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The Implementation of Resilience Engineering to Deal with Climate Change Impact

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Climate change is a very interesting subject, because it has been compelling us to review our thinking, our development concepts, practices, paradigms, models, and so on from the view of the environment. In such introspections, we may identify the mistakes, weaknesses and unintended consequences of our development concepts, practices; and we may try to overcome those mistakes and will be conscious to avoid such shortcomings in the future. Land and water resources degradation are the major problems in the world. Poor land use practices and improper management systems have played a significant role in causing high soil erosion rates, sediment transport, and loss of agricultural nutrients. This causes various effects on resource bases like deforestation, expansion of residential areas, and agricultural land. The watershed is also facing high erosion due to the effects of intense rainfall of the watershed which aggravates the land cover change of the watershed. This continuous change in land cover has influenced the water balance of the watershed by changing the magnitude and pattern of the components of stream flow between surface runoff and groundwater flow in increasing the extent of the water management problem. In this study, the assessments of resilience engineering and its function as a framework for the environmental issues, such as resilience and management of water and public infrastructure has

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been done. After risk assessment, we obtained five risk levels and their corresponding resilience levels. The two can be regarded as negatively correlated. And at the same time, four corresponding adaptions are also proposed according to the resilience levels.

Keywords: Hazard; resilience engineering; risk; vulnerability.

1. INTRODUCTION

In the fields of engineering and construction, resilience is the ability to absorb or avoid damage without suffering complete failure and is an objective of design, maintenance and restoration for buildings and infrastructure, as well as the communities. A more comprehensive definition is that it is the ability to respond, absorb, and adapt to, as well as recover in a disruptive event. A resilient structure/system/community is expected to be able to resist to an extreme event with minimal damages and functionality disruptions during the event; after the event, it should be able to rapidly recovery its functionality similar to or even better than the pre-event level.

Resilience is a multi-facet property, covering four dimensions: technical, organization, social and economic. Therefore, using one metric may not be representative to describe and quantify resilience. In engineering, resilience is characterized by four Rs: robustness, redundancy, resourcefulness, and rapidity. Current research studies have developed various ways to quantify resilience from multiple aspects, such as functionality- and socioeconomic- related aspects.

The built environment need resilience to existing and emerging threats such as severe wind storms or earthquakes and creating robustness and redundancy in building design. New implications of changing conditions on the efficiency of different approaches to design and planning can be addressed in the following term. Ecological resilience was defined as a "measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between state variables. The application to ecosystems was later used to draw into other manners of human, cultural and social applications. Stability, on the other hand, is the ability of a system to return to an equilibrium state after a temporary disturbance. Unlike material and engineering resilience, ecological and social resilience focus on the redundancy and persistence of multi-equilibrium states to maintain existence of function. Engineering resilience has inspired other fields and influenced the way how they interpret resilience on each other.

2. THEORETICAL CONSIDERATIONS

Engineering resilience refers to the functionality of a system in relation to hazard mitigation. Also known as adaptive resilience is a new concept that shifts the focus to combining the social, ecological and technical domains of resilience. Add recovery for the operation phase of a building and Risk Avoidance for the planning phase is crucial for the risk avoidance.

2.1 Resilience and Sustainability

Resilience in socio-ecological system is synonymous with a region that is ecological, economically and socially sustainable. Resilience focuses on designing for the unpredictable, while sustainability focuses on responsive designs. (not only for “climate”). Some forms of resilience such as sustainable design focuses on efficient and optimized systems.

2.2 Quantification

The first influential quantitative resilience metric based on the functionality recovery curve was proposed by Bruneau et al. [1] on the community losses as follows:

$$R_L=\int_{t_0}^{t_f}(100\,\% - \mathrm{Q(t)})\mathrm{dt} \qquad (1)$$

where $\boldsymbol{R_L}$ is the magnitude of resilience, Q(t) is the functionality at time t; t_0 is the time when the event strikes; t_f is the time when the functionality full recovers. Resilience index is a normalized metric between 0 and 1, computed from the functionality recovery curve (Reed et al., 2009).

$$\mathrm{R}=\int_{t_0}^{t_h} \mathrm{Q(t)dt}/(t_h\text{-}t_0) \qquad (2)$$

where R is the risk, Q(t) is the functionality at time t; t_0 is the time when the event strike; t_h is the time horizon of interest.

