Promoting Climate Resilient Infrastructure in Northern Mountain Provinces of Vietnam

Technical Report – Deliverable No. 2 - UNDP component

METHODOLOGY FOR VULNERABILITY ASSESSMENT OF RURAL INFRASTRUCTURE IN 15 MOUNTAIN PROVINCES

Ha Noi, July 2015

METHODOLOGY FOR VULNERABILITY ASSESSMENT

1.1 Conceptual framework

The conceptual framework for the vulnerability assessment draws from the recent work carried out in the Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). The resulting report, Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, referred to as the SREX report, was the key input to the latest IPCC Assessment Report Number 5 (AR5). This report synthesizes the most up to date knowledge and international best practices on climate change adaptation.

As shown in Figure 3.1, infrastructure system naturally shows its exposure to climate-related hazards. The vulnerability of rural infrastructure is defined as a function of internal vulnerability (physical properties) and coping capacity (external). While the internal vulnerability is referred to those resulted from physical resilience of the infrastructure system to climate-related hazards, for instance, high quality construction materials showing low vulnerability and vice versa; coping capacity is understood as a reverse manner with the vulnerability, lower coping capacity means higher vulnerability and vice versa. The internal vulnerability is more dependent on the quality features of the infrastructure while the external vulnerability is influenced by a series of factors such as local knowledge, socioeconomic development, governance and so forth.

In order to gain a good understanding of vulnerability it is necessary to consider both indicators of physical vulnerability and coping capacity. The purpose of these definitions is to represent different influences when developing the conceptual framework; however, they can simply called vulnerability indicators for vulnerability index computation processes.

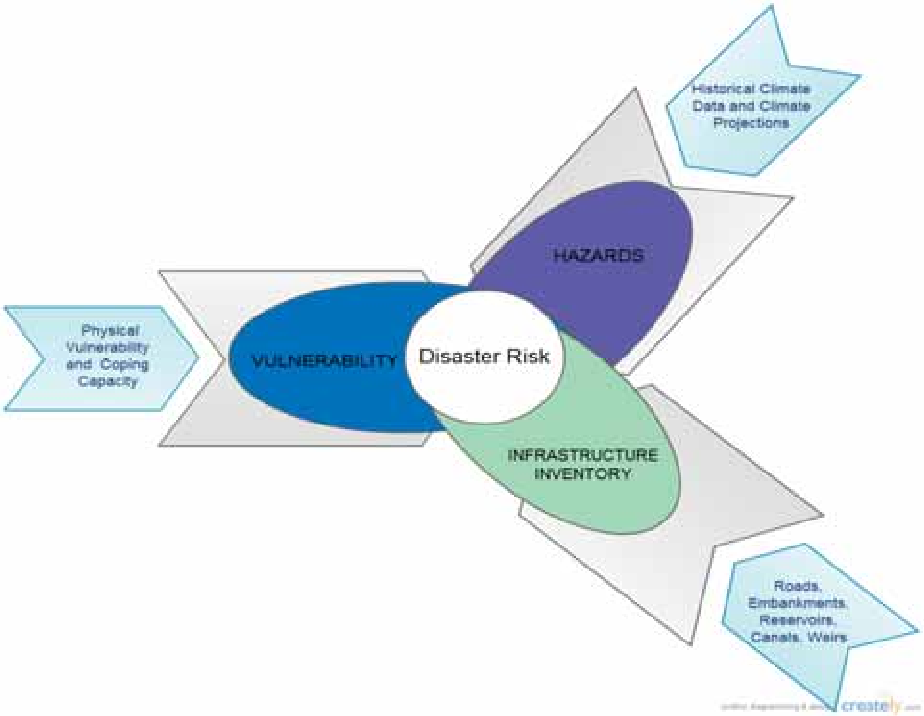

Figure 3.1 Conceptual model[1]

[1] Promoting Climate Resilient Infrastructure in Northern Mountain Provinces of Vietnam - Methodology for vulnerability assessment and risk mapping, Ujala Qadir, 2014

1.2 Assessment methodology

The assessment methodology employed in this report aims to combine internal and external vulnerability indicators to gain an estimate of combined vulnerability. This is part of the project's combined work, which will then further add in data on underlying hazard risk from events like floods and storm as factors in combined vulnerability, and finally will also they overlay future climate change projections.

