Original Research Article

Resilience Engineering onClimate Change in Environment

Abstract

Climate change is 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 environment. In such introspections, we may identify the mistakes, weakness and unintended consequences of our development concepts, practices, models and paradigms; and we may try to overcome those mistakes and will be conscious to avoid such shortcomings in the future/ new models, plans, programs and projects. 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 area and agricultural land. The watershed is also facing high erosion by 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 that are surface runoff and ground water flow, which results increasing the extent of water management problem. An integrated and holistic approach is necessary to find solutions for flood management problems. Besides, a regional water resources management plan should be developed, taking into account both flooding and water scarcity issues. In this study, the assessments of resilience engineering and its function of framework on livelihood the environmental issues, such as resilience and management on water, soil, foods, flood-drought, and public infrastructure, are presented and discussed.

Keywords: *Hazard；Resilience Engineering；Risk；Robustness；Resourcefulness；Rapidity；Redundancy；Recovery；vulnerability；infrastructure；*

I INTRODUCTION

According to the dictionary, resilience means "the ability to recover from difficulties or disturbance." In the 19th century, the term was used to describe a property in the strength of timber, as beams were bent and deformed to support heavy load.Resilience was then refined in relation to the capacity of specific materials to withstand specific disturbances. These definitions can be used in engineering resilience due to the application of a single material that has a stable equilibrium regime rather than the complex adaptive stability of larger systems. While the 20th century, researchers studied resilience in relation to child psychology and the exposure to certain risks. Resilience was used to describe people who have "the ability to recover from adversity."

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** (as Fig. 1)**.** 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." Such a framework can be applied to other forms of resilience. The application to ecosystems was later used to draw into other manners of human, cultural and social applications. The random events are not only climatic, but instability to neutral systems can occur through the impact of fires, the changes in forest community or the process of fishing. Stability, on the other hand, is the ability of a system to return to an equilibrium state after a temporary disturbance. Multiple state systems rather than objects should be studied as the world is a heterogeneous space with various biological, physical and chemical characteristics. 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, e.g. supply chain resilience.

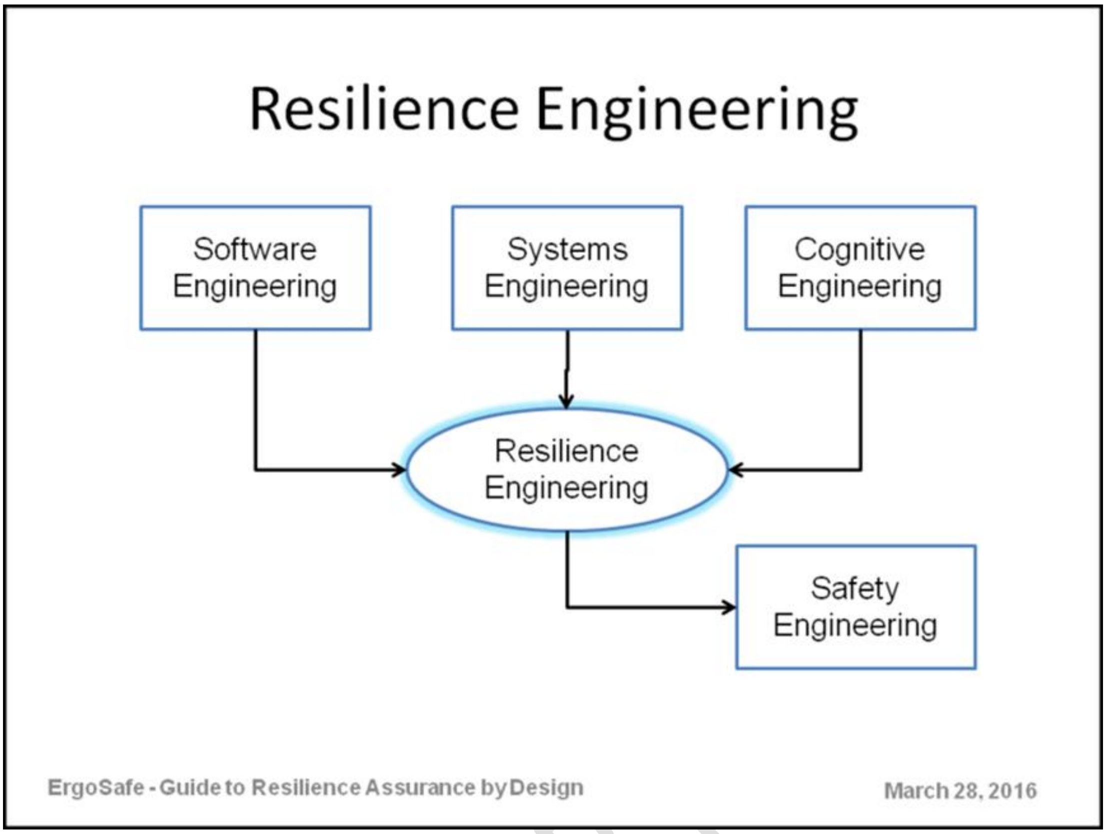

Fig. 1 The Diagram of Resilience Engineering

II THEORETICAL CONSIDERATIONS

Engineering resilience refers to the functionality of a system in relation to hazard mitigation. Within this framework, resilience is calculated based on the time it takes a system to return to a single state equilibrium. Researchers at the MCEER (Multi-Hazard Earthquake Engineering research center) have identified four properties of resilience: Robustness, resourcefulness, redundancy and rapidity.

- Robustness: the ability of systems to withstand a certain level of stress without suffering loss of function.

- Resourcefulness: the ability to identify problems and resources when threats may disrupt the system.
- Redundancy: the ability to have various paths in a system by which forces can be transferred to enable continued function
- Rapidity: the ability to meet priorities and goals in time to prevent losses and future disruptions.

Also known as adaptive resilience, social-ecological resilience is a new concept that shifts the focus to combining the social, ecological and technical domains of resilience. The adaptive model focuses on the transformable quality of the stable state of a system. In adaptive buildings, both short term and long term resilience are addressed to ensure that the system can withstand disturbances with social and physical capacities. Buildings operate at multiple scale and conditions, therefore it is important to recognize that constant changes in architecture are expected. Add Recovery for the operation phase of a building and Risk Avoidance for the planning phase of the building in the planning phase of a building, site selection, building placement and site conditions are crucial for the risk avoidance. In the operation phase of the building, a disturbance does not mark the end of resilience, but should propose a recovery plan for future adaptations. Disturbances should we be used as a learning opportunity to assess mistakes and outcomes, and reconfigure for future needs.

2.1 Resilience and Sustainability

It is difficult to discuss the concepts of resilience and sustainability in comparison due to the various scholarly definitions that have been used in the field over the years. Many policies and academic publications on both topics either provide their own definitions of both concepts or lack a clear definition of the type of resilience they seek. Even though sustainability is a well-established term, there are generic interpretations of the concept and its focus. A new characterization of the term 'sustainable resilience' is proposed which expands the social-ecological resilience to include more sustained and long-term approaches. Sustainable resilience focuses not only on the outcomes, but also on the processes and policy structures in the implementation. Both concepts share essential assumptions and goals such as passive survivability and persistence of a system operation over time and in response to disturbances. There is also a shared focus on climate change mitigation as they both appear in larger frameworks such as Building Code and building certification programs.

A resilient socio-ecological system is synonymous with a region that is ecological, economically and socially sustainable. Whilea development strategy is not sustainable if it is not resilient. Therefore, the two concepts are intertwined and cannot be successful individually as they are dependent on one another.