3. QUANTIFICATION METHODS on RESILIENCE MEASUREMENT

Strengthening resilience is critical if communities are to respond positively to extreme events, climate change and disasters. An increase in the frequency and severity of disaster events since the turn of the century have caused significant economic and social damage, and demonstrate the considerable challenges communities face around the world. Globally, poorer communities also disproportionately face diverse impacts associated with climate change, which may widen social inequality and alter access to natural resources. Such challenges affect not only the present but have the potential to stretch into the future. In context of unpredictability and dynamic change, the concept of resilience has gained prominence in science, policy and practitioner circles, as a positive attribute of people to be strengthened. This is reflected in international frameworks such as the Sustainable Development Goals, rich literature in the fields of disaster risk reduction, conservation, climate change adaptation and community development [2].

3.1 Institutional Framework for Operational Resilience Engineering

Quantitative metrics lack explanatory power around how resilience is strengthened, in what ways and, importantly, for whom and why, and do not adequately inform future investment on resilience alone. There are also limits to capacity frameworks that are commonly used in resilience programmes. Much research has identified capacities that confer resilience. Yet people's resilience is more than the sum of a set of capacities they build up to address extreme events and other climate changes [3]. More focus on the dynamics and process of resilience building is needed to better evidence progress and support more radical responses to change that pushes beyond 'business as usual' development programming.

3.2 Improving Resilience Measurement: Learning to Adapt

Resilience has been put at the center of the development agenda, particularly with regard to climate change and disasters [2]. Resilience has become a concept widely used as a positive attribute of people, institutions or ecosystems that should be enhanced, as it supports beneficial change and development in times of uncertainty. Here we focus on the resilience of communities in relation to environmental and climatic change. Unpredictability conceives of resilience as a dynamic approach to effectively manage and shape people's response [4]. To help minimize negative impacts on people's livelihoods and build flexibility to adapt to changing conditions is the purpose. The more resilient a household or community is, the greater its potential ability to respond and recover [5].

There are four key characteristics of the resilience concept that challenge its application [2].

- Uncertainty is part of how systems work.
- Systems are inherently dynamic. Both positive and negative, direct or indirect, and can suppress or accelerate change situation.
- Temporal, societal and spatial cross-scale are interactions.
- Multiple stressors and catalysts including hazards or events already known and identified, such as a flood or drought, as well as those more un-foreseen and not necessarily experienced before, such as a pandemic, act on systems and interact.

Due to the complexity of resilience, and the process of resilience building itself, which requires different approaches to assessment in differing contexts, assessing people's resilience in practice is challenging, with no agreed approach, method or tool established.

Resilience measurement is challenging for a variety of reasons. First, conceptually, resilience is difficult to pinpoint in tangible terms. Second, the challenge of identifying appropriate evaluative methods and tools which adequately capture resilience. Third, "when" to measure resilience is tricky [2]. Resilience is a process which evolves – it is not an end point that can be measured at a set point in time [6], as such an approach does not fully capture the emergent nature of how people's resilience unfolds. Fourth, we might also be measuring people's potential latent capacity, which comes into play in a given set of circumstances, but may not have been tested in response to recurring hazards and stresses or other more novel events. Fifth, typical programming approaches to development are often superimposed onto resilience interventions with timing and flexibility, not only. Standard programmes are typically short and rarely phased or structured around key policy or government timelines which could help activities achieve the most impact [7]. Many typically focus on people–place connections, knowledge and leadership. Strategic relationships or networks can provide essential support to help people prepare for and recover from climate extremes [8]. Improved knowledge and forms of learning have also been demonstrated [4]. This might include learning from a past disaster to enhance a community's social memory [9].

3.3 Applying 3As Capacity Frameworks (Lucy Faulkner and Vicky Sword-Daniels, Itad [10]):

The 3As framework unpicks people's resilience in terms of their adaptive, anticipatory and absorptive capacity. They are:

1. Adaptive capacity refers to people's ability to positively respond to the dynamic and evolving risk of shocks and stresses, and to multiple climate-related changes, to reduce the likelihood of harmful outcomes. It is activated before, during and after disturbances, through actions such as income and livelihood strengthening activities, climate-resilient agriculture, climate-resilient development plans and processes, and mainstreaming risk in sectoral development plans.
2. Anticipatory capacity means people can undertake proactive actions to avoid upheaval from different climate-related events. This capacity is activated before disturbances, through actions such as the uptake of climate information, the preparation and use of disaster preparedness plans, and the use of climate-resilient building practices.
3. Absorptive capacity is the ability of people to buffer the impacts of climate variability and hazards in the short term to avoid collapse. This capacity is activated after disturbances, and is supported by actions such as income diversification, dietary diversity, access to credit, and access to insurance and other safety nets.

