Assessing and Characterizing Community Recovery to Earthquake: the Case of 2008 Wenchuan Earthquake, China

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Abstract. Our world is prone to more frequent, deadly and costly earthquake disasters, which are increasingly uncertain and complex due to the rapid environmental and socio-economic changes occurring at multiple scales. There is an urgent need to recover rapidly and effectively for community after earthquake disasters. To enhance community recovery, it is necessary to have a good initial understanding of what it is, its determinants and how it can be assessed, maintained and improved. Considering the original perspective of recovery, this article proposes the concept of community recovery as the capacity to recover and rebuild after the earthquake disasters. And this paper presented a framework for defining community recovery and specifying quantitative measures to assess it that can serve as focus for comprehensive characterization of the earthquake problem to establish needs and priorities. The framework integrates those measures into the four dimensions of community recovery-population, economic, building, and infrastructure. Taking the community of Wenchuan as the example to test our mathematical model and compare different recovery levels of four dimensions under the situation of Wenchuan Earthquake, the results can help Chinese Central Government to assess and measure the recovery capacity and performance of local government officials of Wenchuan, and identify the low-recovery dimensions of Wenchuan to enhance post-disaster recovery and reconstruction efforts, and address the vital importance of local government in improving the post-disaster recovery.

1 Introduction

The damaging earthquake risk of cities as the most devastating in terms of impact, but not in terms of likelihood, has specifically increased over the years due to the increasing complexities in urban environments and a high concentrated urbanization in seismic risk-prone areas. The growing large-scale devastating effects caused by recent catastrophic earthquakes (e.g. 15 August 2007, Peru; 12 May 2008, Wenchuan, China; 12 January, 2010, Haiti; 11 March 2011, Honshu Island, Japan) have attracted the attention of the policy makers to formulate effective risk prevention policies. The earthquake risk depends on the seismic hazard, but it is more dependent on the inherent properties of the communities which is compounded by the vulnerability, adaptation and resilience. Above all of these inherent properties, resilience is interpreted to be the central component of disaster risk reduction, which is used to bridge the two other properties together. Some researchers asserted that a disaster-resilient community has the ability to cope with the disaster strikes, and improve its inherent genetic or behavioral characteristics to better adapt to disasters rather than regain pre-disaster levels of vulnerability (Mooney, 2009). So policymakers have called for concerted efforts to build "earthquake-resilience community" for the purpose to find the new stable states and rebuilding a safer community in the historically experienced deleterious earthquake disasters (Alesch, 2009). The definition of resilience is the ability that is exposed to seismic hazards to resist, absorb, accommodate and recover from seismic hazards quickly and efficiently, which is divided by some scholars into during-disaster resistance, short-term post-disaster recovery, and long-term post-disaster trans-formative (UN/ISDR, 2010). Recovery represents a fundamental dimension of disaster resilience, includes both the possibilities to return to normal, that is, pre-disaster condition, or alternatively, to be rebuilt or transformed to a completely different status. So reconstruction, restoration, rehabilitation and post-disaster redevelopment are all considered to be the parts of the recovery process, yet it is widely acknowledged to be the final phase of the disaster life cycle (Tierney et al., 2001; NRC, 2006; Peacock et al., 2008; Olshansky and Chang, 2009).

In academia, recovery has traditionally taken on a more outcome-oriented conceptualization, with emphasis on the physical aspect as seen in early studies (Haas et al., 1977). Researchers like Nigg then began to point out that recovery should be conceptualized as a social process that "begins before a disaster occurs and encompasses decision-making concerning emergency response, restoration, and reconstruction activities following the disaster" (Nigg, 1995). Some other scholars have suggested that recovery can be defined as the "process by which a community has experienced a structural failure of this sort to reestablish a routine, organized, institutionalized mode of adaptation to its post-impact environment" since the disaster is often seen as a failure of social structure (Bates and Gillis Peacock, 1989). These changes in the definition to reflect the shifts in conceptualizing disaster recovery in the last few decades from a linear, static issue focused on the physical aspects referred to a specific set of stages, to a dynamic, interactive, multi-dimensional decision-making process, including the 'reconstructing, and remodeling of the natural and social-economic environment by pre-disaster planning and post-disaster actions' (Smith and Wenger, 2007). And the researches surrounding "disaster recovery" have attracted more and more attention in recent years. Definitions of this term vary in the literature, which are commonly used in the sense of 'returning to pre-disaster conditions', or 'reaching a new stable state that may be different from either of these' (Quarantelli, 1999). The new National Disaster Recovery Framework developed by FEMA (2011) define recovery as "those capabilities necessary to assist communities affected by an incident to recover effectively, including, but not limited to, rebuilding infrastructure systems, providing adequate interim and long-term housing for survivors; restoring health, social, and community services; promoting economic development; and restoring natural and cultural resources". And community recovery emerges "as the outcome of several sets of activities: restoring basic services to acceptable levels, replacing infrastructure capacity that is damaged or destroyed, rebuilding or replacing critical social or economic elements of the community that are damaged or lost, and establishing or reestablishing relationships and linkages among critical elements of the community" (Alesch et al., 2009).

In recent years, much of the current disaster literature provides two major perspectives and interpretations to assess recovery: (i) returning to pre-disaster situations; and (ii) obtaining a new normal conditions (Chang et al., 2011). The first perspective and interpretation is conceptually based on the comparison of the community conditions before the disaster and after the recovery process, and it emphasizing on the rebounding as quickly as possible (Wildavsky, 1991; Sherrieb et al., 2010). In this regard, the pre-disaster situations are considered to be the normal state. The rapid recovery process is designed to minimize losses caused by disasters (Alesch et al., 2001). The second perspective and interpretation highlights how there is a new normal state after a disaster (Alesch et al., 2009; Chang et al., 2010). However, the 'new normal state' is more applicable to post-disaster attitudes and behavior of human, showing the evolution of the collective psychology, than it is to physical recovery. Beside that, some recovery indexes have been designed to track the recovery progress, such as the Social Vulnerability Index proposed by Cutter and Finch (2008), Spatial Recovery Index (SRI) proposed by Ward et al. (2010), "ability of the economy to cope, recover, and reconstruct and therefore to minimize aggregate consumption losses(i.e. indirect impacts)" by Hallegatte (2014) and so on. These recovery indexes resonate with the fine view of the bouncing back method in as much as these dimensions are critical to understand the post-disaster improved situations.