Some scholars argue that resilience and sustainability tactics target different goals. Resilience focuses on the design for unpredictable, while sustainability focuses on the climate responsive designs. Some forms of resilience such as adaptive resilience focus on designs that can adapt and change based on a shock event, on the other hand, sustainable design focuses on systems that are efficient and optimized.

2.2 Quantification

The first influential quantitative resilience metric based on the functionality recovery curve was proposed by Bruneau et al. 2003 where resilience is quantified as the resilience loss as follows.

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

where $\mathrm{Q(t)}$ 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.

The resilience loss is a metric of only positive value. It has the advantage of being easily generalized to different structures, infrastructures, and communities. This definition assumes that the functionality is 100% pre-event and will eventually be recovered to a full functionality of 100%. This may not be true in practice. A system may be partially functional when a hurricane strikes and may not be fully recovered due to uneconomic cost-benefit ratio.

Resilience index is a normalized metric between 0 and 1, computed from the functionality recovery curve (Reed et al., 2009).

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

where$\mathrm{Q(t)}$ is the functionality at time t; t_0 is the time when the event strikes; t_h is the time horizon of interest.

A resilient system is one that shows:

1. Reduced failure probabilities to low down the risk;
2. Reduced consequences from failures, in terms of lives lost, damage, and negative economic and social consequences to shorten the social impacts;
3. Reduced time to recovery (restoration of a specific system or set of systems to their "normal" level of functional performance) by giving the recovery strategy;

The methods proposed to quantify resilience can be useful to provide a comprehensive understanding of damage, response, and recovery. The resilience functions explain quantitatively and qualitatively the time variation of damage as well as its relationship to response and recovery.

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2.3 Risk versus resilience

The field of resilience engineering tends to propose resilience-enhancing principles which remain theoretical, abstract, and very broad. Furthermore, the need for an operational framework of resilience engineering need to stretch across the coupled domains of ecological resilience, social resilience, and resilience engineering with concrete and specific components. There are three distinct notions related to resilience engineering as follows: (i) definition of resilience and the difference between risk and resilience approaches to clearly differentiate them in practice, (ii) metrics for resilience engineering and common quantification methods, (iii) systematic approach to resilience engineering including modelling and simulation. The proposed approach to enhance resilience engineering should use a conceptual institutional theory framework involving regulative, normative, and cultural-cognitive elements. Main features of resilience include the necessity to establish critical functionality through stakeholder engagement, ability of the system to integrate temporal evolution in recovering from threats, as well as integrate memory of past experience through adaptation. Resilience is connected to risk in the phase of absorbing threats where thresholds and comparative benchmarks should be established.

While in the conventional safety approach there is a focus on failures, as stated by Hollnagel (2006), the resilience approach based on the current definition focuses on how the system can function under different scenarios. As a result, resilience is a dynamic concept that covers a continuous state of the system in contrast to static focus at the time of failure (Park et al. 2013, Linkov et al. 2014). Despite this difference, resilience is not a replacement for conventional risk approach and both concepts should be used as complementary in infrastructure systems (Park et al. 2013, Linkov et al. 2014, Hollnagel 2006). While risk analysis can provide the policy makers and operational managers with the detail analysis of the time of failure, the resilience approach can provide an analysis of trends and dynamics before, during, and after the failure in the form of shock or disturbance. In operational paradigm this distinction implies the application of incremental adaptations of risk analysis in quantitative analysis of resilience engineering (Park et al. 2013). Quantitative interplay between risk and resilience can be depicted showing the function of a system in different scenarios of shocks with higher impacts or more loss of functions (associated with higher levels of risk) versus lower impacts or less loss of performance (associated with lower levels of risk) in contrast with longer recovery (associated with lower degrees of resilience) versus lower recovery time (associated with higher degrees of resilience). While risk management is a bottom-up approach that starts from data collection to development of management strategies, resilience enhancement starts from the values of the stakeholders and then applies models and metrics to inform risk assessment (Linkov et al. 2016). The combination of recovery time and performance of the system is a common quantification approach to analyze the dynamics of the system before, during and after the shock, reflecting the concept of resilience. Therefore, it is necessary to differentiate the concepts of risk and resilience while they should be used in conjunction for more comprehensive analysis of the infrastructure system behavior.

III 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 (Brown, 2016). The heightened interest has led to an increase in approaches to measure resilience. In international development settings, this is so implementers and donor agencies can demonstrate results and understand whether resilience-strengthening programmes are achieving their objective to reduce poverty and improve people's wellbeing. There are limits, for example, to key performance indicators (KPIs). While these KPIs provide an important accountability tool, such quantitative indicators take a static view of resilience and seek concrete outcomes as a way to assess people's resilience at the end of a programme – in contexts that are seldom static and concrete. A three tiered approach to resilience management can be taken depending on the resources and the required precision of the analysis, decision makers. Analysis of engineering resilience requires both quantitative data from engineering models, historical records, and qualitative data from experts and diverse stakeholders. Such that there is a need for qualitative studies to validate the quantitative analysis of simulation models as well as quantitative studies to model new phenomena observed in qualitative studies. The data collection often faces challenges such as lack of quantitative data on extreme case, reliability of qualitative data, as well as limitations due to ethics and resources for data collection, other issues related with the metrics-based approach includes difficulty of quantifying emergent dynamics as well as difficulties in translating the data and analysis into decisions, policies, and behavioral changes.

3.1 Systematic approach to resilience

Interdependent infrastructure systems can be defined based on the lexicon and taxonomy of system of systems. In order to define the interdependent infrastructure systems, five characteristics need to be satisfied: as the component of the SoS need to be operationally and managerially independent, geographically dispersed, exhibit evolutionary behavior, and emergence at different levels. These characteristics can be observed in the interdependent infrastructure system of a community with the interactions across social and ecological domains. Defining the interdependent infrastructure systems through the framework may facilitate modeling, quantification, and communication of the models across different boundaries. This framework can be then used based on different modeling and quantification methods including modeling and simulation of infrastructure and social systems for the case of extreme events.

Systematic approach to resilience engineering should be complemented by further analysis through modeling and simulation as well as qualitative studies. The resilience-enhancing principles are mainly based on qualitative methods (case studies and conceptual analysis). A research gap for future studies is observed in application of quantitative methods (e.g., modeling and simulation) or micro-level empirical methods (e.g., human-subject behavioral experiments) for fine-tuning the principles. Existing quantitative approaches to resilience include metrics based on performance level and recovery time or input-output models. These methods still do not sufficiently reflect the interdependency of the infrastructure systems or provide a comprehensive picture of the associated dynamics. Above all, the lack of operational applicability is reflected within the metrics, as they are not sufficiently detailed for use in practice. A systematic approach to resilience based on the framework may facilitate reflecting interdependencies within the system and across domains of social, technical and ecological resilience in the model through the lexicon and taxonomy, while providing a real picture of the dynamics and interactions of multiple systems.

3.2 Institutional framework for operational resilience engineering

Institutions are the rules of the game that shape human interactions with one another and the surrounding environment in a repetitive, structured situation. Institutions thus reduce uncertainties in the exchanges among parties, promote trust among people, and alleviate the cost of exchange in such interactions. Although less visible than physical infrastructure, institutions are in fact a form of “soft” human-made infrastructure that gives structure to recurring situations that people face. More importantly, institutions also matter for community resilience. Interdependencies between institutions and physical infrastructure, or the “fit” between institutions and the biophysical context within which they operate, can heavily influence how well people cope with the challenges that face, be they natural hazards, social problems, or a combination of both. This beneficial role of institutions is particularly relevant for promoting four system-level abilities linked to infrastructure resilience (the ability to monitor, respond, learn and adapt, and anticipate). These four system-level abilities cannot function effectively without governing institutions. Normal and emergency manuals used by managers and engineers, hazard mitigation plans used by communities, and norms of conduct among people as they organize community-level actions to deal with and recover from natural disasters are all instances of rules or institutional arrangements that contribute to these four abilities. Institutions can also operate at multiple levels of social organization: operational, collective-choice, and constitutional rules. Rules operating at the operational-level concern the rules that people, engineers, or managers use in their field settings, e.g., rules that specify people's interaction with one another and their use of infrastructure. Collective-choice and constitutional rules concern a broader direction in rules (i.e., a policy) and rules about the rulemaking, respectively. The working manuals used by engineers, managers, and people (e.g., disaster plans, emergency manuals, etc.) are instances of the operational-level rules.

