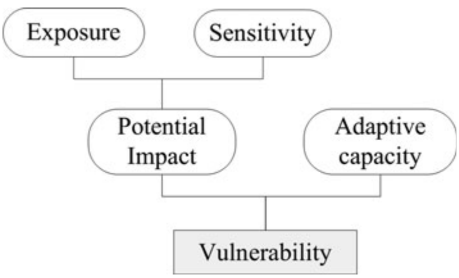


**Fig. 1** A framework describing the measurable components of vulnerability (from Marshall et al. 2009)

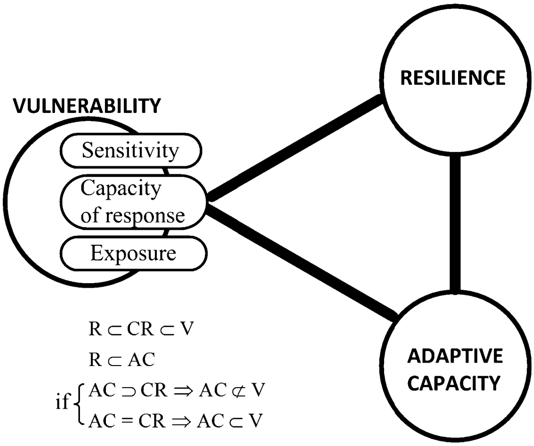


**Fig. 2** A diagram of the conceptual relations of vulnerability, resilience, and adaptive capacity (from Gallopin 2006)

### 3.3 Overlapped relationships

In many cases, the relationships of V, Re, and A are inter-overlapped rather than mutual contained. It is important to note that numerous vulnerability and resilience scholars have recognized the potential linkages between vulnerability and resilience frameworks (Young et al. 2005; Vogel et al. 2007; Miller et al. 2010). Vulnerability and resilience constitute different but overlapping research themes (Turner et al. 2003), and the separate concepts of vulnerability and resilience are uniquely linked through adaptive capacity (Engle 2011). In the field of disaster risk, the relationship between vulnerability and resilience can be illustrated as Fig. 3 (Zhou et al. 2010). Vulnerability focuses on the situation of a system before disaster, exposure, and sensitivity are two aspects of vulnerability, while resilience is a process, mainly focused on the stages of in- and post-disaster, which helps to enhance the abilities of the system to resist and recover from hazards. Smit and Wandel (2006) emphasized adaptive capacity at various scales, and the processes driving exposure, sensitivity, and adaptive capacity are frequently interdependent and inseparable in the different levels (Fig. 4). Adaptive capacity is scale-specific and place-specific, which varies from country to country, from community to community, among social groups and individuals, and over time. At the local scale, adaptive capacity can be interpreted as adaptation that has significant impacts on vulnerability.