Nowadays, the research of disaster recovery is in the initial stage, more key research questions need to be resolved: Why do some communities recover more quickly and successfully than others? Is there a timetable for recovery? How does the recovery trajectory of communities differ by type and magnitude of the hazard event, conditions of initial damage, characteristics of the community, and decisions made over the course of reconstruction and recovery? How do different types of assistance and recovery resources affect recovery? What types of decisions and strategies are most critical to recovery? How do disasters affect communities over the long term? In the past studies, the idea of post-disaster improvement is preferred by many scholars to the idea of bringing back to or regaining the pre-disaster normality, especially when the disasters are occurring in developing countries, while the concepts and practices of sustainable development and risk reduction are being integrated into disaster recovery processes. The concept of disaster recovery is recognized as ordered, knowable, and predicable, for the emphasis is mainly focus on the building environment. However, later studies have shown that the recovery process does not follow a predictable timeline, and that the recovery process is increasingly to multi-dimensional, including both physical (economic) and social-psychological aspects. The determinants of disaster recovery are many, include socioeconomic status and development trends, structural change and adaptation, disaster impacts and disruptions, post-disaster response efforts, informal and formal external assistance (governmental and institutional capacity), and macro-socioeconomic or program/policy changes. So the assessment of disaster recovery is a complex construct, a recurrent problem is the lack of a simple, feasible and effective assessment of disaster recovery. After 2008 Wenchuan Earthquake, Chinese Central Government have provided disaster assistance and developed many recovery programs for the impacted communities. The total investment of these recovery programs is 1 trillion yuan. The local government officials take the most important role in the post-disaster recovery. So when these emergency response activities and programs carried out, challenges must be faced and key decisions made included of Chinese Central Government is to assess the recovery capacity and performance. How these recovery programs runs? How is the recovery effect and efficiency of these recovery programs? How to develop new guidelines for improving and managing the complex recovery process. Similar challenges will be faced in other earthquake-prone regions, and the Wenchuan Earthquake provides an important opportunity to learn from the decisions made by the local governments and their consequences for recovery. So the intended outcome of this paper is to propose a new, practical method for assessing and characterizing community recovery to earthquake in four dimensions, and applied it to Wenchuan Community. The final products of our research provide insights for Chinese Central Government to assess and measure the recovery capacity and performance of local government officials of Wenchuan, in order to maximize the overall post-disaster community recovery by prioritizing efforts, and formulating effective, operational and valuable reconstruction strategies and policies in the future.

2 Study Area

The Wenchuan Community (31°East, 103.4°North) in Sichuan Province of China was hit by a magnitude 8.0 Ms (the surface-wave magnitude) and 7.9 Mw earthquake (Wenchuan Earthquake) (Figure 1) at 14:28:04 CST (China Standard Time) on May 12, 2008. The Epicentral intensity of this earthquake was up to 11 degrees, and the areas directly devastated by this earthquake were as large as 100,000 square kilometers. Wenchuan Earthquake is the most destructive and widespread earthquake since the founding of the People's Republic of China, which affected more than half of China and other Asian countries and regions. Up to September 18, 2008, the Wenchuan Earthquake caused 69,227 people dead, 374,643 injured, and 17,923 missing. Direct economic losses reached 845.2 billion yuan ($ 133.2 billion). The Wenchuan Community as the epicenter of Wenchuan earthquake was the hardest hit (Figure 2b). In Wenchuan Community, this earthquake left 15,941 people dead, 34,583 injured, and 7,930 people have been listed as missing. The Wenchuan Community was razed by this earthquake: all infrastructures were completely destroyed, most buildings were severely damaged, many economic sectors such as industry, commerce and tourism were suffered heavy losses (64.3 billion yuan ($ 10.1 billion) in direct economic losses).

Figure 1. Location of Wenchuan Earthquake

After Wenchuan Earthquake, Chinese Central Government commanded a large number of rescuers (including firefighters, special police, volunteers and humanitarian relief experts) from all over China and around the world to take emergency response measures. On June 8, 2008, "Regulations on Post-Wenchuan Earthquake Rehabilitation and Reconstruction" was promulgated, and the Chinese government announced to invest 1 trillion yuan ($157.7 billion) to rebuild the affected areas over the next 3 years. In the rebuilding and recovery processes, with the principle of "one province helps one severely affected communities", 19 provinces and cities (e.g. Guangdong, Jiangsu, Shanghai, Shandong, Zhejiang, Beijing, Liaoning, Henan, Hebei, Shanxi, Fujian, Huan, Hubei, Anhui, Tianjin, Heilongjiang, Chonging, Jiangxi, Jilin) supported the reconstruction of 18 worst-hit communities (e.g. Wenchuan, Qingchuan, Beichuan, Mianzhu, and so on) for three years. Just forced on the Wenchuan Community, the reconstruction projects of the national plan are more than 4,000, with the total investment of 40 billion yuan ($ 6.3 billion) from 2008 to 2011. On the third anniversary of Wenchuan Earthquake (May 12, 2011), the reconstruction of the Wenchuan Community is completed (Figure 2c).

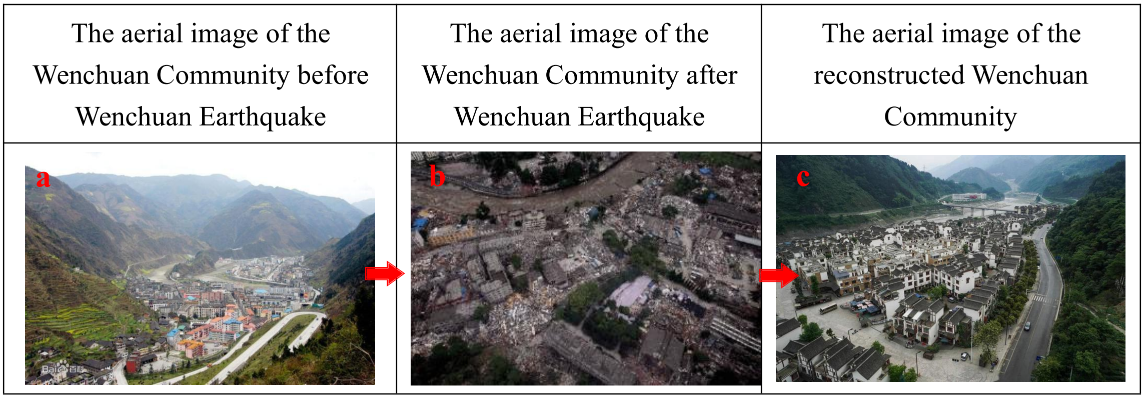

Figure 2. The development process of the Wenchuan Community in, during, and after Wenchuan Earthquake (from May 12, 2008 to May 12, 2011)

3 Data and Methods

3.1 Data Sources

Data of the detail reconstruction or recovery processes of Wenchuan after the earthquake including population, economy, building and infrastructure are mainly obtained from the reports on the work of the Wenchuan government from 2008 to 2016. Data of the recovery process and status of the affected people were gotten by questionnaire and interview. We selected 10 resettlement sites of the Wenchuan where the most affected families are concentrated, and the random interviewed 1000 affected families from these resettlement sites. The settlement sites along the Minjiang River were built around Wenchuan Community, the remote sensing image of these settlements are showed in Figure 3. The largest resettlement site is located in Yanmen Township of Wenchuan Community, which covers an area of about 240 mu. There are more than 2,800 active board houses, which can resettle more than 10,000 affected people. During the questionnaire and interview, the investigators randomly selected a family member over 18 years of age of each affected family to fill the questionnaire and interview.