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 (Berkes and Ross, 2013). 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 (Faulkner et al., 2018). 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.

3.3 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 (Brown, 2016). The concept has been widely applied to different sectors and policies including food and water, health, the environment and fragile and conflict-affected settings. As such, 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. In this context of unpredictability, we conceive of resilience as a dynamic approach to effectively manage and shape people's response (Magis, 2010). 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 (Adger et al., 2011).

There are four key characteristics of the resilience concept that challenge its application (Brown, 2016).

- Uncertainty is part of how systems work, and we should expect the unexpected.
- Systems are inherently dynamic and there are multiple links and feedbacks between processes and changes. These can be both positive and negative, direct or indirect,

and can suppress or accelerate change by influencing how change occurs in a given situation.

•There are important temporal, societal and spatial cross-scale interactions.

•Multiple stressors and catalysts act on systems and interact, sometimes with synergistic results, but not always. This includes hazards or events already known and identified, such as a flood or drought, as well as those more unforeseen and not necessarily experienced before, such as a pandemic.

Such characteristics of complex adaptive systems show that they self-organize to adapt and change their behavior over time, and are made up of different components whichthemselves evolve, learn and interact to influence how change plays out within asystem.Complex adaptive systems have emergent properties – which means changes or outcomes can be hard to predict as they are non-linear, with behavior often emerging at the level of the system as a whole. For example, small actions can have largereactions.Overall, resilience concepts present a different way to understand causalityand how change happens in complex environments (Rogers, 2008). In ‘simple’ situations, thereis a clear end result underpinned by a linear and largely predictable process. In the caseof “complicated”, such as “non-linear”,there is also a clear end result, but the processesis less straightforward, with multiple causal pathways. In complex systems, change isunpredictable, but not random, with the progress of interventions not always assured.Working with resilience, as in other complex operating environments, means that the projects, programmes and systems must adapt, flex and be nimble to stay on track andavoid being locked into pathways that may become obsolete in the future.

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 is the challenge of identifying appropriate evaluative methods and tools which adequately capture resilience.Third, ‘when’ to measure resilience is tricky (Brown, 2016). Assessing people’s past resilience to an event, or present resilience, may not reflect their resilience in the future. Resilience is a process which evolves – it is not an end point that can be measured at a set point in time (Beymer Farris et al., 2012), 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. We might not know if what is being measured are actually the 'right' things that really matter. Fifth, typical programming approaches to development are often superimposed onto resilience interventions. This adds further challenges to assessing resilience, which is about timing and flexibility, not only programme duration. Standard programmes are typically short and rarely phased or structured around key policy or government timelines which could help activities achieve the most impact (Faulkner and Villanueva, 2019). This challenges implementers who support changes, and evaluators in detecting and measuring those changes, which take a more forward-looking, longer-term and flexible perspective.

There is no general consensus on capacities influencing a community's resilience. Many typically focus on people–place connections, knowledge and leadership (Berkes and Ross, 2013). For example, strategic relationships or networks can provide essential support to help people prepare for and recover from climate extremes (Maclean et al., 2014). Improved knowledge and forms of learning have also been demonstrated (Magis, 2010). This might include learning from a past disaster to enhance a community's social memory (Wilson, 2012).

3.4 Applying 3As Capacity Frameworks (Lucy Faulkner and Vicky Sword-Daniels, Itad 2021):

The 3As framework unpicks people's resilience in terms of their adaptive, anticipatory and absorptivecapacity. 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 capacit*y 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.

IV APPLICATION

Result

A. Surface Water

A.1 Water, Agriculture and Food Security

The world is projected to have around 9.6 billion inhabitants by 2050. Most of the population increase will be in developing countries where food is often scarce, and land and water are under pressure. There remains great uncertainty as to how climate change will affect any given locality, but it seems likely that it will have a profound effect on water resources.Adapting water management to potential future changes in climate emphasizes the need to:

1. Accept existing climatic variability as a given measure and improve understanding of variability, and improve understanding of the impacts of climate change on variability.
2. Rethink water storage, emphasizing underground opportunities to minimize the impacts of variability and utilize the storage continuum.
3. Improve understanding of the role of natural ecosystems in variability.
4. Improve understanding of how humans influence variability.
5. Develop and manage water resources fairly – share water, land, and food in a cooperative manner and in a way that does not leave vulnerable groups disproportionately burdened by the impacts of variability.

Adapting water management to climatic variability is not something that can be done in isolation (Fig.2). Depending on local contexts, needs, and interests there are opportunities for improving water management that help adaptation to climatic and other change, and simultaneously advance development. These opportunities usually integrate and apply the best and most promising approaches, tools, and technologies to help vulnerable rural communities build resilience and develop sustainably.

Change is nothing new. But the people, communities, and societies that cope best with change of any kind are resilient and able to adapt. The more resilient they are, the more they are able to manage climatic variability, diversify their livelihoods, and reduce risk.

A. 2 Transform Water Governance: Integration and Coordination

Unraveling the multiplicity of interests and issues in water and ensuring equity in accessing water resources is enormously challenging. social, cultural, governance, and political issues can hamper or advance adaptation to climate change just as they can hamper or advance development. Technical solutions by themselves are of no practical value unless they are supported by people with the power to make policies and to ensure that policies are implemented through appropriate governance and institutional processes.

Improving water governance through integrated water resources management is widely promoted as a critical need throughout the developing world. Realizing such approaches have had varying degrees of success, often requiring a pragmatic solution suited to the particular context. It takes time for governments to establish coordinating mechanisms for bringing multiple agencies in both the public and private sectors under one umbrella. At the local level, effective adaptation depends to a large extent on the institutions – formal and informal, local and district – which plan and manage individual and collective action on water resources.