To complete this task, the assessment team worked closely with MARD to:

1) Establish a criteria for which type of infrastructure could be feasibly included in the report (given the large number of possible variables);
2) Establish a core set of vulnerability indicators to be applied and to assign relative weights to respective factors;
3) Establish a data collection mechanism and adjust indicators based on the availability and quality of respective data. This step was particularly important as it was recognised that the future usability of a tool would be heavily dependent on the ease by which the Government could feasibility maintain and strengthen datasets in the future.

Further details on each of these steps are provided below:

1.2.1 Infrastructure inventory and selection criteria

- Infrastructure inventory

The infrastructure inventories for roads, embankments and irrigation works and its attributes (information) were collected for provinces and districts for regional and provincial assessments, respectively.

- Selection criteria

Given the fact that the number of infrastructure elements is quite large, and many elements (small scale ones) are without information, not all infrastructure is included in the study. The infrastructure inventories were selected, so that sufficient information of the infrastructure inventories can be collected for vulnerability assessment. Following are the screening methods employed to select each type of infrastructure to be included in the inventories.

Roads: Roads greater than 4 km were included in the vulnerability assessment, because it was too difficult to gather information on smaller roads, for instance, roads located within a commune or villages.

Embankments: All embankments, currently managed by local authorities except those managed by Vietnam Army because of the national security secret, were selected.

Reservoirs: Reservoirs with storage less than 3 million cubic meter were included because small reservoirs are considered more vulnerable given the insufficient maintenance of the dams. Meanwhile, larger reservoirs always receive greater attention from the central government and presently belonging to the National Programme for Dam Safety Assessment governed by MARD.

Weirs: Weirs supplying water for irrigation area of more than 5 ha were selected; others are too small to gather enough information for this assessment.

Canals: Only the primary irrigation canals from the reservoirs selected above were considered in this assessment; while secondary canals were not considered because of the data unavailability.

1.2.2 Vulnerability indicator and weight

Indicators representing the vulnerability were determined for each type of infrastructure based on the information and data which are considered to be collected in the field with consideration of the details of each assessment scales (regional and provincial). Indicators and the associated weights were primary determined following a series of discussion among the vulnerability assessment (VA) team in consultation with the international consultant. The lists of indicators and the corresponding weights for regional and provincial vulnerability assessments were then finalised based on the results from the consultation workshop attended by experts (climate change, road, irrigation, etc…), managers and practitioners (as seen in the report of the consultation workshop on methodology for vulnerability assessment).

The influence of each indicator on vulnerability to climate related shocks is different. So that the selected indicators were then classified into three groups representing very important, important, and less important levels. Each important level was first assigned a weight; and they were finalized based on the results from sensitivity analysis. Table 3.1 illustrates the VA team's (including the international consultant) suggestion for the weights of different levels of importance; Table 3.2 present the lists of indicators and their meaning, and corresponding weights for each type of infrastructure and assessment scale.

Table 3.1 Indicator weights

Very important	Important	Less important
0.5	0.3	0.2

Table 3.2 Description of vulnerability indicators and their weights for different types of infrastructure and geographical assessments

(Note: VI, I, LI, R, and P denote Very Important, Important, Less Important of the indicator, Regional and Provincial assessment, respectively)

1. ROAD
1. Material of the road (VI,R,P): The material of the road indicates the relative strength and ability of the road to withstand hazards.
2. Number of secondary structures on the road (LI,R,P): The assumption here is that the more structures (e.g culverts, bridges) that are present, the more the vulnerability. This is because the road would require more maintenance, and there are a greater number of elements exposed to the hazard events which can lead to total failure of the functionality of the system.
3. Number of communes cut-off from the main road per year (I,P): This indicator is used because very little information is available on how often roads are closed in the area. Though this appears to be a hazard indicator, it is included here because it is assumed that the Hazard Maps do not look at infrastructure exposure. Rather, the maps usually look at either population or socioeconomic exposure. Therefore, in order to ensure that the past damages due to hazards are reflected in our study, we include this indicator here.
4. Past damages (I,P): Past damage is used to indicate vulnerability in the area. The reasons for damage is related to various factors which includes some or all of the following: landslides, flash floods, poor design, poor construction, lack of maintenance, etc. The assumption made for this indicator however is that the damage information indicates vulnerability and not hazard frequency, magnitude or extent. The reasoning for including this indicator is the same as that for the previous indicator described above.
5. O&M (I,R,P): The annual planned budget for Operation and Maintenance for the roads represents the capacity of the institutions to plan, manage and maintain infrastructure. The assumption is that the higher the planned budget, the higher the financial capacity of the institution to take O&M.