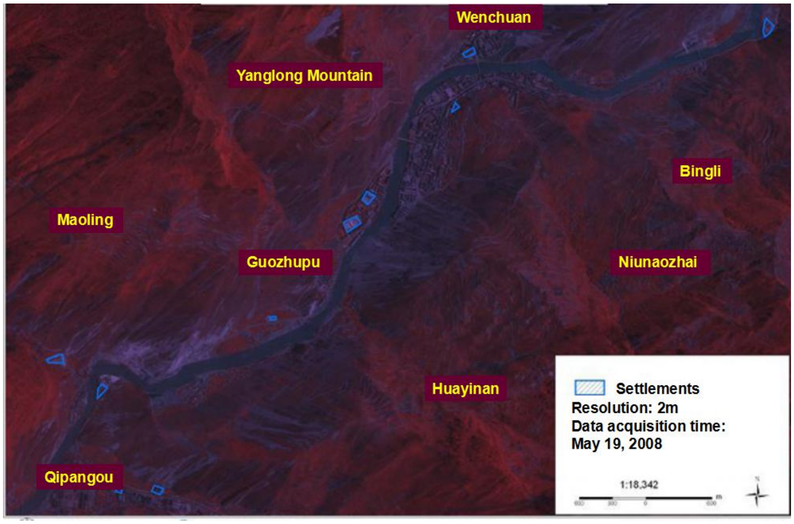

Figure 3. The remote sensing image of the interviewed settlements of Wenchuan

Other statistics and description data (showed in table 1) are gathered by combining different sources (e.g., research report, government report, government agency and website) following the Wenchuan Earthquake. And the local information of the reconstruction processes of buildings and infrastructure of Wenchuan Community, which were obtained by field surveys and interviews. After the earthquake, the government made every effort to restore infrastructure services of the affected areas, and the emergency water supply, telecommunications, electricity, and roads were recovered respectively on May 13, May 15, May 17, and August 12, 2008. With regarding to repair and rebuild the earthquake-affected buildings, 501 reconstruction projects with the total investment of 22.177 billion yuan ($ 3.5 billion)are completed in Wenchuan Community. From 2008 to 2011, reconstruction projects had been completed by 19%, 53%, and 94.7% in each year. In 2012, all of these 501 reconstruction projects were completed. These all data were entered into a computerized database. This database was an important source of information for assessing the recovery of the Wenchuan Community to the earthquake.

Table 1 Statistics and description data sources

Research Report
Statistical Report on the Direct Loss and Quantity and the Main Hazard Bearing Body in Wenchuan Earthquake
Assessment Report on the public health environment of the core area of Wenchuan in Wenchuan Earthquake

Investigation Report on Recovery of Victims in Wenchuan Earthquake
Government Report
Regulations on the Reconstruction of Wenchuan Earthquake
Work Plan for Reconstruction of Wenchuan Earthquake
Main Plan for Reconstruction of Wenchuan Earthquake
Technical Guide for Reconstruction of Highway of Wenchuan Earthquake
Support Program on Reconstruction of Wenchuan Earthquake
Action Platform for Twenty-year Psychological Assistance of Wenchuan Earthquake
Data Collection from Government Agency
Earthquake Relief Leading Group of Chinese Academy of Sciences
Working Group on Disaster Reconstruction Planning of Wenchuan Earthquake
Working Group on Remote Sensing Monitoring and Disaster Assessment of Wenchuan Earthquake Disaster
Data Collection from Website
Institute of Mountain Hazards and Environment,CAS
China Geological Survey
Institute of Geographic Sciences and Natural Resources,CAS
Institute of Geology and Geophysics,CAS

3.2 Defining and assessing the community recovery to earthquake

The researches contain many major conceptual and assessment approaches to define and assess community recovery. Community recovery, as the final phase of the disaster life cycle, continues beyond emergency response, that might be taken in the immediate aftermath of a disruption until returning to pre-disaster normality or transforming to a new stable state. This phase may take days, months, even years, to accomplish; thus, requiring long-term planning. The recovery is a dynamic, complex and challenging process that involves all sectors of a community, comprised of the impact of disasters, households, business, buildings, as well the lifeline system (Miles and Chang, 2007). In many cases, it is not even clear if and when recovery has been achieved because of varying stakeholder goals for the community, for example with some wanting it returned to its pre-disaster status and others wanting it to undergo change to realize a vision in which advances are made in risk reduction and other areas. But most of all, the decision-makers of local governments mainly through improving the recovery process to restore the operation of the interrupted business, and to rebuild damaged infrastructure to allow the restarting of normal activities (Alesch et al., 2001). So in the initial research, the recover time can be defined as the key indicator to assess the community recovery in much disaster literature, such as the term of rapidity as the four properties of resilience (4R’s) (Bruneau et al., 2003). That is Bruneau et al. argued that resilience has four properties:

(1) Robustness: strength, or the ability of elements, systems, and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function.

(2) Redundancy: the extent to which elements, systems, or other units of analysis exist that are substitutable.

(3) Resourcefulness: the capacity to identify problems, establish priorities, and mobilise resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis; resourcefulness can be further conceptualised as consisting of the ability to apply material (i.e., monetary, physical, technological, and informational) and human resources to meet established priorities and achieve goals.

(4) Rapidity: the capacity to meet priorities and achieve goals in a timely manner in order to contain losses and avoid future disruption.

The broad group of authors, such as Paton (2005), Longstaff et al. (2010), Ainuddin and Routray (2012), that provided the most comprehensive conceptual definition of resilience (Bruneau et al. 2003) introduced the so called “resilience triangle”, which represents the loss of functionality from the damage and disruption, and is the root of assessment approach of recovery. Figure 4 illustrated the concept of resilience triangle. In general terms, some key features should be expressed. Q(t), which varies with time, has been defined for the percentage “functionality” (or “quality”, or “serviceability”) of a community. And t is time. Specifically, the percentage functionality can range from 0% to 100%, where 100% means no degradation in service and 0% means no service is available. If an earthquake occurs at time t_0, it could cause sufficient damage such that the quality is immediately reduced (from 100% to 50%, as an example, in Figure 4). Restoration of the system is expected to occur over time, as indicated in that figure, until time t_1 when it is completely repaired (indicated by a quality of 100%). During the time interval of t_0 to t_1, the recovery curve represents the dynamic recovery process.

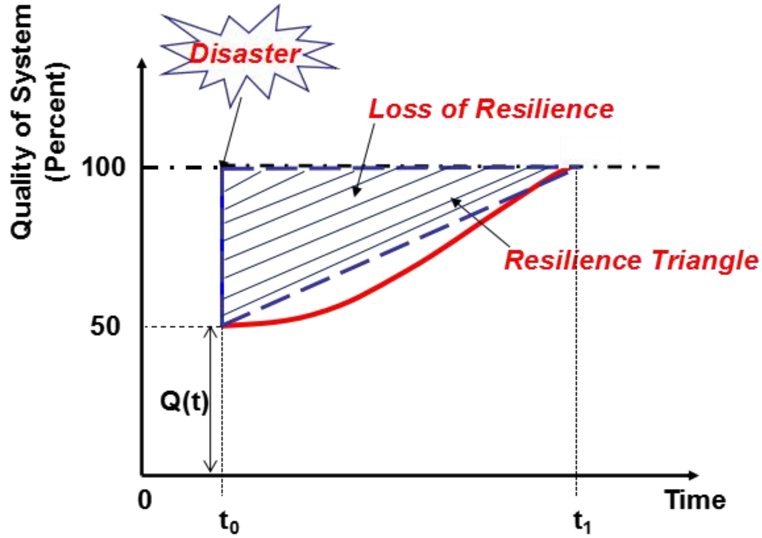

Figure 4. The concept of resilience triangle

They used this approach to primarily measure community resilience in the event of natural disasters like earthquakes. It plots the quality or functionality and the performance of system after a 50% loss. The triangle represents the loss of functionality from damage and disruption, as well as the pattern of restoration and recovery over time. It is used to measure the functionality of the community after a disaster, and also the time it takes for the community to return to pre-disaster levels of performance. So the depth of the triangle shows the severity of damage, and the length of the triangle shows the time to recovery. Loss of community resilience, R, with respect to that specific earthquake, can be measured by the size of the expected degradation in quality (probability of failure), over time (that is, time to recovery). The smaller the triangle, the more resilience is the community. Mathematically, it is defined by

$$R = \int_{t_0}^{t_1} (100 - Q(t))dt \qquad (1)$$

where R is the loss of resilience experienced by the community, t_0 is the time instant when the earthquake occurs, t_1 is the time when the functionality of the community is fully restored, Q(t) is the percentage "functionality" (or "quality", or "serviceability") of the system, and t is time.

