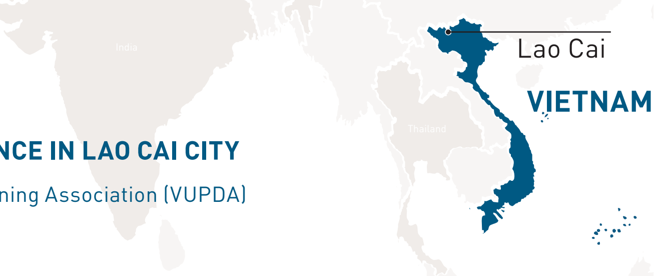
Published October 2018

Project Level

INSTITUTE FOR SOCIAL AND ENVIRONMENTAL TRANSITION-INTERNATIONAL

CLIMATE RESILIENCE CASE STUDY

Lao Cai, Vietnam



RED RIVER EMBANKMENT AND CLIMATE CHANGE RESILIENCE IN LAO CAI CITY

2015–2018 | Implementing Partner: Viet Nam Urban Development Planning Association (VUPDA)

LAO CAI CITY
© Thanh Ngo, ISET-Vietnam. 2013

AUTHORS

ISET-International, Vietnam

Tuyen Nghiem

This is part of a series of case studies developed for the professional training for architects and urban planners in Vietnam to enable them to integrate climate change adaptation into their professional work. The training was developed and delivered by a team by ISET and VUPDA, with funding by the Rockefeller Foundation under the Vietnam National Engagement and Extension of Resilience Practice Project.

Introduction

Vietnam and China have about 144 km of shared natural borders by rivers and streams. China has constructed many river embankment infrastructures, some of which had led to changes in the flow of rivers and consequently, causing riverbank erosion in Vietnam's territory. Since the day Lao Cai Province was re-established, the Lao Cai Provincial People's Committee (PPC) have considered this a priority issue. They have requested the central government to allow Lao Cai to build a system of embankment on the two sides of the Red River and Nam Thi River close to the border with China. This centennial infrastructure was intended not only for the prevention of flooding, erosion and border disputes, but also for the improvement of Lao Cai City's landscape. The construction began in 1994, starting from the area of the Water Company through to the T-junction between Nam Thi River and Red River.

Seeing the effect of this border embankment, the Lao Cai PPC developed and proposed to the central government a project to build another section of embankment in Lao Cai city (inner city embankment), running from the Coc Leu Bridge over to the Pho Moi Bridge. In 2004, the construction of this internal embankment started. Besides the purpose of riverbank protection, this embankment also helped to expand the city's land area, for it to scale up its urban plan and improve its urban landscape.

However, after the new embankment was built, some issues started to emerge. As a result of the construction, the river was narrowed, its course was disturbed,

Image: A section of Red River embankment in Lao Cai City

Lao Cai City

Lao Cai is a mountainous city by the sides of the Red River, with a border with China to the north. There are two rivers running through the city: Red River and Nam Thi River. The city has a population of 102,000 people, falling into 21 different ethnic groups. Its population density is 444 people/km2, mostly concentrating in the urban wards (73%). The city's economic structure has undergone major shifts towards enlarged industry and construction sectors, and shrinking agriculture, forestry and aquaculture sectors. The city has a multi-modal transport system, with national highways (70, 4E, 4D), Noi Bai-Lao Cai highway, railway, waterway (Red River), and airway (with an airport planned in Gia Phu commune). The city's land pool includes agriculture land (59.5%), non-agriculture land (21.2%), and unused land (19.3%). Lao Cai has a policy to expand its area by 8,203 ha by the year 2030, towards a total area of 31,170 ha. Lao Cai is exposed to many types of natural hazards such as flash floods, landslides, floods, droughts, and severe cold. Among these, flooding, which is often caused by discharge from the Red River, is one of the most critical types of hazard.

and large masses of land was eroded and washed away from its banks. In addition, several areas in the city experience flooding whenever heavy rain occurs. During these rain periods, water level in the river rises higher than that in the city, making it impossible for flood drainage from the city area into the river. Households living in new urban areas next to the embankment worry about the risk of damages in the event of a flood equivalent to those in 1971 and 1986.

Currently, Lao Cai is still receiving billions of VND of investment mobilized from government bonds for the construction of new dykes in the city and the reinforcement of critical border embankment infrastructures along the Red River, Nam Thi River and Chay River. Lao Cai needs to build the Red River embankment to be a "safe failure" system in order to strengthen the city's climate change resilience.