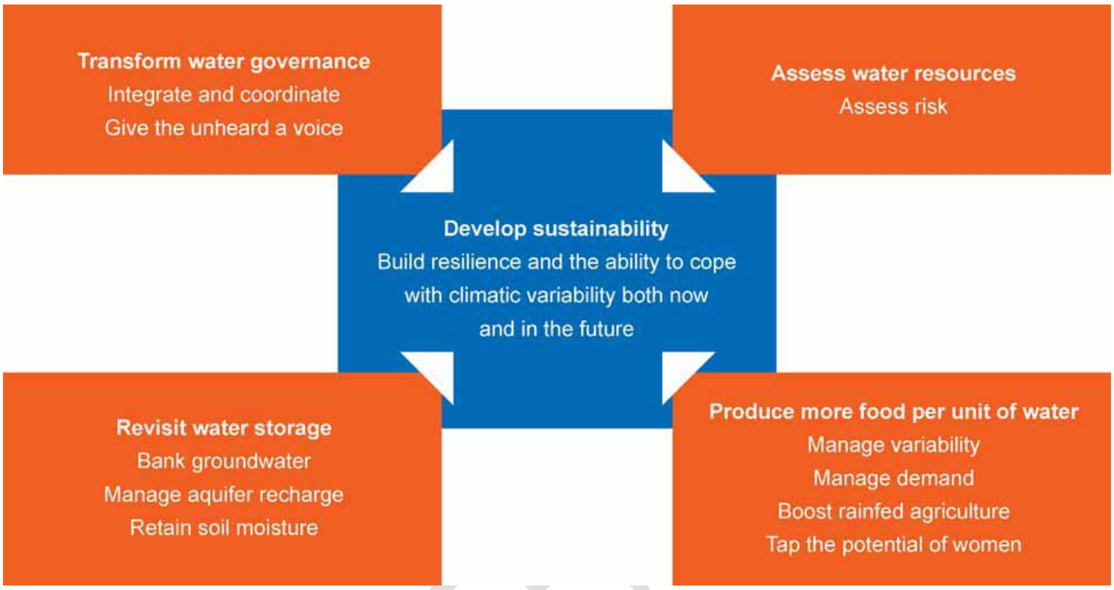

Fig. 2 Adapting water management to climate change

Planning and managing adaptation programs at the watershed scale need to take local vulnerability, and local culture and social organization into account. At this scale, it is in many cases possible to overcome barriers posed by competing interests and to make plans that are mutually beneficial. At larger scales, adaptation planning requires going beyond water to consider links to other sectors – it needs to be part of overall development planning rather than a separate activity.

A.3 Assessing the Need for Water Storage

An analytical tool to evaluate the need for water storage and its likely effectiveness under existing and possible future climate conditions is developed including the consideration of reliability, resilience, and vulnerability, and the economic, social, and environmental aspects of water storage options for different areas as Fig. 3**.** The diversifying phases for solving the need of water storage is useful for the reduction of climate vulnerability as following.

A. 4 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. 4). Storing water may enhance both water security and agricultural productivity. However, all kinds of water storage are also potentially vulnerable to changes in climate. With less rainfall, ponds and tanks may not fill or may fill less frequently, so that they may not be able to provide enough water for irrigation.

B. Groundwater

B. 1 Bank Groundwater

Storing water underground is underused. Adaptive strategies, such as allowing shallow groundwater systems to fill in the wet season and drawing on the water to irrigate crops in the dry season, do not need large-scale infrastructure. Storing and

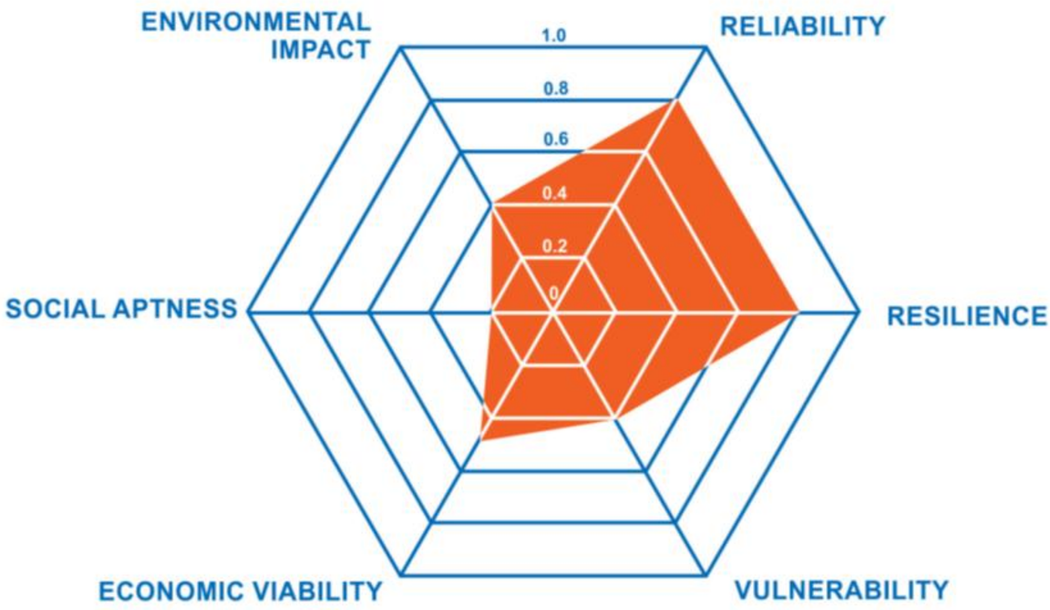

Fig. 3 Assessing Diagram of the need for water storage (McCartney and Smakhtin 2010; McCartney et al. 2013b)

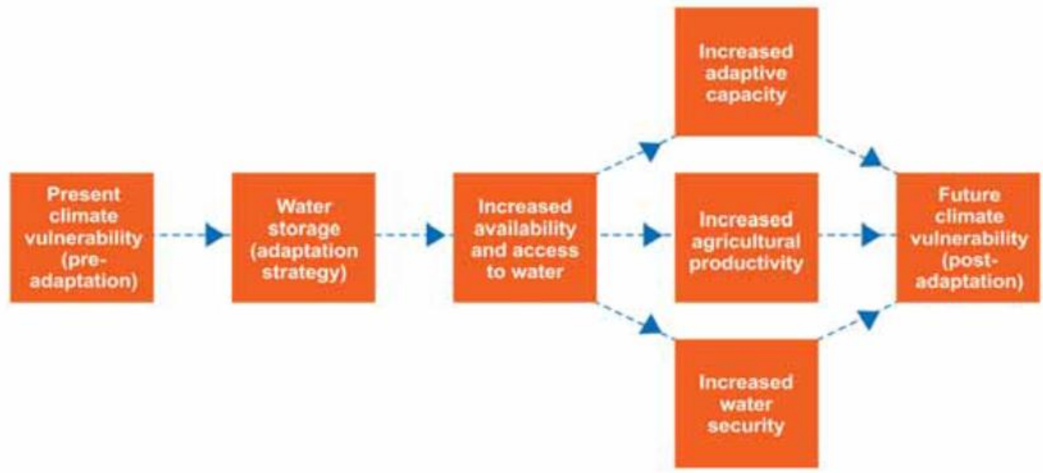

Fig. 4 Adaptation strategy on water storage for Reducing climate vulnerability (McCartney and Smakhtin 2010)

transferring water in this way can in most years provide a few extra weeks of irrigation water.By encouraging the millions of farmers, households, and communities who have ponds and wells to adapt them, they feed groundwater systems in the rainy season, much more precipitation could be saved in the ground and prevent groundwater levels falling.A reliable supply of groundwater would enable farmers to cope better with climatic variability.Groundwater banking helps ensure that farmers and pastoralists have sufficient, reliable supplies of water under increasingly variable and severe drought conditions.

B. 2 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. Combining all the strategies effectively reduced surface runoff and increased percolation, thus making more water available in the dry season. Combining strategies for rehabilitating degraded land and water resources is also an adaptation strategy in drylands.

C. Soil and Food

C. 1 Retain Soil Moisture

Water held in the soil is crucial for plant growth. However, at any given locality, the soil moisture is limited and is quickly depleted by evapotranspiration. Various tried-and-tested field-scale techniques – widely referred to as soil and water conservation – can improve infiltration and retain soil moisture, thus stabilizing and improving crop yields and using rainfall more effectively. The most promising techniques include deep tillage, reduced tillage, zero tillage, and various types of planting basins.