4. APPLICATION

4.1 Surface Water

4.1.1 Water storage as an adaptation strategy to reduce climate vulnerability

Water storage can play a key role in both sustainable development and adaptation to climate change (Fig. 1). All kinds of water storage are also potentially vulnerable to changes in climate with less rainfall, ponds and less frequently to provide enough water for irrigation.

4.2 Groundwater

4.2.1 Manage aquifer recharge

In many cases, adaptation measures to reduce the vulnerability of groundwater to climatic change are the same as those needed to deal with issues such as overallocation or unsustainable withdrawals of groundwater, or floods. Managed aquifer recharge (MAR) cuts losses from evaporation, stores water for use in dry years, and can lessen flooding in downstream areas. In dry climates MAR is increasingly common as shallow aquifers are often widespread and the costs can be relatively low, but it also has potential in humid regions. Afforesting degraded land, on-farm conservation, infiltration ponds, and small reservoirs are all good strategies in the dry season and also an adaptation strategy in drylands [12].

4.3 Livelihood: Society in Institution and Natural Hazards of Floods and Droughts

Change is inherent to the human context. Whether the need is catalyzed by extreme events such as floods, droughts and economic collapse or more gradual processes of change in environmental, technological or economic systems, we survive via adaptation.

Strengthening the adaptive capacity of populations at all levels from the local to the global is, as a result, among the most important challenges facing development. The ability to adapt to local problems such as floods and droughts often depends on systems and flows that connect to regional and global levels.

Resilient livelihoods are those that can first recover (self-organize) after disruption and, following recovery, are capable of learning and adapting; they have a strong ability to cope with surprises and change as conditions require.

4.4 Public Infrastructure

The main spirit of the disaster risk management framework is to achieve maximum disaster reduction benefits with the minimum investment cost. For the connection between analysis aspect and analysis aspect, five stages works, such as risk pre-assessment, risk analysis, risk characteristics description and assessment, risk management and risk communication.

The currently more accepted view is: "Disaster (Risk) is formed by the combined effect of Hazard, Exposure and Vulnerability of disasters in a certain area." The intersection area of the three factors represents the degree of disaster risk faced, that is, the size of the intersection area, is directly proportional to the disaster damage endured. We can first conduct a risk assessment, and then control, avoid, reduce, transfer and strengthen the organization's disaster resistance and response capabilities to reduce the losses that may be caused when the company faces disasters, which can reduce the vulnerability of the company and reduce the disaster risk area. ; Exposure can be reduced by formulating laws and disaster reduction plans to regulate buildings in disaster-prone areas, or by increasing social awareness of risks and changing people's habit of living and building in disaster-prone areas. exposure purpose. General risk management methods can be divided into risk avoidance, risk mitigation and risk transfer. The final unavoidable part is the disaster risk that the enterprise itself needs to bear, that is, the degree of risk retention. The part reserved through disaster assessment and management to reduce disasters is the specific actions for disaster reduction. In all things, be prepared before you act, and you will definitely do something accordingly. In terms of disaster prevention, you must first know about disasters and dangers, and then avoid disasters and take action to avoid dangers, so that you can get twice the result with half the effort. According to the international risk management standard ISO31000, the process of risk assessment can be divided into three major steps: risk identification, risk analysis and risk assessment. Risk assessment identifies potential risks through subjective. The judgment and classification of disaster types can be divided into two categories: natural disasters and man-made disasters using consciousness or objective statistical methods; risk analysis is to evaluate the scope and degree of possible impact of risks.

Disaster risk is expressed as the likelihood of loss of life, injury or destruction and damage from a disaster in a given period of time. They own the following relationship:

[Disaster Risk]=[Hazards (Mainly Natural Causes)] × [Vulnerability (Mainly Social) Causes)] × [Exposure (Previous Actions)] (See Figs. 2 and 3).

And meanwhile we have that Resilience= 1 – Risk = Adaption (See Fig. 5).

A hazard is a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Hazards may be natural, anthropogenic or socio-natural in origin.

The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas, and we call it “Exposure”. If a hazard occurs in an area of no exposure, then there is no risk. Take the example of typhoons, if it in impact was because there were no people or property in the path of typhoon, in other words, there was no exposure. The extent to which exposed people or economic assets are actually at risk is generally determined by how vulnerable they are, as it is possible to be exposed but not vulnerable.

Vulnerability accounts for the susceptibility to damage of the assets exposed to the forces generated by the hazard. Fragility and vulnerability functions estimate the damage ratio and consequent loss respectively, and/or the social cost (e.g., number of injured, homeless, and killed) generated by a hazard, according to a specified exposure.