Data collection methods

This case study uses information collected from interviews with stakeholders regarding the construction of Red River embankment, and from the Vulnerability Assessment conducted by the Lao Cai working group of the Mekong – Building Climate Resilient Asian Cities (MBRACE) project, funded by USAID.

Research informants were selected using the snowball sampling method. The term "snowball" refers to the observation that the size of a snowball keeps increasing as it rolls downhill. This sampling method is based on the assumption that relevant informants are likely to know about one another because of their similarities. In this case study, the similarity between interviewees is their connection in one way or another to the construction of the Red River embankment. Using the snowball sampling method, a large amount of information can be acquired through newly formed connections.

The advantage of the snowball sampling method is that researchers can be referred to individuals and organizations that they might not have been aware of before, or those related to new and relevant issues that they had not thought of in the preparation of the interviewee list. However, this method also presents several disadvantages. The resulted sample is not random, thus lacks impartiality and might be more or less

The Red River embankment from Coc Leu Bridge over to Pho Moi bridge (on both sides of the river) is nearly 5.2km long, is designed straight up with the average height from 7-13.5m, and has a life duration of hundreds of years, and a total approved budget of over 440 billion VND (Lao Cai Newspaper, 2012).

According to survey by the Lao Cai Department of Agriculture and Rural Development (DARD), during the last 15-20 years, the Bao Thang Forestry Site lost about 2 km of land downstream of Pho Lu bridge due to erosion, while Phu Long village (upstream of Pho Lu bridge) lost 40-50 m. The Lao Cai PPC had reported to the Ministry of Natural Resources and Environment (MONRE), and the ministry approved to provide 147 billion VND from the climate change fund to support the affected areas. Lao Cai Province provided a matched fund of 15 billion VND to make up a total of 162 billion VND for the construction of a dyke that runs through Pho Lu bridge. This dyke was designed according to the elevation of the city and of the river terrace area (which has been deposited a long time ago). There was no hydrological data available to support the designing of this dyke.

biased. When applying this method, researchers need to have network analysis skills, or a reliable source of information for data verification.

The process of constructing Red River embankment in Lao Cai

The embankment in Lao Cai was constructed for multiple purposes: border defence, riverbank stabilization (preventing erosion) to protect infrastructure, and creation of land for urban development. The section of embankment in Lao Cai City has two major parts: (1) embankment at the border; and (2) embankment inside the country to surround the city and protect residential areas, infrastructures and land areas from erosion (primarily) and flooding.

The sources of finance for these two types of embankment are different. The border embankment was built with 100% national budget (for national infrastructure), and the internal embankment draws funds from the state budget allocated to the province/district, ADB provided official development aid (ODA), and the city's matched fund.

DESIGN PROCESS

Lao Cai's embankment was designed by consultancy companies. Consultancy Company of the University of Water Resources, and Water Resources and Agriculture Development Consultancy Joint-stock Company of Lao Cai Province are the two companies often involved in this work. Consultancy companies measure the river's gradient, identify basin boundaries, and draw graphs to show the relationship between flow rate and water level, based on which to calculate flood level and frequency. The internal embankment plan was approved in 2004. In this plan, the dyke was designed in accordance with the river flow and to be resistant to 100 year (1%) floods. This plan is in line with the Government's regulations on river waterworks, dykes and embankments, which provide that dyke infrastructures must have a life duration of 50 years and built to the optimized hydrological standard of 1% probability event. However, in reality, the city's regulations provide that river embankments must not be higher than the its ground elevation to avoid causing floodwater from the river to flow through drains into the city. The city's elevation varies from place to place, therefore the height of its river embankment also varies, corresponding to the level of different frequency flood, within the range of 4-7% floods. Unable to design the dyke to the standard of 1-2% flood, the companies designed its height according to the city's ground elevation and then calculated backward for the corresponding flood frequency. Limited funding is also a challenge in determining the height of the dykes. Several interviewees reported that people did "consider flood control, but did not build [the dyke to needed height] due to limited funding". In addition, a critical issue for the entire embankment, yet not considered in the original design, is the requirement that the first 200 meters of the embankment must be 4 m high. In theory, the technical requirement is that the height of 3.2 m is enough to ensure safety for the infrastructure. However, in the case that floodwater rises higher, the most upstream section of the embankment, being the entry point for incoming flood flows and the first critical point of impact with damaging flood currents, has to be 4 m high, or higher than the flood level, to be able to protect the rest of the embankment.