And the recovery time in "resilience triangle" is taken to assess community recovery. The advantage of using this parameter is that it can assess the community recovery quickly, directly, and simply. But the disadvantage is that this parameter is strictly connected to the quality of community (the vertical axis). For example, in Figure 5, if the initial quality ($Q(t)_2$) is the same, the recovery time of Community 2(a) is less than the recovery time of Community 2(b) ($t_{2a}<t_{2b}$),

which can represent that the recovery degree of Community 2(a) is better than Community 2(b). But the recovery time of Community 1 is also less than the recovery time of Community 2(a)($t_1<t_{2a}$), which maybe due to the more initial quality ($Q(t)_1>Q(t)_2$), not due to the better recovery degree. So it can't represent the same conclusion about the recovery degree of Community 1 and Community 2(a). Because the initial quality of Community 1 and Community 2(a) are different, the quality of the community has the interference effect in assessing community recovery.

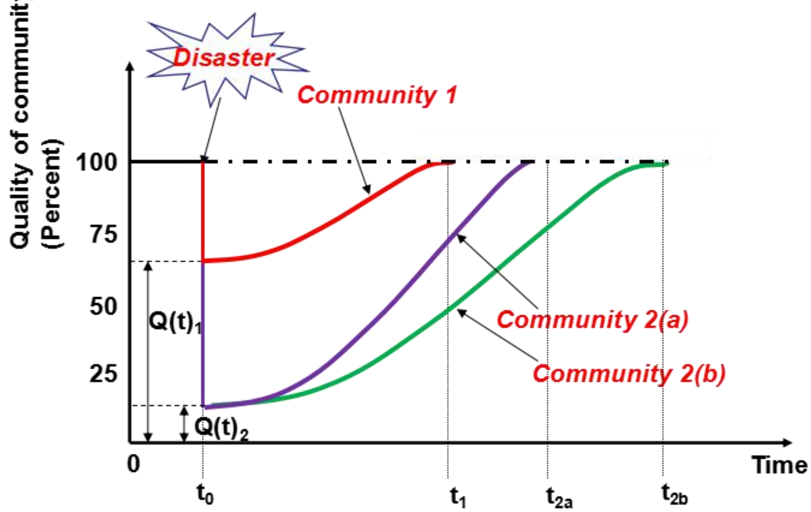

Figure 5. The concept of the resilience triangle

Therefore, in order to exclude the influence of the quality of community in assessing the community recovery, this paper extends the original concept of resilience triangle and use the term of rapidity from four properties of resilience (4R's) (Bruneau et al., 2003) to assess community recovery, which refers to how fast the community returns towards equilibrium after the earthquake. Dynamic recovery refers to the rapidity with which the community returns to an acceptable level of functioning and structure after severe external perturbation or shock. The speed at which the community recovers to achieve a desired state can be used in our paper to assess the community recovery. Figure 6 sketches the assessment framework proposed here. Earthquake impacts compare a 'with-earthquake' time path to 'without-earthquake' expectations. A simplification that is often made in practice is to compare pre- and post-disaster states, assuming that pre-disaster conditions are 'normal' and static. The proper comparison is between 'with' and 'without' earthquake scenarios. In the without-earthquake scenarios, the quality of community $Q(t)_0$ is plotted as the horizontal straight line over time. In the with-earthquake scenarios, the quality of community Q(t) is plotted as the fluctuation curve over time. The occurrence of an earthquake is at time t_0, and the total functionality is restored at time t_1 or t_2. The slope of the recovery curve is the recovery speed of the recovery process. Finally, the resilience triangle is the shaded region above the curve of the functionality recovery path.

However, quantifying the slope of the recovery curve to assess the community recovery is very difficult and a challenge in this paper, because the recovery speed of the curve is different at each time point, and not a constant. For the purpose of facilitating the calculation, assuming that the performance of community of the resilience is unchanged and equal, we use the linear functionality recovery path to approximate the curve functionality recovery path. The three key variables of the resilience triangle are particularly meaningful for assessing the community recovery. One is the percentage quality of community ($Q(t)_{curve}$, $Q(t)_{linear}$), which expresses the remaining quality of community after the extreme event. The second is the total recovery time (t_1, t_2). The third and most valuable variable is the terms of recovery score (expressed by the value of recovery speed), which approximately equals to the slope of the linear of the functionality recovery path. Based on the notation, the recovery score is formulated as the following two-stage stochastic program:

First stage:

$$R_{curve}=\int_{t_0}^{t_1}[100-Q(t)_{curve}]dt \qquad (2)$$

$$R_{linear}=\int_{t_0}^{t_2}[100-Q(t)_{linear}]dt \qquad (3)$$

Where R_{curve} is the loss of resilience experienced by the community in the curve functionality recovery path; R_{linear} is the loss of resilience experienced by the community in the linear functionality recovery path; $Q(t)_{curve}$ is the percentage functionality of the community in the curve functionality recovery path; $Q(t)_{linear}$ is the percentage functionality of the community in the linear functionality recovery path; t_0 is the time instant when the earthquake occurs; t_1 is the length of recover time in the curve functionality recovery path; t_2 is the length of recover time in the linear functionality recovery path.

Second stage:

$$R_{curve}=R_{linear} \qquad (4)$$

$$t_2=\frac{2\times\int_{t_0}^{t_1}[100-Q(t)_{curve}]dt}{100-Q(t_0)_{linear}} \qquad (5)$$

$$RS=\tan\alpha=\frac{100-Q(t_0)_{linear}}{t_2}$$

$$=\frac{(100-Q(t_0)_{linear})^2}{2\times\int_{t_0}^{t_1}(100-Q(t)_{curve})dt} \qquad (6)$$

Where RS is recovery score that can be expressed by the value of recovery speed; α is the tangent angle of the linear functionality recovery path; $Q(t_0)_{linear}$ is the percentage functionality of the community at the time of earthquake occurrence in the linear functionality recovery path;

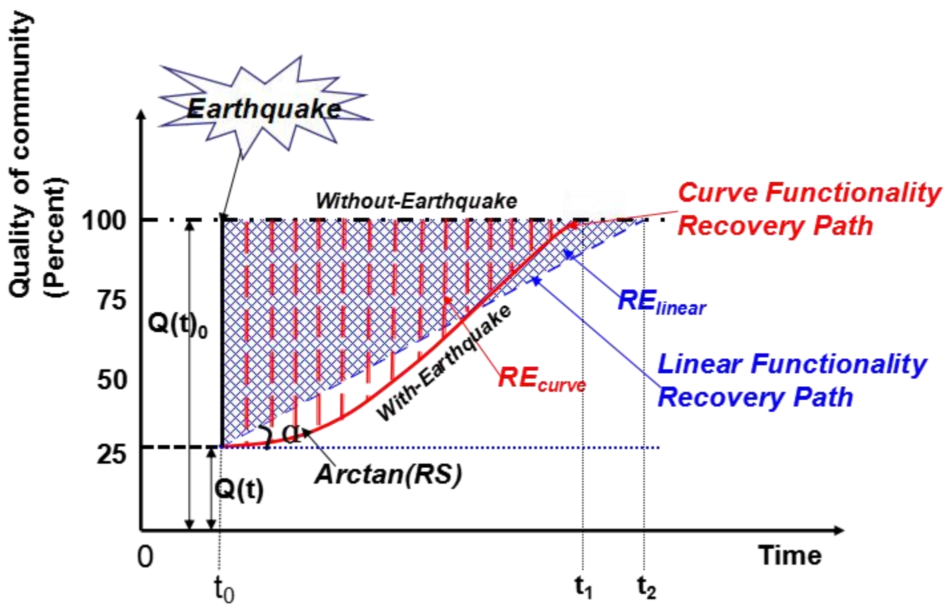

Figure 6. The recovery assessment framework

3.3 Core dimensions and indicators of community recovery

The challenge in defining core dimensions of community recovery lays in its complex nature. The purpose of our paper is to help Chinese Central Government assess and measure the recovery capacity and performance of local government officials of Wenchuan. Before performing the core dimensions and indicators of community recovery, it is necessary to answer the question the community recovery “of what” and “to what” should be the most concerned by Chinese Central Government. In addition, the choice of the core dimensions and indicators of community recovery depends on the particular case (Wenchuan) for assessment, as well as on availability of data.