General risk management methods can be divided into risk avoidance (avoid), risk mitigation (mitigation) and risk transfer (transfer). Finally the unavoidable part is the disaster risk that the enterprise itself needs to bear, that is, the degree of risk retention. Reducing the disaster retention part through disaster assessment and management is the specific action for disaster reduction. Risk avoidance means completely avoiding risks and cut off sources of risks, such as removing vulnerable factors and relocating settlements within the area affected by landslides. Risk mitigation is taking countermeasures to reduce the probability of disaster and reduce losses for controllable risks, including engineering, non-engineering and management. Risk transfer characterize as transferring all or part of the risks to others or other places to reduce risk losses. For example, contract signing, disaster insurance, etc. And Risk retention act as if the cost of risk countermeasures is greater than the loss, or if the loss is small and the frequency is high, the manager can manage the risk to ensure that it is within the acceptable range. (Fig. 4).

This study conducts a large-scale hotspot analysis on the country's major public infrastructure under the scenario of climate change, and evaluates the possible impact of disasters through a systematic and objective scientific demonstration and analysis method. Among them, the relevant data and information on meteorological changes are the basis for the relevant impact analysis of this study. In the future, relevant assessment indicators can still be refined to conduct vulnerability assessments more in line with the key indicators of each major public infrastructure. Various public infrastructure authorities can subsequently target hot spots and analyze the causes of their vulnerability, so as to carry out effective climate change adaptation actions to reduce the vulnerability of major public infrastructure systems, improve their adaptability to climate change, and thereby maintain their due operational functions and reduce the impact on society.

From Figs. 4 and 5, the risk assessment results are as follows in Fig. 5, and show the 5 risks severity levels as normal-low, low-medium, medium, high-medium, and high; there are corresponding to the resilience levels as high, high-medium, medium, low-medium, and normal-low by combining Eqs. (1) and (2) and Fig. 5. The adaptions for the resilience levels are retention (high resilience), transfer (high-medium resilience), mitigation (medium resilience), and avoidance (low-medium and low resilience).

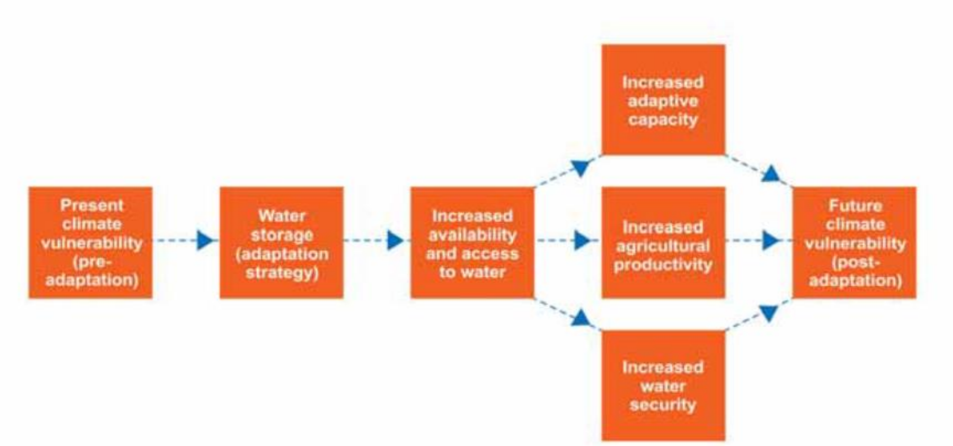

Fig. 1 Adaptation strategy on water storage for Reducing climate vulnerability (McCartney and Smakhtin [11])