In short, the river embankment was not designed according to flood control standards, but based on current ground elevation. Many sections of the embankment was not designed based on data and calculations from hydrological models. Moreover, the design lacks consistency and overall coherence.

APPROVAL PROCESS

The approval of the embankment construction project has to follow a series of steps. First, the investors design the embankment and submitting the design to different departments including Department of Planning and Investment (DPI) for appraisal, and Department of Agriculture and Rural Development (DARD) for technical review. The Planning and Statistics Unit of DARD is responsible for reviewing riverbank infrastructures. Throughout the reviewing process, if DPI finds that any other department's input is needed, it will send an official document to ask for their opinion. After that, DPI synthesizes all comments and suggestions and submits to the PPC for approval.

EMBANKMENT CONSTRUCTION AND MANAGEMENT

The building of embankment in Lao Cai was mostly reactive—the construction followed the progression of riverbank erosion, and depended on availability of funds. There are many different investors participating in embankment construction and management. While the Lao Cai PPC is the project owner of the border embankment section, the internal embankment section is the responsibility of the city and district level governments. Before, only projects with total budget of 15 billion VND and above require appraisal at the provincial level. For this reason, from 1994 up to now, the province has had about 50-60 embankment related projects. However, according to Decree no. 15 (issued in August 2013), the management responsibility was handed over to the provincial DARD.

Following is the list of relevant stakeholders in embankment construction projects in Lao Cai:

- DARD is the project owner of 29 on-going projects of river embankment construction under the border embankment category. The department's Centre for Management and Monitoring is responsible for supervising these projects.
- Viet Hoang Limited Liability Company is responsible for the construction of a section of the Nam Thi River embankment with total length of 318 m.
- The Headquarter of Border Defending Forces is the project owner and in charge of the construction of 7 river and stream embankment projects in border areas with total length of 5 km and total fund of 175 billion VND.
- Hong Hao Limited Liability Company is responsible for the construction of the border embankment at Nam Thi River with 42 sections and total length of 290 m.

The biggest challenges in building river embankments in border areas are in agreeing with Chinese counterparts on the embankment design, and acquiring funds for the construction. According to the delegation of authority rules, the local level governments of the areas where the dyke runs through are responsible for negotiating with their Chinese peers on the other side of the river. For example, for the dyke section in Bat Xat district, the People's Committee (PC) of Bat Xat district is responsible for negotiating with Hekou district of China; and for the section running through Lao Cai City, Lao Cai City PC is to negotiate with Hekou city government. In the negotiations, there are often arguments over the location of the dykes, whether the centre line of the dyke lies exactly on the border area, what the purpose of the dyke is, and how the dyke will be constructed.

PLANNING OF LAO CAI CITY

The overall spatial planning of the city was done with consultancy by the Institute for Architecture and Construction Planning under the Ministry of Construction (MOC). This plan includes the construction of the North Duyen Hai and East Pho Moi Industrial Zones (because the province has a priority in developing light industry), Kim Thanh Trade Area in Duyen Hai Ward, and urban residential areas (20 quarters) to provide residential housing. This plan was developed on the basis of plans for water supply, power supply, and population development of the city. The Planning Division under the provincial Department of Construction (DOC) is in charge of annual review and update of the plan. This plan is considered unsuitable for climate change adaptation in the city, because the water supply system for production and domestic use, transport system and housing system are not aligned and connected with one another.

Inundation caused by river floods often happens in areas by the Red River such as Xuan Tang, Binh Minh, Van Hoa and several locations in Kim Tan Ward (along Ngoi Dum Stream, Nhac Son road in group 23-26), Nam Cuong Ward (B4 road, Tran Hung Dao and Square area). The cause of inundation is local rainfall combined with flood flows from upstream. The flood in May 2009 affected 488 households in Binh Minh ward, including 80 poor households and 17 policy-favoured households. In residential group 21 alone, a house was washed away, 85 households had more than 50% of their assets damaged; 29,400 m^2 of land was eroded; 31,660 m2 of agriculture land was damaged and another 18.161 m2 affected; and 60 pigs and a large amount of poultry were washed away (From the results of vulnerability assessment in Lao Cai City, Mekong – Building Climate Resilient Asian Cities [MBRACE] funded by USAID, 2013).