C. 2 Produce More Food per Unit of Water

Given that globally agriculture accounts for 70–80 percent of freshwater use, competition for water among agricultural and other water users will be an issue for years to come in many countries. The degree of competition will depend on geography and scale, and factors such as urbanization, changing demands for food, industrial development, and the relative scarcity of water in a particular season. Poverty and food insecurity are generally highest where water productivity is lowest. Increasing water productivity is an effective way to intensify agricultural production, improve community resilience, and reduce environmental degradation. There is a considerable body of knowledge on the changes in agricultural systems and water management needed to safeguard and boost agricultural production. Growing rice more intensively requires more labor, more weeding, and more attention to water management. There are very few completely win-win solutions.

D. Assess Water Resources

In many parts of the world there are no long-term climatic data or records of river flows. In other parts the data may exist, but may be dispersed and difficult to access. This deficiency in data and information is not likely to be resolved soon and adds to theuncertainties of climate change projections. Decision-makers are faced with projectionsthat take historical trends and extend them to a range of possible futures. The uncertainty at the global scale – on the scale of the changes and even on the direction of change – is considerable. Moreover, global models are at a scale and resolution difficult for water resources managers at local, national, or regional levels to work with. Analytical tools help decision-makers to understand the costs and benefits involved inproposed adaptation measures. They present scenarios that allow stakeholders anddecision-makers to envision the effects of climate change on water resources. Assess risk should be the sensitive topic to pay attention. Analytical tools can also be used to identify the communities and areas – particularly those that are major food producers – which are likely to be most vulnerable to climate change. Governments can then direct adaptation efforts to areas most at risk.

E. 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.

Vulnerability and adaptive capacity in flood and drought contexts are heavily influenced by at least eight factors:

1. The nature of livelihood systems within a region;
2. The ability of people to migrate or commute in order to obtain access to non-farm or agricultural sources of income outside of drought- and flood-affected areas;
3. The ability of information, goods and services to flow into and out of affected areas;
4. The social capital and institutional checks and balances that households have Accessto including education, community institutions such as self- help groups

(SHGs), formal institutions such as government departments and banks, NGOs, the Mediaandsocial networks;

5. Existing patterns of vulnerability created by gender, income and social position;
6. The nature of physical infrastructure (roads, houses, water supply systems, etc.), in particular:
   a. the degree to which such infrastructure is vulnerable to disruption by floods and droughts; and
   b. the extent to which such infrastructure promotes the maintenance of livelihoods during drought and flood periods by serving as a point of refuge, helping to protect assets, and facilitating the movement of goods, services and people;
7. The ability of households in regions to obtain secure sources of water for domestic uses, whether from local or trans-boundary sources, water markets or rural supply schemes. The ability to diversify is critical to the maintenance of rural agricultural livelihood systems. Social capital and institutional checks and balances are important,and
8. Natural resource conditions, particularly the degree to which ground and surface water systems have been disrupted. Specific indicators of disruption include:
   a. Long-term decline in water level is a major warning signal to irrigated agricultural systems of increasing drought vulnerability;
   b. The increased presence of structures (such as roads, bridges, railway and flood control embankments) that interfere with the existing pattern of natural drainage, an indicator of the potential for increased flooding.

Adaptation is not only dependent solely on the presence of markets and other systems that enable flows to occur. The social capital and institutional checks and balances present in rural areas are equally central to adaptive capacity. Institutions provide credit for whatever investments are essential for rebuilding livelihood systems and can create a critical formal check on moneylenders and other informal capital markets. Such institutions along with organizations (such as NGOs, the media and government departments) which provide education and access to information and critical services are central components of the social capital underpinning adaptive capacity. The presence of diverse, competing organizations and sources of information is essential both to 'keep such organizations honest' and to provide the diverse array of services required for adaptation to unexpected natural events, climatic variability and other similar types of change.

Natural resource condition and the nature of physical infrastructure can also magnify the risk to livelihood systems and thereby exacerbate the scale of humanitarian disaster. Local hydrological systems have been altered by the overdraft of a regional groundwater aquifer or by the construction of roads, bridges, railway lines, and flood control embankments that fundamentally alter drainage patterns and water availability. These alterations, along with the inherently unpredictable weather patterns that are likely to emerge as consequence of global climatic change, limit the ability of a society to regulate regional hydrologic systems. Forms of infrastructure that are themselves adapted to hydrologic variability, in contrast, enable social adaptation and thereby minimize vulnerability. Diverse sources of information are needed. Specific factors within livelihood systems can increase or decrease vulnerability.

Environmental degradation, particularly of water supply systems, can be an advance indicator of flood and drought vulnerability. Long-term declines in groundwater levels during normal years are, for example, a key advance indicator of vulnerability to drought. Although the timing of a drought may be impossible to predict, the severity of its impact depends heavily on the ability of a local population to access groundwater. In areas where water levels are declining rapidly and regional hydro-geological conditions (such as the presence of hard rock or saline zones underlying productive aquifers) mean that water is available only to a limited depth, and communities will be highly vulnerable to drought. Areas where development activities have included the construction of structures that impede drainage are likely to be vulnerable to floods. Overall environmental conditions are central to determining the degree of disaster vulnerability.

Long-term declines in groundwater levels during normal years are a key advance indicator of vulnerability to drought. Local to global flows of information, finances, goods and services influence local adaptive capacities.

While droughts and floods are an inherent feature of life in the world, they have been greatly exacerbated *by human interventions* that have changed both hydrologic systems and the impacts associated with extreme events.

Floods and droughts are times of crisis but also times of change and opportunity. Adaptive strategies weave together long-term development and vulnerability reduction.

Adaptation is, perhaps, the single most important mechanism human society uses to respond to change and the impacts that has on basic livelihood systems. Many of the factors governing adaptive capacity have direct relevance to a much wider array of situations. Whatever the nature of the extreme event – whether caused by the sudden onset of conflict or economic collapse or more gradual processes of environmental degradation, technological evolution or systemic economic change – livelihood systems must respond at multiple levels from the individual household to the supranational in order to remain viable.

“Adaptive strategies” for responding to floods, droughts and long-term water management problems are defined as approaches that respond to variability and work with change processes to reach socially desired goals. While this philosophy sounds fine, it does not provide much practical direction. Translating it into more practical terms requires much greater specification. 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. Understanding this and addressing the inherent implications for trade, migration and other sensitive global policy arenas is, perhaps, one of the most significant challenges facing society on risk and the dynamics of ecological and social systems in this century.

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. Studies on system dynamics indicate that resilience and the ability to adapt are themselves dependent on disruption. High levels of stability are, in fact, often undesirable.

Attempt to reduce variability and increase security often have the unintended consequence of reducing the ability of livelihood systems to cope with or adapt to major changes in fundamental system parameters.

Reduction of exposure to the risks associated with agriculture is often associated with employment in the non-farm economy. Community continues to exist but it is more individualized and less defined than it was traditionally. As market access has increased, nuclear family units have become less and less dependent on larger joint family groupings for economic survival.

NGOs have played a major role in flood and drought relief and mitigation activities, largely by assuming responsibility for implementing governmental programmes. NGOs' lead role in watershed programmes has contributed to the sustained presence of NGO

activities in many rural areas.

As the proportion of investments made in community assets increases, perceptions of social equity and of the inclusion of weaker sections of the community increases. Investments in watershed projects are justified not just by their economics but also by non-tangible social benefits such as drought-proofing and social equity.

The best chances for sustainability are when all stakeholder groups are satisfied with their roles and responsibilities and their potential shares in the benefits and when both the facilitating agency as well as the concerned community-based organization to develop a long-term developmental orientation.

Effective governance is central to risk reduction. A wide variety of strategies have been developed for protecting belongings and other essential assets from flood damage.

Transportation is a critical problem during floods. Disaster can serve as a catalyst for changes in work patterns that result in gender, caste and social inequity.