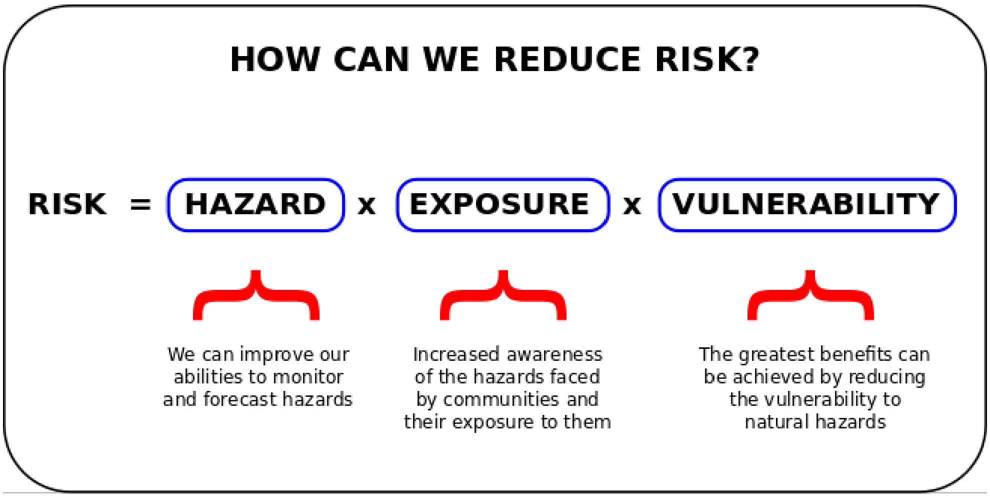

Fig. 2. Components of risk

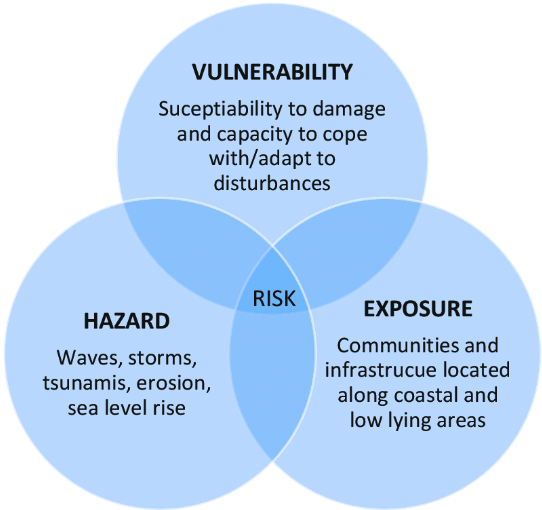

Fig. 3. The details of the examples for each component of risk

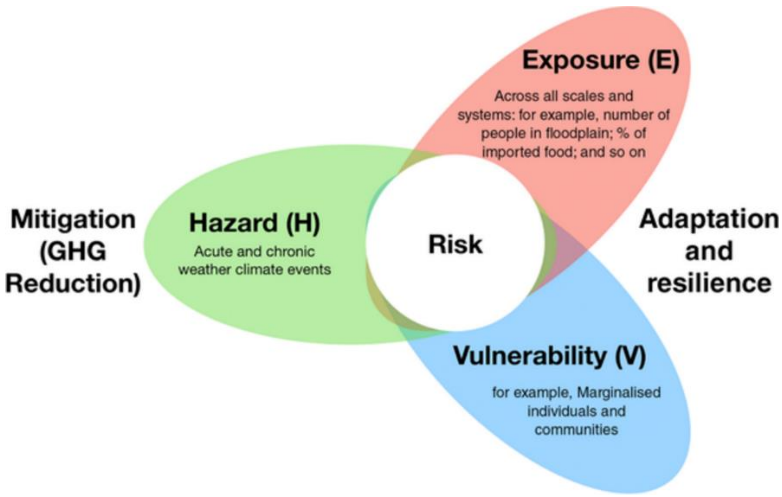

Fig. 4. The conceptual example of adaption and resilience

Items		Disaster Risk =[Hazards (Mainly Natural Causes)] ×[Vulnerability (Mainly Social Causes)] × Exposure (Previous Actions),								
	Score	2	3	4	5	6	7	8	9	10
Adaption	5									
	4									
	3									
	2									
	1									
There are 5 levels: normal- low (green), low-medium (light green), medium (yellow), high-medium (orange), and high (red). Index: The higher the risk, the lower the adaption or resilience.										

Fig. 5. The score or level for the relationship between risk and resilience (or Adaption)

5. CONCLUSION

Climate change will become more prominent in the future with extreme rainfall, strong winds and extreme temperature to cause notable increases in climate related risks. After risk assessment, we obtained five risk levels and their corresponding resilience levels. The two can be regarded as negatively correlated. And at the same time, four corresponding adaptions: retention, transfer, mitigation, and avoidance (avoid), are also proposed according to the resilience levels. Some phases for the processes on resilience could be:

A. Profile information: Preparing for establishing the level of priority of the different river basins. The needed information are: demography, political boundaries, legal land classification, land use and land cover, land tenure, irrigation, hydropower and other infrastructures, priority sites for biodiversity conservation, and climate risks and vulnerabilities and geohazards.
B. Multi-agency process: Some of the key criteria with a multi-sectoral and multi-agency process in high cultural and historical value on is necessary.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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