6. Ratio of poor households (LI,R,P): In the rural areas of the northern region, communities are heavily involved in the management, maintenance and repair of infrastructure. Communities that have a higher ratio of poor households are at a disadvantage and more vulnerable due to the lack of economic capacity to contribute financially to the infrastructure repair and maintenance. Moreover, poverty indicators can also roughly represent levels of education, literacy and other key coping capacity factors due to the linkage between poverty and opportunity. Information on exactly which communes the road passes through is unavailable. However, we do have the location of the start and end points of the roads. Thus, the average of these two figures will be used to approximate poverty levels. This assumption is not expected to be too far from reality, as the variability of poverty proportions across communes within the same district are not very high.
7. Proportion of ethnic minorities (LI,R,P): Ethnic minority populations have historically been marginalized, leading to lower capacity to withstand shocks and contribute effectively to the resilience of the infrastructure. While national poverty rates in Vietnam have decreased dramatically in recent decades, the poverty rate among ethnic minorities remains high and the gap between them has increased. Moreover, there is limited access of ethnic minority groups to appropriate government services, existing social exclusion and ongoing limited access to markets will continue to constrain the opportunities that could be available to them to adapt to climate change. As well as the climate-livelihood linkages, disaster risk and the policy and institutional context, there are other underlying causes of climate vulnerability.
8. Proportion of working age population (LI,R,P): Working age is defined by the Vietnamese government as between 15 to 60 years for men and 16 to 55 for women. The proportion of working aged population represents the capacity of the population to contribute to community projects such as infrastructure development and repairs. On contrary to the behaviour of the previous two indicators, higher rate of working age population indicates higher capacity of the community to cope with climate-related hazards.
2. EMBANKMENT
1. Material of embankment (VI,R,P): The material of the embankment represents the relative strength and ability of the embankments to withstand hazards, particularly flash floods.
2. Age of the embankment (VI,R,P): The age of the embankment (similar to other infrastructure) is calculated by subtracting the date of construction from 2014. The age of the embankment represents its present condition and assumes that the older the embankment, the higher the vulnerability. This is especially true for the northern mountain provinces due to the general lack of regular operation and maintenance (O&M) activities.
3. Year of applied designing code (VI,R,P): There have been a number of important changes in designing codes for embankment and irrigation system, including reservoir, weir and canal. As the designing codes have improved over the years, the older infrastructure seems to be more vulnerable. The age of the infrastructure is already considered; however, this indicator was divided into categories depending upon which designing code would have been applied during the year it was constructed.
4. Past damages (VI,R,P): This indicator is similar to that for road.
5. O&M (I,R,P): This indicator is similar to that for road.

6. No of site inspections (I,P): Embankments are crucial infrastructure to protect people, livelihoods, property, infrastructure and productive land from floods. Regular checking of the embankments before the rainy season is assumed to be carried out every year. These activities can help to identify potential failures of the infrastructure.
7. Community contribution to infrastructure (LI,P): This indicator is added based on the fact that for many repairs to the infrastructure after a hazard event, it is the community that is mobilized to carry out the work.
8. Ratio of poor households (LI,R,P): This indicator is the same for all types of infrastructure[2]
9. Proportion of ethnic minorities (LI,R,P): This indicator is the same for all types of infrastructure
10. Proportion of working age population (LI,R,P): This indicator is the same for all types of infrastructure
3. RESERVOIR
1. Material of reservoir (VI,R,P): The material of the dam indicates the relative strength and ability of the dam to withstand hazards, floods, overtopping flow, seepage resistance, slope sliding, etc.
2. Age of the reservoir (VI,R,P): This indicator is similar to that for embankment.
3. Year of applied designing code (I,R,P): This indicator is similar to that for embankment.
4. No of reservoirs that have stopped functioning (VI,R,P): Total failure of the reservoir will help to identify extremely vulnerable reservoirs and is information that most district officials will remember.
5. Number of times the spillway has been damaged (I,R,P): Damage information about a reservoir is difficult to ascertain given that there are many aspects of the reservoir that are damaged, and there are no records available. However, this information is very important and a simplified measure is required to assess vulnerability. We use damage of spillways as a proxy indicator of past damage because we assume it will be easier to recall specific damage to spillways, and also because the damage to spillways will most likely be due to hydro-meteorological factors such as heavy rains leading to flooding.
6. O&M (I,R,P): This indicator is similar to that for embankment.
7. Community contribution to infrastructure (LI,P): This indicator is similar to that for embankment.
8. Ratio of poor households (LI,R,P): This indicator is the same for all types of infrastructure
9. Proportion of ethnic minorities (LI,R,P): This indicator is the same for all types of infrastructure
10. Proportion of working age population (LI,R,P): This indicator is the same for all types of infrastructure
4. WEIR