Since recovery begins when a community ‘repairs or develops social, political, and economic processes that enable it to function in the new context within which it finds itself’(Alesch et al., 2009). When a devastating earthquake hits a community, people are injured or killed, economy interruption begins, buildings are collapsed, and infrastructures are disrupted. The ability of the community to carry out recovery activities to minimize the immediate impacts caused by an earthquake. According to the characteristics of earthquake disaster, and in order to better interpret all aspects of community recovery, a total of 15 interviews involving 20 experts were conducted to judge and choose the core dimensions and indicators of community recovery, which can significantly reflect local government capacity the recovery capacity and performance of local government officials. All of these experts were organizational specialists on post-disaster recovery and reconstruction from National Workplace Emergency Management Center which can be the decision-makers of assessing and measuring the recovery capacity and performance of local government officials. Core dimensions and indicators of community recovery was defined and choose on the basis of three stages: first, the dimensions was developed from a systematic analysis of existing recovery assessment literature, which gathered together a set of qualitative indicators of community recovery; and second, that the expert interview collectively represented the entire dimensions and indicators for the experts to judge the most important core indicators of each dimension.

Last, we captured and summarized the experts judgments of the core dimensions and indicators of community recovery. That four core indicators were chose to assess the four dimensions of community recovery, which included: (a) population recovery, assessed by the recovered quality of the interviewed affected families; (b) economy recovery, assessed by the recovered quality of gross domestic product (GDP); (c) building recovery, assessed by the recovered quality of damaged or destroyed buildings, and (d) infrastructure recovery, assessed by the recovered quality of key infrastructure system (e.g. electricity, roads, telecommunications, and water supply).

4 Results

In the result of our study, with the assessing approach of community recovery proposed in 3.2, we calculate the recovery scores of Wenchuan Community in four dimensions (population recovery, economic recovery, building recovery and infrastructure recovery), respectively. And three levels (low-recovery, medium-recovery, high-recovery) with the recovery scores are adopted in this study to assess the degree of recovery. So the low-recovery level belongs to the calculation of the recovery score RS as [0-0.577] and the tangent angle α as [0º-30º], the medium-recovery level belongs to the calculation of the recovery score RS as [0.577-1.732] and the tangent angle α as (30º-60º], the high-recovery level belongs to the calculation of the recovery score RS as [1.732-+∞] and the tangent angle α as (60º-90º]. The calculation results suggest that the economic recovery which can be obtained by the recovery score $RS_{economy}$=1.15 is the minimum value in the four dimensions, and the infrastructure recovery which can be obtained by the recovery score $RS_{infrastructure}$=135.19 is maximum value in the four dimensions. And the economic recovery of Wenhuan which belongs to the medium-recovery level, the population, buildings and infrastructure recovery belong to the high-recovery level.

FEMA has recognized that the recovery process is “a sequence of interdependent and often concurrent activities that progressively advance a community toward a successful recovery”. According to the time phases of community recovery proposed by Rubin(1985), National Research Council (2011) and FEMA, we divided the recovery and reconstruction process into three interrelated phases (shown in Figure 7), which can be used to determine the recovery degree of four dimensions of community recovery at different time phases: (1) Short-term recovery(<2 weeks), it “addresses the health and safety needs beyond rescue, the assessment of the scope of damages and needs, the restoration of basic infrastructure and the mobilization of recovery organizations and resources including restarting and/or restoring essential services for recovery decision-making”. (2) Intermediate recovery(2-20 weeks), it involves “returning individuals, families, critical infrastructure and essential government or commercial services to a functional, if not pre-disaster, state. Such activities are often characterized by temporary actions that provide a bridge to permanent measures.” (3) Long-term recovery (>20 weeks) is the phase“that may continue for months or years and address complete redevelopment and revitalization of the impacted area, rebuilding or relocating damaged or destroyed social, economic, natural and built environments and a move to self-sufficiency, sustainability and resilience”.

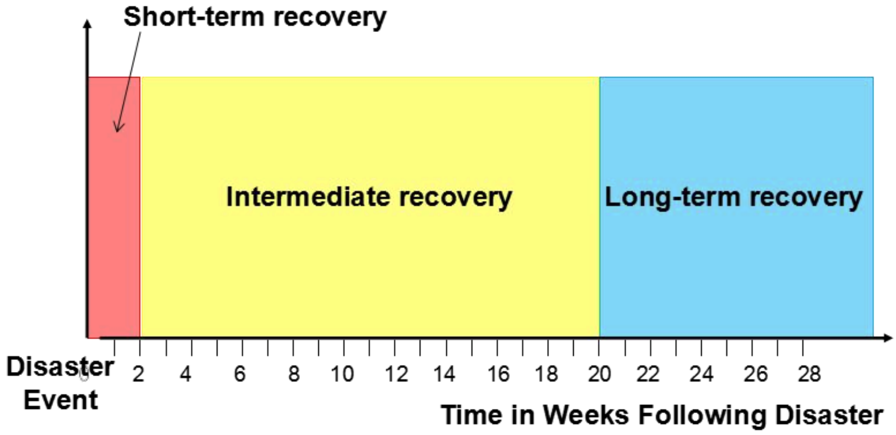

Figure 7. The three interrelated phases of recovery process

The data used to assess the four dimensions of the community recovery are all standardized (by dimensional analysis, a dimensionless quantity is a quantity without an associated physical dimension) to eliminate the impact of the different unit of each indicator.

4.1 Analysis of the population recovery of Wenchuan

Earthquake disasters are becoming more complex and uncertain in recent years as a result of the increasing populations living in seismic areas, which is considered to be exposed to a relatively high degree of earthquake risk. So this would increase the population affected by earthquake disasters, which in further can increase the pre-disaster extent of casualties. On the contrary, the trend of rapid urbanization could induce a future of increased post-disaster population recovery. And benefits and restoration efforts are distributed unequally in the recovery process amongst different sub-populations according to their geographic locations, socioeconomic status, and different reconstruction programs. Figure 8 plots the recovery process and score of population of Wenchuan. The interviewed data analysis was conducted to examine the recovered patterns of affected and matched population after Wenchuan Earthquake, and black curve plotted in this figure shows the actual recovered process of them in months following the earthquake disaster. By setting the status of the affected population we interviewed before the earthquake disaster as the initial pre-disaster status, and all of these affected population return to normal life (e.g. the injured people were treated, the homeless people were placed) as the acceptable post-disaster level. After the Wechuan Earthquake occurred, more than 80% families and population were severely injured, even homeless. But the affected population displayed a rapid recovery after the Wenchuan Earthquake, it only took less than three months to regain their pre-disaster levels. Previous studies have noted that the earthquake produced major spatial disparities not only in terms of physical damage, but also over the course of recovery (Hirayama, 2000; Murosaki, 2004). Red dotted line plotted in this figure shows the approximate recovered process of affected population, which is calculated by the assessment method we proposed in 3.2. The population recovery score of Wehchuan $RS_{population}$ is 98.46, and the tangent angle α is 89.41°, which belongs to the high-recovery level, suggesting that the affected population completely recovered from negative effects of earthquake disaster in the intermediate recovery period. The high-recovery level of population in the process of the post-disaster reconstruction is mainly due to the rescue principle of the Chinese Central Government that life is of top priority to make the effective emergency rescue measures. Within 24 hours after the Wenchuan Earthquake occurred, more than 20,000 soldiers of People's Liberation Army, and 70 medical teams were sent to search and rescue 4,130 wounded, and evacuate more than 3 million affected people. About 1.2 million relief tents, stretchers and other equipment, more than 800 tons of military food and supplies, 6380 tons of fuel were transported to the affected area. Focusing for the recovery process of affected population of Wenchuan, it can be observed that while most buildings suffered notable losses, which made the population no housing to live. The built of many settlements migrated the affected population from heavily-damaged areas to safer areas. These settlements concentrated the affected population, so that the affected population were more conducive to be treated, and can recover in a more quick speed.