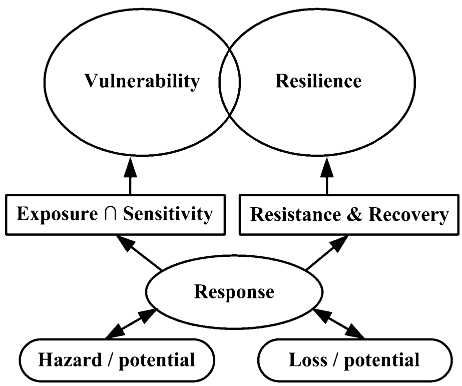


**Fig. 3** The relationship between vulnerability and resilience (from Zhou et al. 2010)

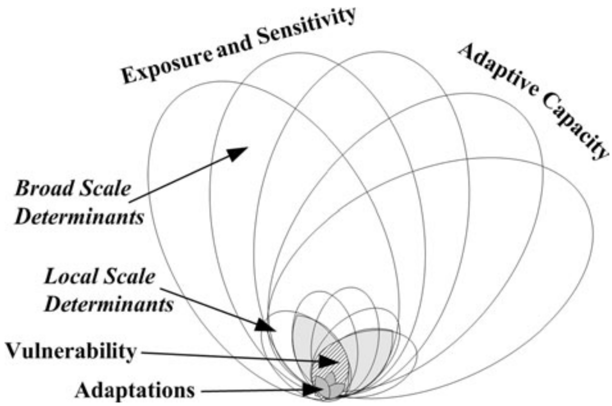


**Fig. 4** Nested hierarchy model of vulnerability (from Smit and Wandel 2006)

Although the relations of V, Re, and A are still ambiguous, one thing for sure is that any one concept of them should not be overstressed alone from the other attributes, but need to be understood based on a comprehensive consideration of the three. Meanwhile, it is becoming clear that no matter vulnerability, resilience or adaptation preferred research to reduce the risk of a SES that confronted with the uncertain threat should be one of their key tasks. It is therefore of great importance to clarify the relationships of V, Re, and A within the disaster risk domain.

## 4 A case study for understanding V, Re, and A in disaster risk domain

Based on a case study of drought disaster management at the local level, this section aims to facilitate better understandings on the relationships of V, Re, and A within the disaster risk domain.

### 4.1 The intractable problems of the historical agricultural droughts

From June to July in 2012, we carried out an in-depth field study in the village of Beidian, located in a typical drought-prone region in northern China. After a range of face-to-face interviews with local village managers and farmer households, some interesting phenomena regarding drought risk mitigation and adaptation were discovered.

Beidian Village traditionally adopted a farming mode of winter wheat–summer corn rotation in order to produce enough food for the villagers. However, with scarce annual rainfall and the uneven distribution of seasonal precipitation, local agricultural production relies heavily on ground water irrigation to meet the high water demand of crops such as winter wheat. If a year witnesses inadequate groundwater due to drought, local agricultural production is much likely to be affected by drought (with high vulnerability), leading to sizable yield reduction. In particular, during the continuous dry period of the late 1990s, drought-induced losses consistently threatened the regional grain security, which in turn damaged local farmers' livelihood.

To cope with the serious droughts, the government invested a lot to improve the local irrigation facilities, such as digging more wells and repairing drainage systems. However, wheat production with high water consumption still caused a sharp decline in groundwater level due to over-pumping. Conflicts among villagers were ongoing due to the intractable water allocation. Frequent droughts not only threatened regional food security, but also caused widespread poverty of village farmers.

With the purpose of alleviating drought-induced rural poverty, the local government provided huge disaster relief fund to this village, which had to some extent expedited recoveries (or short-time resilience) from drought disasters. The financial fund, however, was apparently inadequate to compensate the total drought-induced losses of the farmers. On the contrary, it had unwittingly encouraged some villagers to just wait for the external assistances instead of preparing for and responding to droughts, thus gradually increasing the vulnerability of local agriculture and undermining its long-term resilience to droughts.

### 4.2 Major changes in regional land use modes

Since 2001, the central government initiated a "Grain for Green" program (Zhou et al. 2009) to guide local farmers to adjust their land use patterns. Farmers set aside parts of certain types of farmlands to grow trees. In return, the government compensates the participants with grain allocations, cash payments, and the distribution of seedlings. Local farmers of Beidian Village thus began to tentatively make some adjustments in their planting practices, with the former wheat–corn farmland gradually replaced by apple trees. Until 2012, the previous wheat–corn planting mode was totally abandoned by the village farmers. Land use pattern in Beidian had been transformed from the past wheat–corn rotation to a new mode of apple trees as the main crop and corn and coarse cereals as the subsidiary crops, with 92 % of its farmland was planted with apple trees.

### 4.3 Effects/results of the changes

Interestingly, accompanied by significant changes in land use patterns, the impact of droughts on local agriculture has been dramatically alleviated. Despite a noticeable warming and drying trend over the past decade, the farmers clearly indicated that the impact of droughts on local agriculture in recent years is not as serious as it was a decade ago. And the irrigation system in this village has basically met the water demand for agricultural production. At the same time, local farmers' livelihood has experienced a significant improvement in recent years and the Beidian Village has become famous as a "wealthy model" in adjacent regions.

To explore the causes of the past droughts and their inner relationships with local cropping patterns, we additionally performed a quantitative analysis. We collected rainfall data from local meteorological station and a water demand dataset of wheat, corn, and apple trees from the National Agricultural Scientific Data Sharing Center (http://www.agridata.cn/). The computed results suggest that the temporal asynchronous rhythm between winter wheat growth and precipitation may have been responsible for past serious droughts in Beidian. In this region, over 60 percent of precipitation is concentrated in the period from July to September. The key water consumption stage of winter wheat, however, is from April to June.