Diversification of income generating strategies, often including different forms of migration and commuting was central to making livelihoods resilient and increasing the ability to recover after flood or drought events. A wide variety of factors contribute to the ability of households and communities to both adapt to and cope with climatic variability.

Many of those interviewed either explicitly or implicitly mentioned the lack of advance warning as a major constraint on their ability to mitigate the adverse impacts of both floods and droughts.

The fact that government, nongovernment and private sector organizations as well as markets play different roles illustrates the many layers of institutions affecting vulnerability and resilience.

The specific interventions appropriate for any given area will vary; the thread of commonality lies in the recognition that specific issues are the outcome of systemic constraints and the acceptance of an approach which identifies points of entry to changing the structures that create vulnerability.

F. Public Infrastructure

Urban characteristics are gradually spreading out and reshaping rural hinterlands. The dynamics of transport and communication have changed in fundamental ways. Rural distances have been shortened by the increasing physical proximity of urban areas and by the speed of communication and transport. Changes in rural infrastructure and

demographics have fundamental implications for livelihoods. Many of the advantages of engagement in the non-farm economy are now accessible to individuals living in some formerly rural areas, particularly larger villages and towns and small cities.

Many of the changes now taking place in water resource and climatic systems are transformational. Recognition of the way embankments and other human interventions reshape surface hydrologic systems is nothing new. Although the impacts of global climatic change on conditions within regions are difficult to predict, current research suggests that climatic changes are likely to exacerbate both droughts and floods. As our ability to predict flows, extreme events, sediment loads and other basic hydrological parameters declines with climatic change, the ability of society to implement water management approaches that require precise information on such parameters in order to operate will also decline. Whether or not the initial assumption of stationarity was justified, those involved in water management must shift from approaches based on bounded variability to approaches capable of responding to a much larger reality involving inherent uncertainty and the limitations of current knowledge systems.

The institutional landscape in which floods and droughts occur is a critical factor in determining how disasters are perceived and what responses to them are adopted. Both floods and droughts are, at least in terms of investment, seen as external events to be controlled through physical structures.

The main spirit of the disaster risk management framework is to achieve maximum disaster reduction benefits with the minimum investment cost.The elements of the risk management structure can be divided into two parts: the "management aspect" and the "analysis aspect". The former belongs to the scope of risk management decision-making, which includes the division of rights and responsibilities in the risk management process; the latter belongs to the risk analysis level, as the basis for decision-making, the former and the latter complement each other, and are connected by five stages: risk pre-assessment, risk analysis, risk characteristics description and assessment, risk management and risk communication. Among them, risk assessment is the first step in formulating the risk management framework. Its purpose is to provide further background information on current issues; analyze the sources of risks based on the background information and evaluate them from the perspective of the interests of risk holders, and propose to decision-makers what needs to be faced. risks and the consequences of those risks; the risk-bearing entity risk analysis results are used to judge the acceptable, tolerable, intolerable and undefined ranges of specific risks based on their respective assessment standards; decision makers set and implement various risk reduction measures based on the tolerable and intolerable portions of risks. If an appropriate improvement plan cannot be proposed, return to the "Risk Characteristics Description and Assessment" stage for adjustment; finally, and the most important risk communication is to allow risk stakeholders to understand the risks they face and participate in decision-making, so as to fully understand the role of risk management and be able to trust each other in the risk management process.The definition of risk varies under different environmental conditions, but in a broad sense, risk can be defined as "all natural or man-made disasters that may endanger the safety of human life and property, and the severity (loss size) of their occurrence in the future, A combination with the probability or frequency of occurrence”.

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. 5 and 6**).**

And meanwhile we have that**Resilience= 1 – Risk** = **Adaption (**See Fig. 7**).**

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. Hazards are often categorized by whether they are natural (sometimes termed physical) or technological (sometimes called man-made or human-induced). The term 'peril' is sometimes used instead of hazard, particularly in the insurance industry. Effective disaster risk reduction requires the consideration of not just what has occurred but of what could occur. Most disasters that could happen have not yet happened.Natural (or physical) events are only termed hazards when they have the potential to harm people or cause property damage, social and economic disruption. The location of natural hazards primarily depends on natural processes, including the movement of tectonic plates, the influence of weather systems, and the existence of waterways and slopes (e.g. that might generate landslides). But processes such as urbanization, environmental degradation and climate change can also influence the location, occurrence (frequency) and intensity of natural hazards. These processes are known as risk drivers.The classification schemes for hazards vary across different research institutions and governments, but these can be divided into:

1. Environmental hazards may include chemical, natural and biological hazards. They can be created by environmental degradation or physical or chemical pollution in the air, water and soil. However, many of the processes and phenomena that fall into this category may be termed drivers of hazard and risk rather than hazards in themselves, such as soil degradation, deforestation, loss of biodiversity, salinization and sea-level rise.
2. Hydrometeorological hazards are of atmospheric, hydrological or oceanographic origin. Examples are tropical cyclones (also known as typhoons and hurricanes); floods, including flash floods; drought; heatwaves and cold spells; and coastal storm surges. Hydrometeorological conditions may also be a factor in other hazards such as landslides, wildland fires, locust plagues, epidemics and in the transport and dispersal of toxic substances and volcanic eruption material.
3. Technological hazards originate from technological or industrial conditions, dangerous procedures, infrastructure failures or specific human activities.
4. Biological hazards are of organic origin or conveyed by biological vectors, including pathogenic microorganisms, toxins and bioactive substances.

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. However, increasing evidence suggests that the case of extreme hazards the degree of disaster risk is a consequence

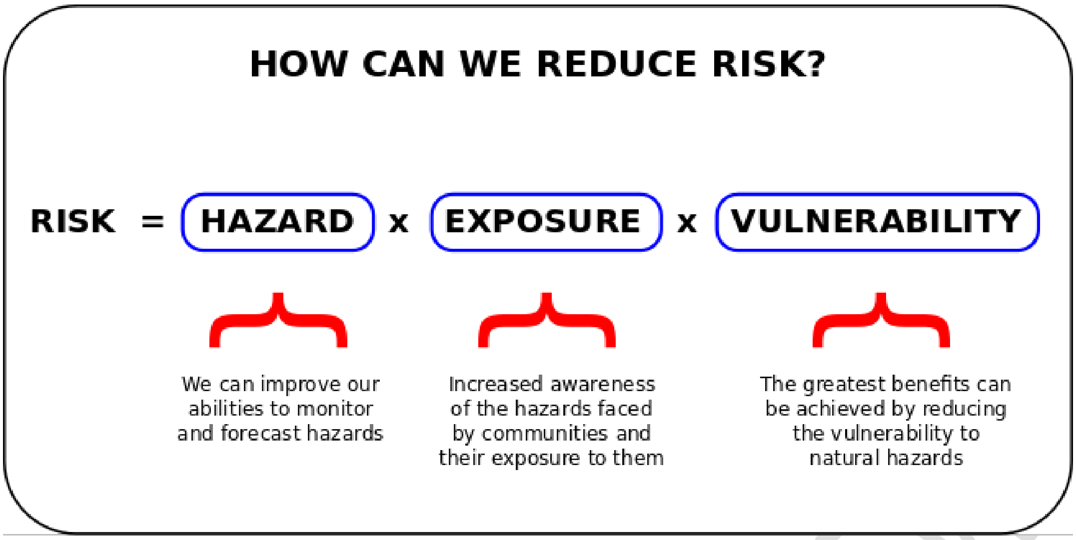

Fig. 5 Components of Risk

of exposure more than it is a result of vulnerability.People and economic assets become concentrated in areas exposed to hazards through processes such as population growth, migration, urbanization and economic development. Previous disasters can drive exposure by forcing people from their lands and to increasingly unsafe areas. Consequently, exposure changes over time and from place to place.