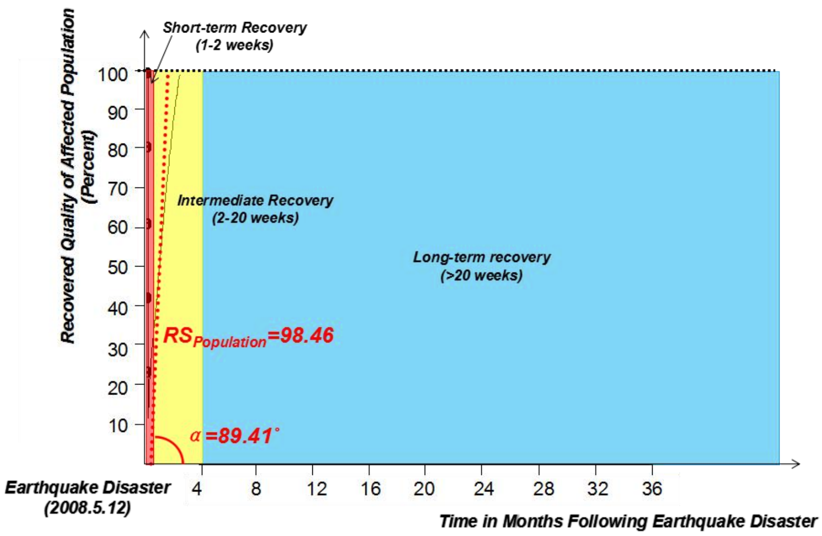

Figure 8. The recovery process and score of population of Wenchuan

4.2 Analysis of the economic recovery of Wenchuan

Economic recovery as a promoter of recovery, refers to making the best of the internal and external resources that are available to accelerate recovery to return to a previous level of economic function at a given point in post-disaster time. The local economic status determines how rapidly a community can recover from such earthquake disasters (Lee, 2014; Anne and Adam, 2011). Statistical time series are extensively available at community levels for key measures of economic recovery. Gross domestic product (GDP) provide a basic flow indicator of economic production or output. Figure 9 provides a summary view of the economic recovery process and score of Wenchuan in comparison to pre-disaster levels. The status of Wenchuan's GDP before the earthquake disaster can be set as the initial pre-disaster status, and after the Wechuan Earthquake occurred, the GDP of Wenchuan is only 22.53% of the pre-disaster status. The main reason of significantly economic damage is the rapid urbanization and the increasing economic development, which emphasized the significantly increased economic exposure and the economic effects (EMDAT, 2012; World Bank and United Nations, 2010). Black curve shows the actual GDP of Wenchuan in 10 years following the earthquake disaster. Statistical analysis here shows that Wenchuan's GDP experienced an accelerated decrease within the first year of Wenchuan Earthquake, which can be considered as the impact of the earthquake. Because after the earthquake, production activities in many sectors remained considerably lower than pre-disaster levels, including manufacturing, construction and wholesale, trade and services, and so on. Moreover, Wenchuan's GDP can be seen to increase rapidly in the second and third years after Wenchuan Earthquake. More detailed data demonstrates that this may be part of a larger restructuring effect that is accelerated by earthquake. A surge in construction activities associated with reconstruction lasted for three to four years in Wenchuan. During this period, GDP experienced a temporary boost (briefly recovered 10 percent of the entire quality) from reconstruction-related activities, including to some degree an inflow of funds from Chinese Central Government, but still lower than pre-disaster level. However, once the temporary reconstruction stimulus had almost completed, GDP stabilised even decreased again from the forth to sixth years after Wenchuan Earthquake. After that, the influence of earthquake gradually dissipated, Wenchuan's GDP received an extraordinary boost from development demand in post-disaster markets, and stabilisation was attained more rapidly in each sector of the economy. But until 2016, statistical data shows that Wenchuan's GDP did not attain pre-disaster levels, which briefly recovered to 60 percent of the entire quality. So we assumes that the GDP after 2016 increases as the average growth rate (25.2%) of 8 years after the earthquake (2008-2016), and finally it recovered to the pre-disaster level in 2018. By using the assessment method we proposed in 3.2, red dotted line plotted in figure 9 shows the approximate recovered process of economy of Wenchuan (used the indicator of GDP to assess) in months following the earthquake disaster, the economic recovery score of Wehchuan $RS_{economy}$ is 1.15, and the tangent angle α is 48.99°, which belongs to the medium-recovery level, and is least recovery of these all four dimensions. Some economic characteristics (a lack of diversified manufacturing and services, a dependence on specialized entitlements, fragile industrial production chains, low-income settlements, limited access to economic resources) of Wenchuan contribute to such a long recovery process of the economy. Aiming to improve the economic recovery to earthquake, built-in a strong and diverse regional economy will be the most effective scenario. The resilient-economy does not merely make the best of the resources available to return to a previous level of economic function rapidly after the earthquake disasters, but also to increase the capacity of the economic support mechanisms in order to keep the built environment operational and adaptable with the support of post-disaster recovery activities (including contextualizing local economic conditions and prioritizing development projects).