In addition, the annual average rainfall of Beidian is only 503 mm, which apparently fails to meet the 775 mm water consumption of the wheat–corn rotation mode. In contrast, the water requirement rhythm of apple trees is much better matched to the seasonal distribution of local rainfall, and its total water demand is only 520 mm, which means that less than 20 percent of water demand of apple trees needs to be supplemented by irrigation, substantially easing pressure on groundwater. Thus, when facing the same drought intensity, the new planting mode was shown to have less vulnerability and greater adaptability to droughts due to its resilient land use structure. Further economic calculation shows that net income of apple trees per unit area is over six times than that of the wheat–corn production, contributing to substantial improvements in farmers' income and livelihood.

## 5 Two conceptual frameworks and their broader implications

### 5.1 Defining the concepts of V, Re, and A within the disaster risk system

Whether positive or negative, the three basic concepts of V, Re, and A have close linkages with disaster risk, and they can be properly addressed in the disaster risk domain (Fig. 5). Hazard is an essential trigger to any disaster or risk, while the degrees of disaster losses or potential risks are largely determined by the vulnerability and resilience of a system and also by what kinds of adaptation measures can be taken. Vulnerability is an inner attribute of a system that makes it susceptible to the damaging effects of a hazard. It indicates the structural and functional disadvantages that exposed to external stresses. Under certain hazard intensity, it is often the vulnerability that determines the probability of a disaster and its losses, so a system with higher vulnerability may amplify its disaster risk (Fig. 5). Resilience in disaster risk domain often expresses as the reactive responses to a specific disaster. It embodies the ability to resist, absorb, accommodate to, and recover from the effects of a hazard in a timely and efficient manner (Berkes et al. 2003; Folke 2006). For example, when a destructive earthquake happens, a resilient city or community can bounce back to normal from the disrupted conditions as smoothly as possible.

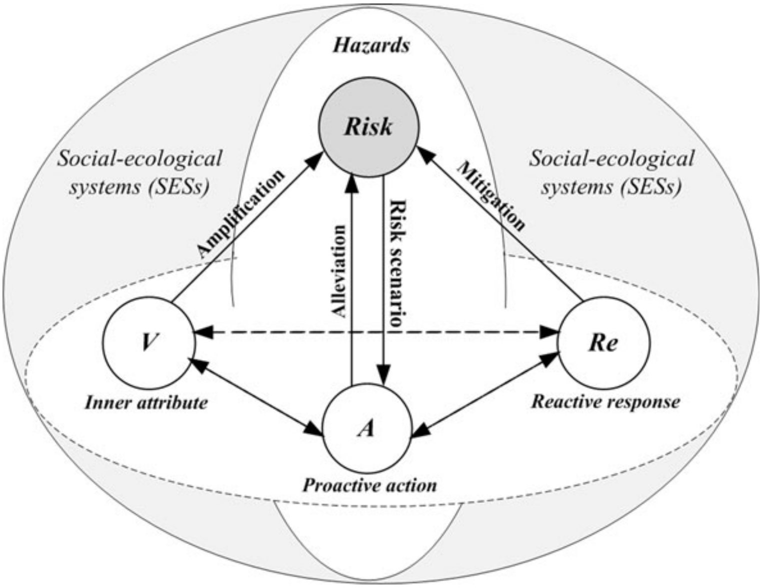


**Fig. 5** A conceptual framework of vulnerability (*V*), resilience (*Re*), and adaptation (*A*) within the disaster risk domain

Adaptation means actively changing one's structure and function to adapt to environmental changes or related hazards. Adaptability is a manifestation of adaptation, which means the ability to develop new knowledge and diversify effective approaches, including its ability to absorb hazard impacts, prepare for, adapt to, and recover from them. In contrast to resilience, usually a reactive response to a disaster, adaptation in most cases is a proactive action to the anticipated hazards so that the potential negative effects or risks could be alleviated in advance (Fig. 5). Of course, a timely risk assessment can provide a range of scenarios that facilitate forward-looking adaptation strategies in the near future. Adaptation usually points to a long-term process, so that a temporary resilient response can be translated into a stabilized strategy.