[2] Some indicators (e.g social indicators) which are administrative unit representation, therefore, all type of infrastructure share these indicators.

1. Material of weir (I,R,P): This indicator is similar to that for embankment.
2. Age of the weir (VI,R,P): This indicator is similar to that for embankment.
3. Year of applied designing code (VI,R,P): This indicator is similar to that for embankment.
4. Community contribution to infrastructure (LI,P): This indicator is similar to that for embankment.
5. Ratio of poor households (LI,R,P): This indicator is the same for all types of infrastructure
6. Proportion of ethnic minorities (LI,R,P): This indicator is the same for all types of infrastructure
7. Proportion of working age population (LI,R,P): This indicator is the same for all types of infrastructure
5. CANAL
1. Material of canal (VI,R,P): This indicator is similar to that for embankment.
2. Age of the canal (VI,R,P): This indicator is similar to that for embankment.
3. Year of applied designing code (VI,R,P): This indicator is similar to that for embankment.
4. Number of times canal was damaged (VI,R,P): This indicator is similar to that for reservoir.
5. Ratio of poor households (LI,R,P): This indicator is the same for all types of infrastructure
6. Proportion of ethnic minorities (LI,R,P): This indicator is the same for all types of infrastructure
7. Proportion of working age population (LI,R,P): This indicator is the same for all types of infrastructure

1.2.3 Data normalization

All of the selected indicators and weights were used to develop a vulnerability index. However, a challenge arose due to the fact that the assessment includes two types of indicator: continuous and categorical. This created complications when comparing the indicators and was resolved by transforming all of the indicators into categories.

3.2.3.1 Continuous indicator

For continuous indicators, normalized value is equal to the value of the indicator subtracted by the minimum observed value divided by the difference between the maximum and minimum observed values, as expressed in Equation 1; whereas the lists of continuous indicators for each type of infrastructure are shown in Table 3.3.

$$\bar{I} = \frac{I - I_{\min}}{I_{\max} - I_{\min}} \tag{1}$$

where:

$\bar{I}$ - normalized value

I - actual indicator value

$I_{\min}$ - minimum value of the indicators

$I_{\max}$ - maximum value of the indicators

Table 3.3 Continuous indicators for each type of infrastructure

Indicator	Type of infrastructure				
	Roads	Embankments	Reservoirs	Weirs	Canals
Age		x	x	x	x
Past damages	x	x			x
Number of communes cut-off from the main road per year	x				
No of reservoirs that have stopped functioning			x		
Number of times the spillway has been damaged			x		
O&M	x	x	x		
No of site inspections		x			
Number of secondary structures on the road	x				
Ratio of poor households	x	x	x	x	x
Proportion of ethnic minorities	x	x	x	x	x
Proportion of working age population	x	x	x	x	x
Community contribution to infrastructure		x	x		

3.2.3.2 Categorical indicator

All categorical indicators have been assigned a transformed value. The value has been decided based on expert opinion of the international climate consultant and infrastructure experts. The value assigned for each categorical type of indicator is presented where appropriate.

Material of the road: The roads in the northern mountainous provinces were commonly made of concrete, asphalt, gravel, or earth materials. Each type of material would be assigned to a level of vulnerability and given the transformative value, as expressed in Table 3.4.

Table 3.4 Indicator values for road material type

Materical type	Vulnerability	Indicator value
Reinforce concrete	Very Low	0.1
Concrete	Low	0.3
Asphalt	Medium	0.5
Gravel	High	0.7
Earthen	Very High	0.9

Material of the embankment: The embankments in the northern region were made of rip rap, concrete, gabion, or a combination of concrete and gabion. The table below shows the transformative value.