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.

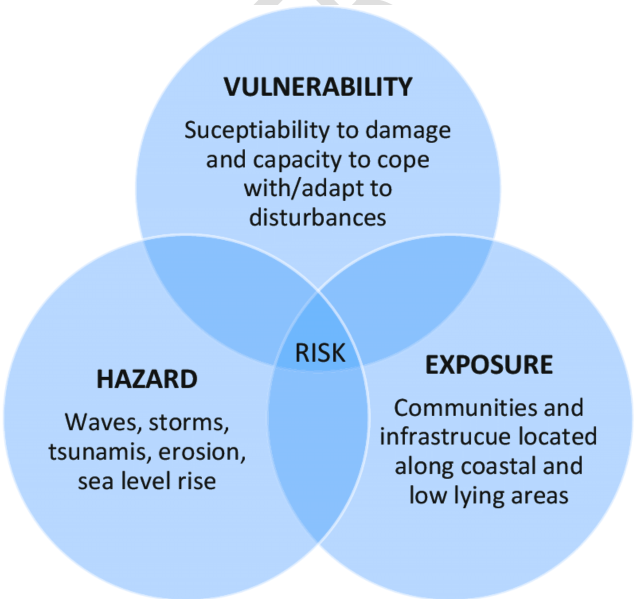

Fig. 6 The Details of the examples for each component of Risk

General risk management methods can be divided into risk avoidance (avoid), risk mitigation (mitigation) and risk transfer (transfer). Finallythe 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.

This study conducts a large-scale hotspot analysis on the country's majorpublic 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

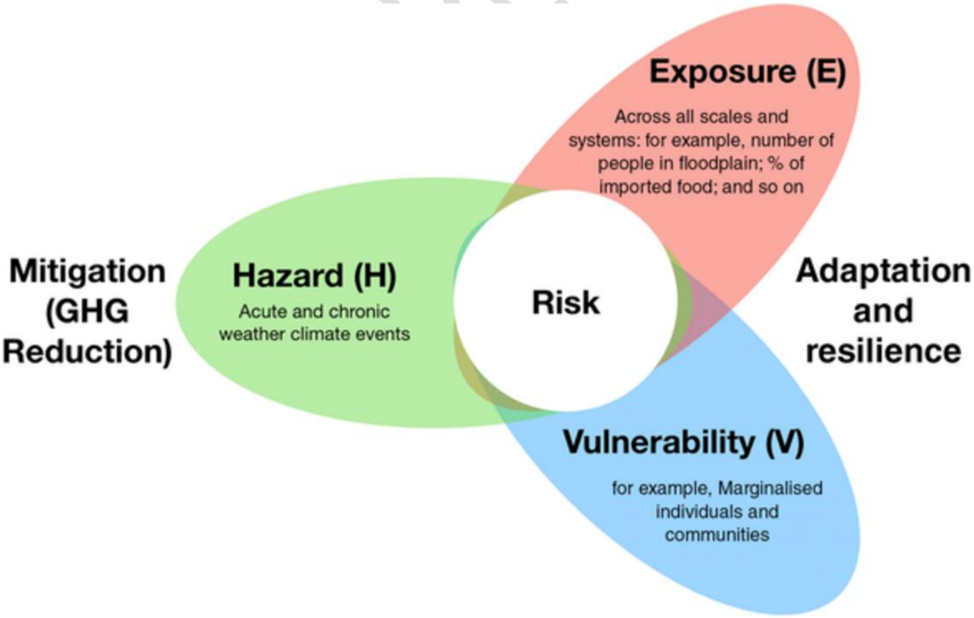

Fig. 7 The conceptual example of Adaption and Resilience

Items	Disaster Risk =Hazards (Mainly Natural Causes)+ Vulnerability (Mainly SocialCauses)+ Exposure (Previous Actions),

	Score	2	3	4	5	6	7	8	9	10
Adaption	5									
	4									
	3									
	2									
	1									
There are 5 levels: 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. 8 The Score or Level for the Relationship between Risk and Resilience (or Adaption)

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 reducethe 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. (See Fig. 8).

V DISCUSSION

This definition of resilience engineering covers four different perspectives, including: rebound indicating how the system returns, robustness indicating how the system responds to disturbances, graceful extensibility indicating how the system extends its adaptive capacity, and sustained adaptability indicating how the architecture of the system can ensure sustained functioning in a changing environment (Woods 2015). While originally the focus was to return to the original state of the system, the definition of resilience was then shifted towards multiple equilibria and the possibility of reaching a new stable state, different from the original equilibrium. Furthermore, the definition has evolved to reduce the emphasis on the risks and focus on sustaining the function of the system in all of its states. As a result, the current definition of resilience may refer to a system that can sustain its function by constantly adjusting itself prior, during, and after the shocks (Hollnagel 2006). First, various applications evolve to incorporate the human-dimension of resilience, that is, adaptability and transformability of the system. The evolved applications imply the importance of the governance structure of resilience engineering of the systems to ensure a systematic approach to their adaptability and transformability. Second, while resilience engineering classically emphasizes the aspects of robustness and recovery, this definition broadens the application to prior and during the shock and includes preventing a damage before the disturbance, mitigating losses during the events, and improving the recovery capability after the events. In summary, the operational paradigm for resilience engineering in view of the current definition should focus on maintaining the operation of the system in different scenarios before, during, and after the disturbance, and as stated by Hollnagel (2006), should focus on the function of the system rather than what can go wrong.

Societies and firms face large numbers of risks and threats, including unexpected man-made events such as terrorism and increasingly problematic extreme weather events driven by climate change. Data on extreme weather events and disasters indicate that the number of events and their impact on the lives and financial conditions of residents continue to increase. Given that it is impossible to defend against all possible risks, resilience—the ability to recover from a shock and adapt to change—remains a critical goal for organizations and government alike. To date, many resilience engineering studies have focused on identifying heuristics or principles for enhancing resilience. Resilience scholars based in engineering, ecological, and social resilience domains have made substantial progress on what broadly constitutes the principles for enhancing resilience (Hollnagel et al., 2006, Walker and Salt 2006, MCEER 2010, Aldrich 2008, Biggs et al., 2012, Park et al. 2013, Ayyub 2014, Aldrich and Meyer 2015). Several studies based in the Resilience Alliance highlight the importance of seven principles: diversity and redundancy, connectivity, slow variables and feedbacks, learning, participation, understanding as a complex adaptive system, and polycentricity (Biggs et al. 2012). Formal and informal institutions are critical to resilience, as they strongly influence patterns of interaction between and among individuals and their social organizations. Without appropriate institutional arrangements, more uncertainty would exist and the level of trust would decline in the exchanges among individuals. Institutions are also crucial to how human controls and manages critical infrastructure systems or how they respond to or prepare for natural disasters (Cifdaloz et al. 2010). Routine infrastructure development comprises of the following steps (Goodman and Hastak 2015): (1) Establishment of goals and objectives, (2) problem identification and analysis, (3) solution identification and impact assessment, (4) formulation of alternatives and analysis, (5) recommendations, (6) decisions, (7) implementation, and (8) operation and management. Resilience suffers from lack of institutional arrangements, established governance framework including regulative, normative and cognitive elements, and lack of enforcement strategies to achieve goals. It should be noted that by in this research we use the term "fragmented resilience engineering initiatives" for efforts by actors such as funds or international agencies to support, formalize and establish resilience for cities, infrastructure systems, or rural areas.