## 5.2 Framing V, Re, and A from an insight of "hit-damage-recovery-learning" cycle

This section develops a conceptual framework to address the relationships of V, Re, and A from the insight of a "hit-damage-recovery-learning" cycle in disaster risk management (Fig. 6). The formation of a disaster is a complex human–nature interactive process. In the temporal scale, a disaster can be divided into three periods: before (pre-), during (in-), and after (post-) disaster. It can also be split into several periods according to the number of disasters, and the post-disaster period in one disaster is often the pre-disaster one in the next disaster (or future risk).

The concept of vulnerability focuses primarily on the situation or attribute of system before a disaster (Fig. 6), and it is helpful for improving preparedness for the potential hazards. The vulnerability of a system could be reduced in advance through a range of rational preparations. For example, when population moves out from the maritime region before a landfall typhoon, the vulnerability of coastal society will become low. Disaster resilience can be defined as the capacity to resist and recover from loss caused by natural hazards within the shortest possible time with minimal or no outside assistance (Zhou et al. 2010). It can help to strengthen the abilities of a system in response to hazards.

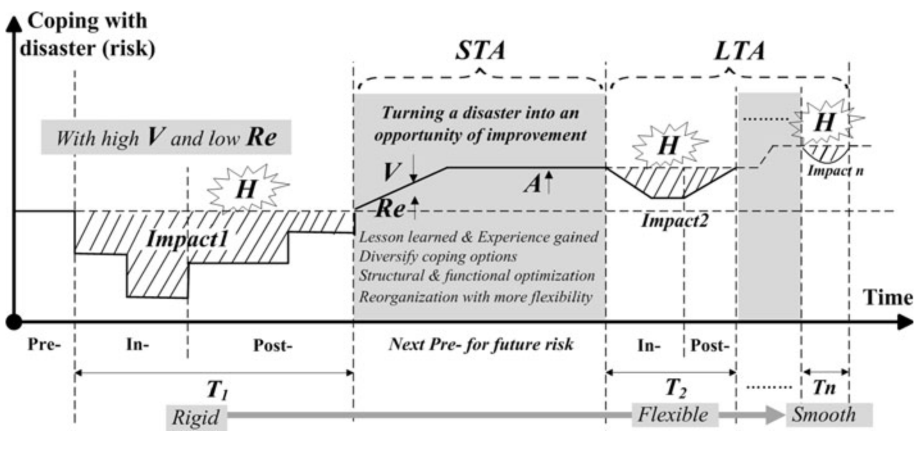


**Fig. 6** Framing the relationships of *V, Re, and A* based on a dynamic cycle of "hit-damage-recovery-learning" in disaster risk management. *H* represents a hazard. At the temporal scale, disaster processes are divided into pre-, in-, and post-disaster in the short term, and the past-, present disasters, and future risk in the long term. The disaster risk adaptation consists of two stages: the short-term adjustment (STA) and the long-term adaptation (LTA)

Adaptation thinking in SES domain means to make use of crises as windows of opportunity for novelty and innovation (Folke et al. 2010). After a crisis or a disaster, there is often a great period for local affected people to get improvements based on lesson learned and experience gained. For example, they can positively reduce the vulnerability (both exposure and sensitivity) of local SESs through a series of structural adjustment and functional optimization (Fig. 6). Resilience and adaptive capacity to future hazards can also be enhanced by diversifying the socio–economic activities. In general, rational and timely adjustments after a disaster allow local community gains more flexibility and options in response to future disasters or potential risks.