Table 3.5 Indicator values for embankment material type

Materical type	Vulnerability	Indicator value
Reinforced concrete	Very Low	0.1
Concrete	Low	0.3
Stonework	Medium	0.5
Gabion	High	0.7
Riprap	Very High	0.9

Material of the reservoir (dam): Dams in the northern region were mostly built using local materials such as earth, stone; and a few of them were made of higher strength material like concrete. Table 3.6 below shows the suggested transformative value.

Table 3.6 Indicator values for reservoir material type

Materical type	Vulnerability	Indicator value
Reinforced concrete	Very Low	0.1
Concrete	Low	0.3
Stonework	Medium	0.5
Riprap	High	0.7
Earthen	Very High	0.9

Material of the weir: The weir can be made of concrete or of stone in the northern region. Thus the weir will fall into one of the categories and given a score.

Table 3.7 Indicator values for weir material type

Materical Type	Vulnerability	Indicator Value
Reinforced concrete	Very Low	0.1
Concrete	Low	0.3
Stonework	Medium	0.5
Brickwork	High	0.7
Riprap	Very High	0.9

Material of the canal: The canal can be made of concrete, brick, stone or earth. Thus, the canal will fall into one of the categories and given a score, as seen in Table 3.8.

Table 3.8 Indicator values for canal material type

Materical type	Vulnerability	Indicator value
Reinforced concrete	Very Low	0.1
Concrete	Low	0.3
Brickwork	Medium	0.5
Stonework	High	0.7
Earth	Very High	0.9

Number of times the spillway has been damaged: In practice, it seems difficult to gather an exact number of times the spillway has been damaged. To further simplify the approach, the question can be asked in terms of categories as follows: How many times has the spillway(s) of the reservoir been non-functional in the past 5 years?

Table 3.9 Indicator values for categories of damage to reservoir spillways

Category	Definition	Vulnerability	Indicator value
Never	0 times	Very Low	0.1
Rarely	1-2 times	Low	0.3
Sometimes	3-6 times	Medium	0.5
Frequently	6-9 times	High	0.7
Every Year	10 times	Very High	0.9

Year of applied designing code: Since the first designing code was applied for irrigation systems, it has been periodically revised and update as a result of innovations in design method and material technology together with changes in hydro-meteorological conditions. The major revisions of designing code along the timeline were purposed to construct more resilience infrastructures to natural hazards. Table 3.10 presents the transform values of the year of applied designing code.

Table 3.10 Indicator values for categories of year of applied designing code

Year of applied designing code	Vulnerability	Indicator value
2012	Very Low	0.1
2002	Low	0.3
1990	Medium	0.5
1976	High	0.7
prior to 1976	Very High	0.9

1.2.4 Vulnerability index

To derive the vulnerability index, following equations were used. Equation 3 describes the vulnerability index of a type of infrastructure (embankment for example) in a certain geographical scale (*X*). It is the average of the vulnerability of a single embankment in that area. Similar method would be carried out for other type of infrastructure and for the different geographical scales.

$$V_X = \frac{(V_X^1 + V_X^2 + ... + V_X^N)}{N} \quad (3)$$

where:

- *V*: vulnerability index
- *X*: province/district
- *N*: total infrastructure of the provincial /district *X*

Equation 4 describes the vulnerability index of a single infrastructure element (e.g. an embankment) in a certain geographical scale (*X*). It is the sum of single indicator *I* multiply by each weight *w*.

$$V_X^1 = w_1 * I_1 + w_2 * I_2 + ... + w_N * I_N \quad (4)$$

where:

- *V*: vulnerability index
- *X*: province/district
- *I*: indicator of vulnerability
- *w*: weight

- N: total vulnerability indicator

The sum of all the weights applied to each vulnerability indicator should equal to one, as seen in Equation 5.

$$w_1 + w_2 + ... + w_N = 1 \quad (5)$$

1.2.5 Sensitivity analysis of the weight

As previously addressed, the initial weights were determined based on experiences or consultation with experts as well as suggestions from similar studies. It is, therefore, necessary to conduct a sensitivity analysis to examine the influence of weights on the vulnerability results. Various weights and calculations should be conducted to test how the overall model is affected. If there are major impacts of certain subjective decisions made by the team, the assessment method should be adjusted accordingly, or the results of the sensitivity analysis presented within the final deliverable to avoid misrepresentation. In addition to the sensitivity analysis of weights, the influence of social indicators on the final vulnerability of the infrastructure was also examined.