Flood warning levels in Lao Cai Province are determined based on the how much the water is raised. There are three levels of warning, corresponding to how much the water level is higher than sea level, specifically:

WARNING LEVEL

- **3** — **83.50 m** old hospital area is flooded
- **2** — **82-83 m** sever flooding
- **1** — **80-82 m** mild flooding

River embankments created more land for Lao Cai City. After the construction is completed, the Project Management Unit (DARD) had more than one million m^3 of earth, rocks and sand (with a total value of more than 10 billion VND) transported to the area to create a level ground of 12 ha (10 ha on the right side and 2 ha on the left side of the river). The province and city governments called for bids for 50% of this land for the construction of restaurants and hotels, which earned the province's budge an amount of over 100 billion. The rest of the land will be used for building welfare facilities, restaurants and tourist attractions along the river sides.

WHAT PROBLEMS OCCURRED AFTER THE EMBANKMENT CONSTRUCTION?

- The dyke narrowed the river, causing increased water level in the river and more prolonged inundation in the city (because floodwater cannot retreat quickly).
- The dyke is now higher than drainage channels, so when there is heavy rain (like in 2008), floodwater rises almost to the top of it and flows through drainage channels to cause flooding in some areas inside the city, such as Ba Chua area.
- When the river is narrowed, its flow speed increases, which leads to landslide in the mountain. As a result, earth from the landslide is carried to areas downstream.
- The embankment led to erosion of the whole accreted ground by the river. For example, when the embankment at the Pho Moi area was completed, it caused erosion of the riverbank in Xuan Tang ward and Bao Thang district.
- The dyke turned the river into an artificial drainage channel (because natural riverbanks with the ability of self-cleaning for the river are gone).
- The newly claimed land area has a very small-sized drain system, so if flooding persists for too long, houses here will start to get flooded too.
- Due to the varying elevation of the city at different locations, the height of the river embankment also varies. This is the cause of localized inundation. For example, the dyke section close to Hoang Lien road has the same height as this road, so since the dyke was constructed, the nearby Hong Ha road, which is lower than Hoang Lien road, started to experience frequent flooding.

1971

Historical data from the Meteo-Hydrological Station showed that the water level in the city in the 1971 flood was 87.6 m (above sea level). This was considered a compound flood because it was caused by both upstream flood flows (from China) and localized rainfall in the province. People in the city remember very clearly that the rain started slightly and gradually became heavier, then flood flows started to come in from the direction of China, raising water level in the river. The entire city was flooded for 5-6 days. Areas such as Bac Cuong, Pho Moi and Van Hoa wards were deeply submerged. At the area that used to be Bridge no. 4 (which was lower than Kim Tam Bridge), the flood level was as high as an adult's chest (or about over 1 m high). Some households in Kim Tan Ward reported that the water almost reached their roof, many wooden houses with thatch roofing were washed away, damages were huge.

1986

A flood occurred at the end of September and beginning of October in 1986, with flood level at about 85.50 m. According to local people, the flood was caused by a broken hydropower dam in China. Many areas in the city was flooded at 30-50 cm (many people said that the water was belly-level). The entire Canh 9 village of Van Hoa commune was submerged, all the earth on the railway was eroded, leaving bare steel rails. Van Hoa is a vegetable growing village of the city. The flood drowned large areas of soybeans and corns in this village, causing huge damages to local households. In the area of Kim Tan Ward, the (former) Kim Tam Bridge was about 1.5 m flooded, and many houses were about 1m flooded.

2008

According to data of the Meteo-Hydrological Station, flood level was at 84.93 m, almost equal to warning level 3. The water overflowed the dyke, flooding nearby areas, such as Kim Tan Ward, at a level of about 50 cm. According to local people, the 2008 flood was caused by intense rainfall upstream, which combined with existing water in the rivers and streams in downstream areas. Meanwhile, the Red River had been built up with dykes on both sides, thus became narrower, which slowed down drainage. Water from the river flowed into drains or caused flooding in adjacent areas. At the same time, water from the city area could not drain out to the river, leading to localized inundation in the city. The 2008 flood caused erosion at several residential areas and roads. During this period, many tourism companies had to arrange helicopters to pick up and fly tourists out of Lao Cai. (Note: in 2008, the internal embankment had not been built, only the border embankment).