The relationships of V, Re, and A can also be illustrated in the process of entry and exit transitions of repeating disasters [according to the scientific plan of Integrated Risk Governance under International Human Dimensions Program on Global Environmental Change (IRG 2010), the entry-transition means that a given system switches into emergency or crisis mode; while the exit-transition signifies that a given system switches back from emergency or crisis mode into a normal status, which may or may not be the same as it was before the crisis]. In the beginning, a system with high vulnerability and deficient resilience is prone to be affected by a hazard but difficult to recover from its induced disasters. The losses could be tremendous due to a prolonged disaster process of "easy entry" but "slow exit" (Fig. 6). However, this kind of disadvantage can be modified by adopting effective adaptation actions, such as adjusting regional land use patterns, enhancing early warning systems, and developing crop varieties with much stronger adaptability to disasters. After a series of positive adjustments that facilitate vulnerability reduction and resilience strengthening, the probability of a hazard be translated into a disaster could be dramatically reduced. The duration of the subsequent disasters under the same intensity of hazards could become shorter and shorter, as a result of more and more difficult entry into but rapidly recover from a disaster (as shown in Fig. 6, T1>T2>……>Tn). Eventually, a robust system should be very hard for a hazard to develop into a disaster and much easier for a system to return to normal once it is affected.

### 5.3 From short-term adjustments to long-term adaptations in disaster risk management

As shown in Fig. 6, adaptation can be divided into two sub-phases: a short-term adjustment (STA) and a long-term adaptation (LTA). STA emphasizes the temporary modulation and regulation aimed at reducing the vulnerability and enhancing the resilience of an unbalanced SES. It can help a destroyed system to bounce back or shift to a new balance. These kinds of temporary adjustments can also be gradually accumulated and solidified as a social memory and long-term adaptability (LTA). In general, LTA means to respond to challenges through managing risk and impact, creating flexibility in problem solving and contributing to cope with and adapt to future risks. It is often achieved through social learning and innovation from the past disasters. For example, if a local community suffers from a certain kind of hazard again and again, impacts of the following ones may get smaller and smaller thanks to accumulated memories and experiences of regional system to the recurrent disasters (see the declining area of oblique line in Fig. 6). During the same process, the properties of a system could be evolved from originally "rigid" that is easy to be destroyed, gradually to a "flexible" one and eventually to a "smooth" state with favorable resilience and sound adaptability to external stresses (see changes in the shapes of oblique line area in Fig. 6). After a number of "hit-damage-recovery-learning" cycles, the coping mechanism of a system to disaster risks can be optimized by taking each chance of responding to disasters as an opportunity to achieve structural and functional improvements.

It is beneficial to change the notion of disaster risk management from a forced short-term adjustment (STA) to a planned long-term adaptation (LTA). Just as the case of Beidian in Sect. 4, the short-term reactive disaster relief did not helped to reduce the impact of droughts on local agriculture, but the planned transformation in land use patterns has not only significantly reduced local vulnerability to droughts, but facilitated poverty reduction and improved livelihood for the local residents. In this case, supposing the government had not been turned to encouraging rational changes in regional land use practice, but to consistently invest on the irrigation facility and providing disaster relief fund to the village farmers as always, although the short-time resilience of local agriculture could be enhanced owing to a faster recovery from droughts, yet the long-term adaptability of farmers' livelihood to future risks could be undermined due to their over-reliance on external assistances. Once the disaster relief fund from the government is unavailable some day, local agriculture would become much more vulnerable to droughts. Therefore, in terms of disaster risk management, it is crucial for us to change minds from a short-term recovery or adjustment to a long-term adaptation and taking the course of disaster response as an opportunity of reducing vulnerability and building long-term resilience.

### 5.4 Much broader insights could be taken into consideration for disaster risk reduction

The proposed conceptual frameworks (Figs. 5, 6) suggest that different countermeasures to disaster risk with various purposes of reducing vulnerability, enhancing resilience, or strengthening adaptability can all contribute to disaster risk reduction. The Beidian case also indicates that through a series of structural transformation and functional optimization, the village farmers have not only greatly reduced the negative impacts of droughts on local agriculture (i.e., vulnerability reduction), but also making their own livelihood more resilient and adaptable to potential drought risks.

Since exposure and vulnerability are broadly perceived as two key determinants of disaster risk and of impacts when risk is realized (IPCC 2012), we have paid too much attention to reduce the negative effects of natural disasters (or vulnerability reduction), but largely ignored the underlying opportunities that arise during the process of adaptation. In addition to the past "vulnerability reduction" dominant disaster risk mitigation, more attention should be paid to a new adaptive thinking in managing disaster risk. This kind of concept focuses on not only to minimize the social–economic losses from disasters, but to maximize the potential opportunities in implementing the adaptation actions.

