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CONCEPTUAL ASPECTS OF VULNERABILITY MAPPING AS MAIN PHASE OF A RISK MAPPING PROCESS

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Abstract: *A vulnerability map gives the precise location of sites where people, the natural environment or property are at risk due to a potentially catastrophic event that could result in death, injury, pollution or other destruction. Such maps are made in conjunction with information about different types of hazards. This maps are most often created with the assistance of computer technology called geographic information systems (GIS) and digital land survey equipment designed for use in the field. However, vulnerability maps can also be created manually using background maps such as satellite imagery, property boundaries, road maps, or topographic maps. In such cases the national or municipality's planning office should be involved in order to take advantage of the base maps that have already been made for other purposes.*

The vulnerability maps will allow them to decide on mitigating measures to prevent or reduce loss of life, injury and environmental consequences before a disaster occurs. An interdisciplinary vulnerability mapping group considers where mitigating measures should be taken before, for example, a flood occurs. Those preparing the maps can overlap flood inundation and slope stability zones with property maps in order to determine which properties and buildings are at risk.

Vulnerability maps can be of use in all phases of `crisis management: Prevention, mitigation, preparedness, operations, relief, recovery and lessons-learned. In the prevention stage planners can use vulnerability maps to avoid high hazard zones when developing areas for housing, commercial or industrial use. Technical experts can be alerted about places where the infrastructure can be affected in case of a disaster. Fire departments can plan for rescues before a potentially dangerous event is at hand. During an exercise where a predetermined scenario takes place, the rescue crews may use the map to determine where to respond first to save human lives, the environment or property. They can also be used to evacuation routes to test the effectiveness of these routes for saving large numbers of residents and tourists and moving special groups such as senior citizens, children and those with handicaps. The operations officer can be updated about the disaster situation and the need for and the location of sensitive areas. The vulnerability map can also include evacuation routes to test their effectiveness for saving lives.

Keywords: *vulnerability, mapping, risk, methodology, crisis.*

1. Vulnerability context

When the map is complete, there will be sufficient information to begin discussions about action plans for the threatened objects such as:

1) How will the sites be protected?

2) In which order will they be protected?

3) Who will accomplish the mitigation work?

4) Who will check to see if the mitigation work is adequate?

5) How will the vulnerable sites be addressed in the emergency preparedness plan?

Define the area that will be mapped

An important part of the vulnerability map is defining and limiting the area affected by one or more hazards. Use the scenarios that the group has decided upon to determine the extent of the affected zone. The area to be mapped needs to encompass the entire area where a hazard can affect the natural environment to be protected or developed sites whether it be a city infrastructure, houses and apartments, or commercial sites and public facilities. Consider also the resources available to do the field mapping. If resources are not adequate, choose the area where vulnerability is likely to be the highest.

Maps made after a disaster can assist in defining hazard areas that were not fully understood or defined prior to the disaster. Historical information is important for determining the extent of the area to be mapped.

Maps distinguish themselves from sketches or drawings because they have a scale which shows how one unit of measure on the map corresponds to kilometres in the field. Maps also have a directional arrow showing north, and symbols or patterns and a corresponding legend. If analogue maps are the only option, then transparent overlays can be made each plastic transparency with a unique map theme such as hotels or ferry routes.

Although analogue vulnerability maps can be made, there is clearly an advantage to creating the map in a geographic information system (GIS). Several vulnerability maps can easily be made using the same base maps and the same threatened objects but with different hazard profiles. Hazard zones might look completely different based on the hazard type and the actual scenario. In addition the maps can be easily laid upon each other so that any overlapping between risk areas and threatened objects is clearly shown. GIS maps can more easily be updated and printed.

Vulnerability mapping efforts for an environmental disaster begin with an accurate representation of natural features such as rivers, lakes, landforms, topography, and vegetation type.

Environmentally vulnerable

Soil type and geology
Hydrology, rivers and lakes
Forest and bush
Agriculture
Pasture and livestock grazing

Man-made features can then be transposed on the natural landscape. The map will then include such information as land use, road and railway systems, power stations, industrial sites, official buildings, business areas, housing areas, schools, and hospitals. Refer to the list of threatened objects presented earlier. Define what is unique about the areas in order to protect biodiversity and cultural integrity for future generations. In addition, any objects that are essential to the emergency operations should be added to the map.

The crisis management group needs to check with the municipality's planning office to determine what other maps have been made and which can be useful when creating the vulnerability maps. In some municipalities where a certain risk is very high, specialised risk maps might be available. For example, general flood risk maps on a scale of 1:50 000 or 1:100 000 can give a general overview the hazard zone, even if the vulnerability map might be created on a larger scale such as 1:10 000 or 1:5 000. Slope stability maps are generally created in a larger scale such as 1:5 000. They might also be available for the area.