FIGURE 1

DISTRIBUTION OF FLOOD-PRONE AREAS AT P=2%

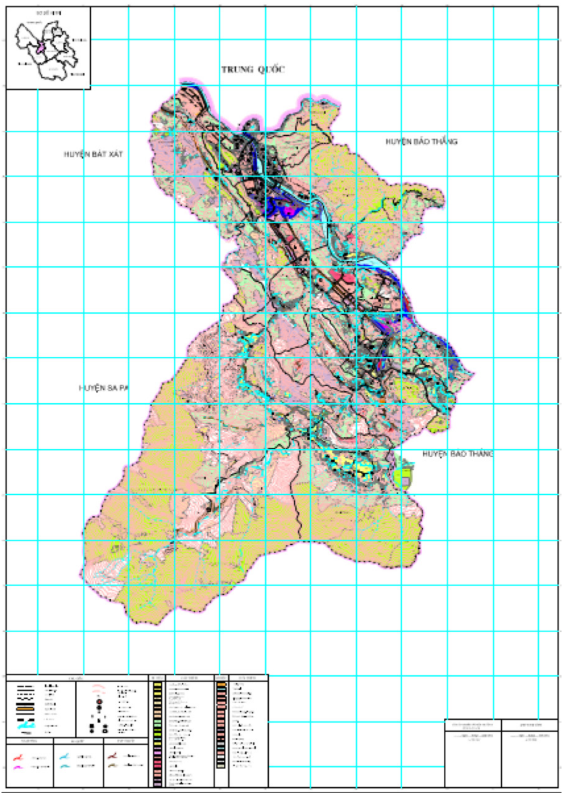


Image: A rather big flood occurring in the Red River in Lao Cai City
Source: Anninhthudo, 30-7-2013

History of flooding in Lao Cai City

Interviews with elderly people who have been living in Lao Cai for a long time revealed that the city experienced many serious flooding events, such as in 1925, 1945, 1967-69-70 (which was the year of reservoir release, when the floodwater was reddish, a lot of furniture was washed from China down to the river in the city area, and when the flood retreated, a lot of fish laid dead by the riverbanks), 1980 (when rainfall was mainly in China, combined with flood flows from upstream and caused flooding in Bac Cuong and riverine areas), 1971, 1986, 2006, and 2008.

ABNORMAL FLOODS

In recent years, Lao Cai City has been experiencing abnormal winter floods. At the beginning of January 2012, there was a flood in the Red River in Lao Cai City. The flood submerged construction equipment along the Red River banks. In July 2012, Lao Cai Province Meteo-Hydrological Centre recorded that the Red River level in Lao Cai City reached 78.15 m, with a range of 1.75 m. In July 2013, a sudden flood flushed down from upstream, carrying a large amount of rubbish and grass, covering the river surface in black. The cause of this sudden flood was extreme rainfall upstream in China. In December 2013, another abnormal flood occurred in the Red River in Lao Cai City, with water level recorded up to 77.77 m, flood range of 1.57 m, equivalent to a rainy-season flood.

FUTURE FLOOD EXPOSURE AND VULNERABILITY

Serious flooding in Lao Cai is often caused by heavy rainfall in upstream areas, combined with large amounts of water from other sources (such as river flows, release of water or failure of hydropower reservoirs in China). When asked whether flood frequency will change and flood will cause more damages under the context of climate change, many interviewees replied that at present, there is little risk of such severe flooding because for some time now, the Red River has stayed very low due to the presence of hydropower plants. Moreover, the likelihood of flooding in Lao Cai is very low because the city's ground elevation has been raised significantly. However, many people also think that the likelihood of localized flooding is increased because many buildings and houses were erected without a drainage system. Many interviewees worried that with the now very narrow riverbed, severe flooding will happen if there is extreme rainfall at the same time of hydropower reservoir discharge from China.