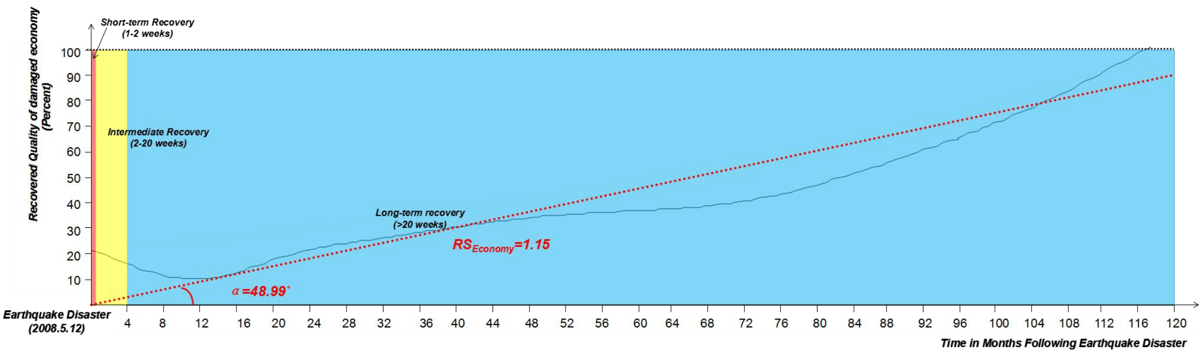

Figure 9. The recovery process and score of economy of Wenchuan

4.3 Analysis of the building recovery of Wenchuan

Buildings built without adequate consideration of the earthquake effects weaken the community recovery to earthquake. At this spatial scale, earthquake damage (calculated as the percentage of housing units damaged and destroyed) of buildings ranged from no signifcant damage to a loss of 95 percent of the building stock in Wenchuan after the earthquake disaster. Figure 10 maps three-year building recovery process of Wenchuan. The status of buildings of Wenchuan before the earthquake disaster can be set as the initial pre-disaster status, and more than 90 percent of these buildings were damaged even destroyed in Wenchuan Earthquake, which can be interpreted that the low-quality building stock and lack of the earthquake-resistant building codes are the directly and important influencing factor of the extremely-high extent of damage (Jie and Shaoyu, 2015). Black curve plotted in this figure shows the actual repaired and reconstructed process of buildings of Wenchuan in months following the earthquake disaster. Almost 10 percent of the damaged building were repaired in the period of short-term recovery(<2 weeks) and the intermediate recovery(2-20 weeks). The repaired and reconstructed process of buildings of Wenchuan did not experience a similar speed. During the first two years is interesting, as it explained the immediate rise in repair speed. The decrease recovery speed after the first two years could indicate the reconstruction of the destroyed buildings need long time to attain pre-disaster levels. By three years after the earthquake, the influence of this earthquake disaster has diminished dramatically, and the destroyed buildings were all reconstructed. According to the guidelines of the central government and heavy financial support ($ 3.5 billion), the local government is almost equivalent to build a "new" Wenchuan Community just over three years. Red dotted line plotted in this figure shows the approximate repaired and reconstructed process of building of Wenchuan in months following the earthquake disaster, which is calculated by the assessment method we proposed in 3.2. The recovery score of buildings $RS_{buildings}$ is 3.37, and the tangent angle α is 73.47°, which belongs to the high-recovery level. Building recovery refers to the capacity of a community for post-disaster building reconstruction and retrofitting, which are often amenable to taking on board resilient technologies, given that they have witnessed the effects of the initial threat. High-level building recovery is addressed in rebuilding and retrofitting these earthquake resistant buildings, which helps to build-in recovery and provide enhanced safety built environment for community. So in the repaired and reconstructed process, the new buildings are designed and built with the application of current high seismic design standards, which can support recovery by helping the built environment prevent or minimize damage during earthquake disasters.

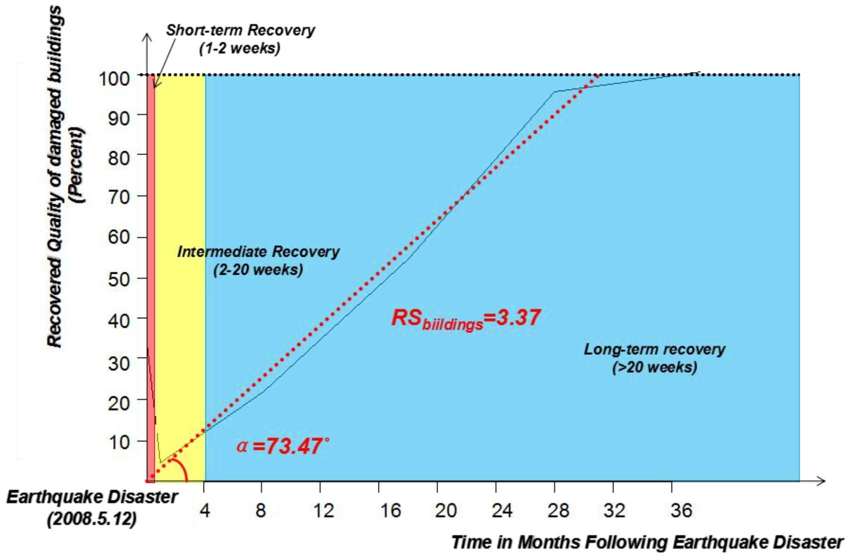

Figure 10. The recovery process and score of buildings of Wenchuan

4.4 Analysis of the infrastructure recovery of Wenchuan

Infrastructure recovery is the judgment to characterize the ability of the key infrastructure which is threatened and disrupted by the earthquake disasters to recover function to the extent possible in post-disaster time. The disruption of the infrastructure system in a major earthquake disaster as the indirect economic damage of a community, suggests whether such community to be resilient, to what extent. The capacity of critical infrastructure to quickly restore services following an earthquake determines how rapidly communities can recover from such disasters. From Figure 11, we can conclude that infrastructure recovery process and score of Wenchuan. The status of infrastructure system (including electricity, roads, telecommunications, and water supply) of Wenchuan before the earthquake disaster can be set as the initial pre-disaster status, and all of them were disrupted and destroyed in the immediate aftermath of Wenchuan Earthquake. A high rate of infrastructure deterioration may be due to the poor quality, the aged equipment, and the highly exposed locations, while the development of the infrastructure system is identified as a strategic priority to be essential to increase the recovery of infrastructure (Kathleen et al., 2010; Whitman et al., 2013). Moreover, the infrastructure systems are considered in most rapid recover trends in the four dimensions, shown in black curve of Figure 11, it is evident that, to a large extent, the critical infrastructure and services took three months to regain its pre-disaster levels. The water supply and telecommunications were recovered in short-term recovery period, the electricity and roads were recovered in the intermediate recovery time period. Red dotted line revealed the recovery score of infrastructure that measured by the recovery assessment approach proposed in 3.2, which was conducted to examine the recovery patterns of the infrastructure system. The recovery score of infrastructure $RS_{infrastructure}$ is 135.19, and the tangent angle α is 89.58°, which belongs to the high-recovery level, and is expected to be most recovery compared with other three dimensions. Because the local government of Wenchuan spared no effort to return the critical infrastructure system quickly to pre-disaster levels within a shortly time period. Many researches addressed that the reliable and resilient infrastructure system is a priority goal for earthquake-resilient communities, and the importance of enhancing defence infrastructure design to optimize mitigation, disaster planning, and response and recovery efforts, which played a vital role in improving the community recovery to earthquake disasters (Chang et al., 2011; National Infrastructure Advisory Council, 2010