### 5.5 Rethinking V, Re, and A in light of social–ecological sustainability

In the Beidian case, the traditional wheat–corn rotation mode was not the best fit to the regional precipitation, which resulted in a higher exposure, thus higher vulnerability of local agriculture to droughts. Due to such deficient farming practice, neither the investments in irrigation system nor the disaster relief fund during that time had helped alleviate the serious impacts of droughts on local agriculture. Thus, it is inadvisable to spend great efforts to maintain the unfavorable planting mode (i.e., the old and bad farming system) with high vulnerability and deficient resilience to droughts. Instead, through an intentional transformation in land use modes, both the natural vulnerability of local agriculture to droughts and the social vulnerability of rural farmers have been dramatically reduced.

Traditionally, the vulnerability and resilience centered research have spent great efforts to maintain a steady system. However, it is often so costly and irrational to build the temporary resilience for systems that are inherently unsustainable. Instead, transformation (e.g., abandoning the old land use mode in Beidian Village) is an essential adaptation strategy for building long-term resilience. In this respect, the social–ecological sustainability could be achieved not by maintaining the “old and bad” resilience but by creating “new resilience” for a new adaptive system.

## 6 Conclusion

Vulnerability, resilience, and adaptation are three very important and interdependent concepts in global change science and social–ecological and disaster risk domains. It is always a great challenge to clarify their intricate relationships within a coupled human–environment system. Despite a wide range of discussions concerning them in recent literatures, a clear understanding on their integral relationship is still rare. This article presented a brief overview of the origins and evolutions of V, Re, and A by considering various academic backgrounds and tentatively classified past diverse understandings on them into three modalities of vulnerability preference, resilience preference, and overlapped relationships. To date, there is no unified framework for understanding the relationships of V, Re, and A due to the diversified academic traditions. However, it is becoming clear that any one concept of them should not be overstressed alone from the others, but need to be understood based on an integral understanding on the three elements.

From a “hit-damage-recovery-learning cycle” insight and based on an empirical case study, this article put forward two preliminary frameworks to conceptualize the relationships of V, Re, and A from the perspective of disaster risk. Vulnerability is an inner attribute of a system that makes it susceptible to the damaging effects of a hazard, and it is helpful for improving preparedness for the potential hazards. Resilience embodies the ability to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, which is often a reactive response to the ongoing disasters. In contrast, adaptation mostly performs as a proactive action to the anticipated hazards, so that the potential negative effects or risks could be alleviated. Adaptation could be further divided into two sub-stages of short-term adjustment (STA) and long-term adaptation (LTA). And, a STA can be accumulated and solidified as a LTA based on lesson learned and experience gained from the recurrent disasters. After a number of “hit-damage-recovery-learning” cycles, the coping mechanism of a system to disaster risks can be optimized by taking each chance of disaster response as an opportunity to get structural and functional improvements.

Within a coupled human–environment system (or SES), actions for the sakes of vulnerability reduction, resilience building, and adaptability improvement can all contribute to disaster risk mitigation. Therefore, a sustainable adaptation strategy to the unavoidable disasters or changes should not only seek to reduce the vulnerability of a social–ecological system, but also to foster its resilience and adaptive capacity to future uncertainties and potential risks. In addition to the past “vulnerability reduction” dominant disaster risk mitigation, more attention should be paid to a new adaptive thinking in managing disaster risk. This kind of concept focuses on not only to minimize the social–economic losses from disasters (i.e., to reduce the negative effects), but to maximize the potential opportunities in implementing the adaptation actions.

Vulnerability, resilience, and adaptation are all integrated concepts to characterize and understand how the systems respond to and cope with changes. This study tentatively developed two conceptual frameworks to address the linkages of V, Re, and A within the disaster risk domain, and their broader implications were discussed in terms of disaster risk management and social–ecological sustainability. It should be noted that the suggested two frameworks do not necessarily fit to all the other research domains such as climate change, with a longer timescale compared with the relative short timescale of disasters. Moreover, the proposed frameworks should be further discussed within multiple spatial–temporal scales. In the long run, more empirical case studies that address the relationships of vulnerability, resilience, and adaptation are needed to provide more credible insights for decision-makers within the broader context of climate change.

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