In addition, according to local people, flooding used to occur following a known pattern, so people were more prepared and were able to prevent flood damages. However, now the Red River water rises much more suddenly and people cannot respond as effectively. Statistical data showed that there have been many abnormal flood events in the Red River. On January

15, 2012, water level at the most upstream point of Red River in Lao Cai City was recorded at 77.15 m. This caused a minor flood with flood range from 20-50 cm. This flood submerged some construction equipment by the sides of the Red River embankment, and also caused disruptions to the Coc Leu Bridge construction. Some areas of cash crops by the Red River were also flooded. Compared to the same period of the previous winter, river levels in Lao Cai were very low, sometimes the rivers were dry to the bottom. This abnormal flood event was caused by extensive rainfall upstream, which pushed water downstream and resulted in abnormal flooding in Lao Cai Province. On July 18 this year, the recorded water level of the Red River in Lao Cai City was 78.15 m, with flood range at 1.75 m. This flood was partly caused by rainfall in Lao Cai, which raised the water level in small rivers and streams in its surrounding areas and gathered it all in the city. Moreover, there was also heavy rain upstream (in China), which flowed into the city and caused severe flooding here.

Discussions

According to Tyler & Moench (2012), for climate change adaptation in urban areas, the resilience approach encourages us to consider innovations and changes that can support the recovery of urban areas after predictable or unpredictable shocks. For complex and dynamic socio-ecological systems facing multiple uncertainties (Walker et al., 2002), building resilience to climate change is a strategic approach with an edge over the conventional systems approach. In this context, urban centres are required to have advanced infrastructure to provide critical services.

As mentioned above, the construction of embankment in Lao Cai Province focused mostly on the purpose of erosion control, border defence (for the border embankment), and claiming land for the city. The contribution of the dyke to improving climate change resilience was not properly valued. This is reflected in the city's requirement that the internal embankment shall not be higher than the city's ground elevation. Because of this requirement, the design of internal embankment sections only provided protection for 4-7% floods. Even if the river embankment was designed for 1-2% floods according to national government requirements, we still do not know with certainty whether the dyke can provide full protection from a 1971 equivalent flood. Historical flood data in Lao Cai showed the occurrence of abnormal flood events (those that happened suddenly or during the winter). Especially, the failure of hydropower dams in China caused the flood in 1986 and 2008, and will continue to happen in the future, causing increased flood risks for the city. In this context, is it still practical to use data from a flood event in Lao Cai in 1971 as baseline? This is not to mention that the city's regulation on ground elevation caused the embankment design to be equivalent to 4-7% floods only.

Another purpose of the inner city embankment in Lao Cai was to create more land for the city's expansion. Also discussed above, after the construction was finished, the project owner levelled the ground in the area next to the embankment, and turned it over to the city. The city then organized to sell part of this land, to be used for housing, restaurants, etc. Revenue from this sale would go to the city's budget. Some interviewees referred to this action as "trading land for infrastructure".

Regarding system characteristics as described in Tyler and Moench (2012), constructing new urban areas right next to a river embankment means that the embankment system will loose one of its three critical feature, i.e. "safe failure". When flood is rising in the Red River, there is no space for storing the floodwater, thus both the new urban area and the existing urban area inside the city will be inundated.

Another important characteristic of a resilience system is redundancy, meaning the ability of to provide alternative options or functions for its service provision. In the case of the internal embankment of Lao Cai City, due to the city's regulations, whenever the river level rises, water will flow and cause inundation in lower areas. At the same time, the river embankment led to increased duration of flooding because it narrowed the river, thus raising water level, and preventing water from the city to drain to the river. Therefore, the Red River embankment cannot provide the combined function of flood drainage for the city.

Finally, it is clear that future flood risk is an important issue with major implications on the robustness of the system's resilience characteristics. The majority of interviewees believe that (1) In Lao Cai, flood is caused by the fact that water in the city cannot be drained out to the river, not by Red River overflow. (2) Before, the Red River was usually full and flooding was frequent, but now with the presence of hydropower plants, the river is dry, and it is unlikely for floods occur as a result of intense rainfall only. (3) Climate change causes droughts, drains river flows, and increases the duration of low flows. (4) Before, rainfall was less intense and flood drainage faster. However, these days rain tends to last for shorter periods, but increases in intensity, causing an increase in extreme flooding and in floodwater gathering. And (5) for river embankment, the largest impact of climate change is the increased unpredictability and variability of rainfall, which leads to increased erosion risk.

There are several key factors to building urban resilience. They include infrastructures and ecosystems that either exist within the city or in its adjacent area, or are part of the city's basic service system.

Resilient systems differ from an engineering approach to robust systems, which rely primarily on hard protective structures (e.g. sea walls) or are designed in ways that emphasize the strength of specific individual components to ensure functionality. Resilient systems, in contrast, ensure that functionality is retained and can be rapidly reinstated through system linkages despite some failures or operational disruptions (Bruneau et al., 2003; McBain, Wilkes, & Retter, 2010; O'Rourke, 2007). Rather than relying on the strength of individual components, resilient systems retain functionality through flexibility and diversifying functional dependence.