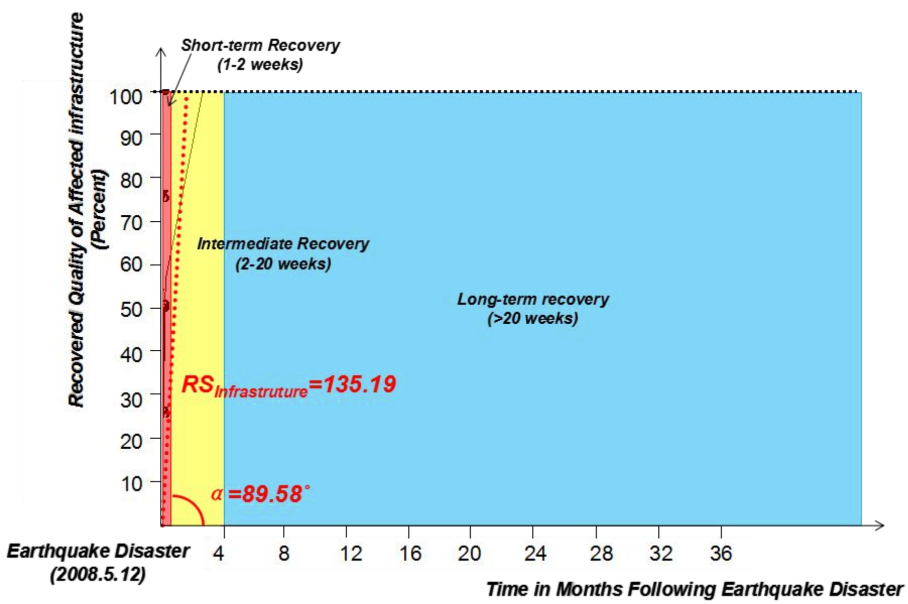

Figure 11. The recovery process and score of infrastructure of Wenchuan

5 Discussion

The overall results of our study highlight the community recovery process which is considered to be an uncertain, complex, conflict-laden, multidimensional and nonlinear process. The extent of damage, land use, building codes, available recovery resources, the broader structural changes, social disparities, prevailing pre-disaster trends, decision making, and organization capacity are factors all directly related to the rate of recovery. “Both long-term trends and an urgent desire to return to normal, exert an important influence on the reconstruction processes” (Haas et al., 1977). And higher recovery scores mean higher recovery levels and lower recovery scores mean lower recovery levels. The population, building and infrastructure dimensions have high-recovery levels, particularly the infrastructure recovery is highest. However, the economic recovery score is poor which tends to have lowest recovery level in contrast to other three dimensions and needs more consideration in the near future. While the external resources will be not sufficient to meet the needs of disaster-affected areas throughout the recovery process of Wenchuan. The decision-makers of local government must learn how to address the challenges of disaster response and recovery at the community level, how to leverage community capacity from the earliest stages of disaster response, and to use external resources to bolster and supplement local capacities. In the rebuilding and recovery process of Wenchuan, the community has received a large number of external resources from Chinese Central Government and other provinces and cities to enhance community recovery to earthquake, including incorporating long-term recovery goals into disaster response and pre-disaster planning, expanding the knowledge base by incorporating research into recovery and harnessing lessons learned from international experiences, and developing an outcome-oriented approach to disaster recovery planning, which makes Wenchuan exhibit a high recovery and the reconstructed community be more resilient to the next earthquake. The rebuilding and recovery process of Wenchuan supports perspective of recent research that returning to pre-disaster levels does not necessarily mean building back for the better (Ganapati et al., 2012). From a dynamic and development oriented viewpoint, there is no exact returning to “pre-disaster” conditions once a disaster has happened. Regardless of whether the disaster has stimulated positive change or has hastened the development trend of a community, the community will never be exactly the same as it was before the disaster occurred (Greene, 2006). Furthermore, recovering to the pre-disaster situation implies restoring the pre-event inequality, exploitation and vulnerability as well (Oliver-Smith, 1990). The idea of “build back better” (Lyons et al., 2010) or “recover better” should be adopted, especially in the case of developing countries where “build back better” is indeed possible (Mulligan and Nadarajah, 2012) if the ideas of development, vulnerability and risk reduction are integrated into recovery activities (Shaw, 2006), with the physical and social planning integrated with one another to address local needs in culturally appropriate ways (Mulligan et al., 2012). And the post-disaster recovery activities provide an opportunity to learn constantly and grow stronger from the previous natural disasters, which can be used to support the proactive mitigation strategies-to rebuild stronger, change land-use patterns, and reduce development in hazardous areas, and also to reshape those negative social, political, and economic conditions that existed pre-event (NHC, 2006; Reddy, 2000; Olshansky, 2006; Birkland, 2006). Mitigation can be a powerful tool for anticipating the unknown, for reducing losses, and for facilitating recovery following a hazard impact. Mitigation strategies, for instance, may reduce potential losses by steering development to the less hazardous areas of a proposed community or by modifying building design to reduce potential losses (Burby et al., 1999). They are also useful in preparing communities to deal with post-disaster scenarios by identifying actions that should be done prior to and immediately following events to help guide recovery processes and to reduce future losses.

6 Conclusion

During the past few years a range of high profile, complex and uncertain earthquake disasters occurred in China, such as the Wenchuan earthquake (May 12, 2008), the Yushu earthquake (April 14, 2010), and the Ya'an earthquake (April 20, 2013), which have stimulated an escalation in theoretical developments concerning the way to be quickly recovered from the earthquake damage. An examination of the current and expected capabilities of communities to confront a potential shock yields understanding the effective risk reduction strategies from another perspective, that build-in the resilient communities are one of the key goals for emergency managers and decision makers to improve the local earthquake prevention and response, and prioritize efforts that need to be undertaken in order to maximize the effectiveness of various recovery measures. Effects to address these needs have focused upon new approaches for analyzing the concept of community recovery and proposing community recovery assessment methodologies. The key challenge is how to measure recovery and recovery improvements. Assessing the community recovery leads to a better understanding of the concept and characteristics of it, thereby making it possible to determine how best to improve the community recovery to withstand shocks in the future. Thus, this paper has proposed and demonstrated a quantitative framework for assessing community recovery, while implemented for the case of earthquake to Wenchuan Community. We drew on much of the current literature that currently exists on studying community recovery in different contexts, and by so doing we define the community recovery, and addressed the multiple, interrelated dimensions of it (population, economy, building, and infrastructure). Well-defined and consistently applied assessment measures of community recovery it possible to carry out various kinds of comparative studies, to determine why some systems are more resilient than others, and to assess recovery changes in communities over time. The results suggest that most dimensions of Wenchuan represented the characteristics high recovery, that infrastructure recovery is highest, and the economic recovery is lowest. The perspectives contributed to identify concentrations of impact and differentials in recovery of Wenchuan for guiding planning of appropriate response and reconstruction policies to enhance the community recovery to earthquake, helping Chinese Central Government to assess and measure the recovery capacity and performance of local government officials of Wenchuan, and emphasizing that the community recovery is strongly influenced by the decision making of local governments. While this paper holds promise for advancing the knowledge of assessing community recovery, it is clear that some limitations should be noted regarding the methodology developed here. First, the approach is focused on one specific earthquake scenario (Wenchuan Earthquake) and one specific community (Wenchuan). Consequently, variations in effects across other potential earthquakes and other characteristics of communities were not discussed. Second, assessing community recovery is focused on describing core dimensions and indicators which can used by the decision-makers to assess and measure the recovery capacity and performance of local government officials (for example, identifying GDP to assess economy recovery), not considering other economic or social indicators, such as personal income, poverty, and unemployment, and so on, in assessing patterns and progress of community recovery. Third, the statistical data used to assess different dimensions of community recovery are likely to be sparser and less reliable, special surveys or arrangements with data collecting authorities may then be necessary in the future research. Last, core indicators of community recovery was defined and chose on the basis of expert interview, these experts we interviewed are all from one organization (National Workplace Emergency Management Center), who may not always have a complete understanding of community recovery.

In our future research, it would be worthwhile developing comparative insights on community-scale recovery. For example, quantitative indicators of community recovery should be used as a benchmark or reference for more in-depth study, which can be used systematically by local governments and researchers to monitor complex recovery processes. And validation may be possible in the future through expanded databases of the consequences of earthquakes for comparable regions, in order to give the operator a wider and deeper insight in the recovery patterns of different communities. Furthermore, the concept framework of community recovery should be evaluated and revised more efficiently and effectively by collecting and analyzing a large number of expert judgments. And considering long-term recovery and reconstruction, the framework should be extended in order to perform a dynamic assessment model of community recovery, where time-dependent indicators reflect post-disaster recovery capacity and performance of local government officials over time. Learning from the past recovery and rebuilding process, new research is needed to fully operationalize and realize the concept of recovery, and develop appropriate techniques of designing mathematical models to assess and characterize community recovery, which can help local government and policy makers develop the scientific and effective disaster recovery plan for the next devastating earthquake disaster.

Competing interests. The authors declare that they have no conflict of interest.

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