VI CONCLUSION

Vulnerability assessment in resilience engineering offers a momentary relief in our search for a safe refuge under this state of apparent helplessness. Vulnerability assessment has proven its usefulness in planning our interventions to anticipate, adapt to and confront the multi-dimensional threats of climate change. Our experience on vulnerability assessment will be shared to all. I strongly believe that by sharing experiences we will learn more about this very important and relevant subject and apply it where it will be most applicable and effective

Ecosystem vulnerability is expected to be increased because the frequency, intensity and duration of disturbance have become intensified under the influence of climate change. As you are aware, environmental changes including climate change have an adverse effect on economy as well as ecosystems. In relation to ecosystem vulnerability,

Climate change will become more prominent in the next two to three decades where extreme rainfall, strong winds and extreme temperature are likely to occur in many areas. These events will likely cause notable increases in climate related risks that will affect profoundly the forests, soil, water and other natural resources, and also cause damages to life and property. Climate change adaptation including vulnerability assessment needs to be integrative and must be responsive to both the climate and non-climate stimuli such as population pressure, poverty that drives poor people to unsustainable use of natural resources, and other drivers of watershed degradation. In this regard, watershed-based approach to climate change adaptation will be appropriate in dealing with risks associated with soil erosion, flood and landslide that are all water driven. Watershed approach is also a good venue for the integration of multi-sectoral and interagency initiatives to address the usually interconnected problems: degradation of the uplands and the loss of services of downstream, lowland and coastal ecosystems.

Phase A. "WHAT" on the Watershed Basin:

(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) Prioritization: To sharpen the focus of investment of limited resources for integrated river basin management, prioritization will be made to determine the level of priority of each of the river basins in the country. The prioritization will be a multi-sectoral and multi-agency process. Some of the key criteria that can be used in determining the level of priority of the different river basins arebiodiversity conservation value (presence of important natural habitats), high cultural and historical value, Actual and potential contributions to economy, actual and potential contributions to livelihood of poor, actual and potential uses for energy, irrigation and water supply, vulnerability to climate change, poses risk of damages from flood, landslide and erosion, and contributions to climate change mitigation.

PhaseB. "HOW": to form the management framework and workshop based on "What":

(A) Formation of River Basin Management Councils: The multiplicity and diversity of stakeholders in river basins make it necessary to have an institutional mechanism through which the different stakeholders can be encouraged to cooperate and collaborate with one another and can have varying range of functions and responsibilities depending on the site-specific biophysical and socioeconomic circumstances including the preferences and perceptions of its constituents. Generally, it is essential that this management body have at least coordinative and integrative functions so as to be able to eliminate the usually destructive effects of competing and conflicting interests and priorities of multiple watershed stakeholders.

The exact form, composition and functions of the management body will be left free to evolve based on the perceived needs, visions and culture of the various stakeholders in the watershed. Some of the potential members of the river basin body are: legislators (LGUs), People's Organizations (POs), NGOs, Private sector , Academe and research institutions, Department of Agriculture (DA), other government agencies (OGAs).

(B) Formulation of Comprehensive River Basin Land Use Plan and Management Plan: The objective of this task is to facilitate the formulation of comprehensive land use and management plans (CLUMP) for the different priority river basins. The CLUMP will be developed through a participatory process involving key stakeholders in the basin and will serve as the framework plan within which the specific watershed plans or area development plans will be formulated. The activities that will be performed are:

a. ***River basin characterization:*** This activity will include detailed description of the biophysical and socioeconomic features of the basin using primary and secondary information. Some of the key analyses that will be performed are:

1. Spatial analysis; 2. Trend analysis; 3. SWOT analysis; 4. Climate risk and vulnerability assessments (disaster risk assessment); 5. Land capability evaluation; 6. Stakeholder analysis.

The key outputs of this activity are:

1. Past and current state of resources;
2. Past and current state of various ecosystem/environmental services;
3. Key drivers of changes in resources and ecosystem/environmental services;
4. Development opportunities;
5. Future risks and vulnerabilities; and
6. Key stakeholders in the basin (by watershed);

b. ***Setting of objectives and targets*****:** The key outputs of this activity are:

1. Objectives for development (protection and production);
2. Physical targets for development (e.g. area of plantation for development, area for biodiversity conservation, area for agroforestry development);
3. Criteria and indicators for monitoring;

c. ***Land use zoning and allocation*****:**The suitability assessment will be based largely on the compatibility of uses with the capability of the land to prevent the long range or irreversible degradation of soil, water and biodiversity in the basin.

The key outputs of this activity are:

1. Climate change vulnerability map;
2. Land capability map;
3. Land use zones; and
4. Recommended uses including adaptation strategies

(C) Project Planning:Based on the land use plan, specific projects can be identified through a participatory process where the local communities and the LGUs will be prominently involved. There are several key activities in this task, some of which can be done in parallel with one another (such as Activities c to f):

a. ***Formation of the project planning team*****:**The aim of this activity is to identify who, among the different stakeholders in the locality where the projects will be implemented, will be involved in project planning and implementation and what their roles will be. The planning team can be formed for a particular project but more preferably planning teams can be organized on a watershed or catchment level. To the extent possible, the local communities and LGUs must be given enough opportunities to play lead roles in the planning process particularly in decision making process. Some of the key stakeholders who may be involved in the planning process are: Local communities/Pos, LGUs, NGOs and Others.

b. *Building the capability of the planning team*:The key output of this activity is a team of local stakeholders who are capable not only of plan preparation but also of implementation of the plan.

c. *Watershed rehabilitation planning*:In appropriate areas, the following plans below may be developed to rehabilitate degraded areas in the basin to improve and restore the original ecological and environmental services of the watersheds including adequate supply of clean water, mitigation of floods and other water related disasters among others, such as:reforestation plan, plantation development plan, agroforestry development plan, timber stand improvement (TSI), enrichment planting, assisted natural regeneration (ANR), and Soil Erosion control.

d. ***Watershed resource conservation planning*:**The intention of this activity is to improve resource-use efficiency in order to promote the conservation and sustainability of the watershed resources. Some of the potential key projects in this activity are:irrigation system improvement and development, forest protection and soil conservation, alternative livelihood development, ecotourism development, and Rural infrastructure development.

e. ***Watershed governance improvement planning*:**This activity is mainly intended to improve the governance of watersheds by:

1. Creating greater space for stakeholder participation in governance particularly the local communities and LGUs
2. Improving the policy environment to attract more investment in watershed protection and conservation
3. Improving the availability and accessibility of more efficient tools, technologies and information to managers and decision makers

To realize the objective of this activity some of the potential projects that may be undertaken are enumerated below.

1. Community-based forest management (CBFM);
2. Training/ information, education and communication (IEC);
3. System for monitoring and information management;
4. Policy reform; and

5. Research and technology development;

f. ***Disaster risk reduction and climate change adaptation planning*:**This activity will have a combination of immediate response to reduce the risks of damagesto people and properties in areas that are highly exposed now and in the nearfuture to climate related hazards and other geohazards particularly floods and landslides; and of medium to long range strategies that will promote the resiliency and adaptive capacity of communities, livelihoods, resources, ecosystems, and plants and animals that are vulnerable to climate change. Someof the potential strategies that may be implemented through this activity are:

Setting in place of early warning systems

1. Disaster preparedness programme;
2. Public education;
3. Climate proofing of indigenous and traditional practices; and
4. Mainstreaming of climate change adaptation and mitigation in comprehensive land use plans (CLUPs) and sectoral development plans;

The implementation phase will commence as soon as the plans for the first priority

river basin are completed. The major tasks that will be undertaken in (C) Project Planning are: *Resource mobilization, Implementation, and Monitoring and Evaluation.*

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