CONTRIBUTING CHARACTERISTICS TO SYSTEM RESILIENCE

FLEXIBILITY AND DIVERSITY

The ability to perform essential tasks under a wide range of conditions, and to convert assets or modify structures to introduce new ways of doing so. A resilient system has key assets and functions physically distributed so that they are not all affected by a given event at any one time (spatial diversity) and has multiple ways of meeting a given need (functional diversity). In other words, a resilient system can meet service needs under a wide range of climate conditions. Its key elements are spatially distributed and can substitute for each other but are functionally linked.

REDUNDANCY AND MODULARITY

Spare capacity for contingency situations, to accommodate increasing or extreme surge pressures or demand, or interacting components composed of similar parts that can replace each other if one, or even many, fail. Redundancy is also supported by the presence of buffer stocks. In fact, it helps to accommodate unexpected service demand or extreme climate events. System components and pathways provide multiple options or substitutable components for service delivery.

SAFE FAILURE

Ability to absorb sudden shocks (including those that exceed design thresholds) or the cumulative effects of slow-onset stress in ways that avoid catastrophic failure. Safe failure also refers to the interdependence of various systems, which support each other; failures in one structure or linkage being unlikely to result in cascading impacts across other systems (Little, 2002). It ensures that failure in one part of the system will not lead to cascading failures of other elements or related systems, and key service delivery can be maintained even under failures. For example, dykes can be opened to drain floodwater into storage areas outside the city.

These characteristics of resilient systems should be seen as guidelines for thinking about complex urban systems in new ways, rather than as technical prescriptions. System characteristics should not be considered as mutually exclusive categories. In any given system, a particular desired performance factor might be ascribed to more than one category (in some systems, modularity may be similar to diversity, e.g. multiple water pumping stations in various locations). Users of the framework could construct their own descriptions in sectors of interest based on their specific local conditions.

Tyler & Moench, 2012

Reference

Bruneau, M., Chang, S.E, Eguchi, R.T., Lee, G.C., O'Rourke, T.D., Reinhorn, A.M., &von Winterfeldt, D. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthquake Spectra*, 19(4), 733-752.

Little, R.G. (2002). Controlling cascading failure: Understanding the vulnerabilities of interconnected infrastructures. *Journal of Urban Technology*, 9(1), 109-123. Doi: 10.1080/10630730220135755

M-BRACE (2013). *Vulnerability assessment in Lao Cai City*. Lao Cai, Vietnam: Lao Cai core working group of M-BRACE project.

McBain, W., Wilkes, D., & Retter, M. (2010). *Flood resilience and resistance for critical infrastructure*. London: CIRIA.

O'Rourke, T.D. (2007). Critical infrastructure, interdependencies, and resilience. *The Bridge: Linking Engineering and Society*, 37(1), 8. Retrieved from http://pdf.aminer.org/000/243/970/robust_and_resilient_critical_infrastructure_systems.pdf

Tyler, S. & Moench, M. (2012). *A framework for urban climate resilience, Climate and Development*, 4:4, 311-326. http://dx.doi.org/10.1080/17565529.2012.745389

Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G., Janssen, M., Lebel, L., Norberg, J., Peterson, G.D. and Pritchard, R. (2002). Resilience management in social-ecological systems: a working hypothesis for a participatory approach. *Conservation ecology*, 6(1).

Resilient systems differ from an engineering approach to robust systems, which rely primarily on hard protective structures (e.g. sea walls) or are designed in ways that emphasize the strength of specific individual components to ensure functionality. Resilient systems, in contrast, ensure that functionality is retained and can be rapidly reinstated through system linkages despite some failures or operational disruptions.

– Bruneau et al., 2003; McBain, Wilkes, & Retter, 2010; O'Rourke, 2007 -

Funded by the Rockefeller Foundation

Implemented by the Institute for Social and Environmental Transition-International (ISET-International) and Viet Nam Urban Development Planning Association (VUPDA)

Contact Information

ISET-International

Country Coordinator
Mai Ngo
lemai@i-s-e-t.org

Technical Consultant
Tuyen Nghiem
tuyen@i-s-e-t.org