Human-caused hazards such as industries, railways, can be pinpointed on a map. When a risk object has been created on the map, the mapmaker assigns the exact coordinates for the object and gives the object an ID-number. Risk objects can be grouped into classes with each class having its own symbol. For large-scale maps, for example, 1:5 000, a symbol which represents the object type can be placed on the building or site. This gives a better overview of vulnerability for those using the map. Objects requiring special protection can also have unique symbols. In order for the map to be complete, risk objects and, where possible, the source of the risk, can also be mapped.

When creating the vulnerability map, consider the type of information that will be needed in case a disaster occurs so that lives, property and the environment can be saved. In order to use the vulnerability map in a useful way, estimate the area in meters or hectares that would be affected by the specific hazard and the number and type of objects within the zone that need protection. Estimate the population that will need to be evacuated. Estimate the total number of villages and if resources allow it, even the total number of houses. If a GIS system with data on the number of inhabitants is not available, then an estimation of population density for areas within any hazard zone might be made. List the environmentally sensitive areas as well as the land uses that are important for the local economy and livelihoods of the residents in the area Map the location and extent of the damage that is incurred during the event. Describe and photograph the damage. Show where environmental recovery work was done and describe the work achieved. Hand- held digital equipment can be used for retrieving and recording the data that will be added to a geographic information system if such a system is available. The vulnerability map is only part of the effort to protect the natural and man-made environment.

2. Vulnerability level assessment (VULNERABILITY INDEX "Vn")

Thanks to specific numerical analysis and/or mere reflections upon the anthropic system, it should be possible to associate a vulnerability index "Vn" to the corresponding zones including elements at risk. The proposed classification of vulnerability includes five vulnerability indicators (vulnerability indices: V0, V1, V2, V3, V4) corresponding to different vulnerability levels (absent, low, medium, high, very high).

Vulnerability Map (VM)

Low vulnerability
Moderate vulnerability
High vulnerability
Very high vulnerability

The accuracy of the vulnerability index depends on the quality and quantity of collected information and on the way such parameters (elements at risk) are compared and combined. Vulnerability can only be measured with a clear definition that can be operationalized. Blaikie et al define vulnerability as "the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard" . These indicators provide a way of specifying discrepancies between present and desired circumstances. In the case of disaster preparedness or human vulnerability the goal for communities is to maximize their preparedness potential and minimized their vulnerability. This report summarizes many of the problems and issues that are associated with indexes constructed for vulnerability and hazards. Several indices related to hazards and vulnerability are compared and a breakdown of each index provided. The breakdown generally includes a formula, items measured, methodology, variables, scope and an example of empirical proofs.

Indexes are generally constructed by the summing or multiplying of several indicators relating to item being measured. Indicators that go into creating an index will have different units such as dollars, miles, degrees, population per square mile, or similar. Various methods are used, such scaling, to create "unit-less" variables. For example, a linear method of scaling was used for the Hurricane Disaster Risk Index and the Earthquake Disaster Risk Index.

Data can also be standardized and made unit-less by using Z-scores and then summing the values-- a method used for the Social Flood Vulnerability Index Other mathematical procedures, such as weighting techniques, are also incorporated into an index value in order to identify the varying levels of importance for each indicator. Weighting is a subjective process, and indicators that are considered to be of utmost importance to the index, can be assigned a higher “weight” to indicate the importance of the specific indicator Another key issue to consider with indices is that an index takes a group of indicators and produces a snapshot of reality. Indices are quantitative subjective measures, acting as proxies for the concept under examination . As indices are proxy measures, they also do not represent the true nature of a hazard or vulnerability. Cobb and Rixford stated that “every indicator is a flawed representative of a complex set of events.” Indices are unitless and the arithmetic is considered to be odd because in most cases the values do not represent anything outside of the context in which the situation is being compared. Contextual representation means an index number measuring the magnitude of a hazard or vulnerability is not on a linear scale, as a score of 5 on an index does not represent twice the vulnerability compared to score of 10.

Data Availability and Bias

Indexes have also been adapted and utilized by various government organizations. There has been considerable use of indices by different agencies to measure health, education, agriculture, economy, and similar socioeconomic trends. Different agencies within the government are also responsible for the collection of a considerable amount of data that is used to compile these indices. Not all data that government agencies collect is easily attainable. Data that would fall into this classification would include anything related to homeland security, which creates a problem for acquiring the data. Agency representatives and their parent organizations are often skeptical about the intentions of those who collect data. One inherent problem is the fact that there is no “correct” method for creating an indicator, and there will be opportunities for the interested parties to alter the indicator to suggest what they want it to.

Data from government sources should not be thought of as free from bias, as social indicators can and will be used to advocate particular political stances, and therefore may be imprecise because of bureaucratic wrangling . At the root, all indicator work has some political aspects, and even the act of deciding what to count is value oriented and subjective in nature. Upon examination of most indexing systems, data availability is seen to be a major limitation to the creation of indicators and indexes. There are costs involved with collecting good data. Who will be willing to pay for the data collection? Or maintain it? These considerations are critical and should be taken into consideration Another problem that arise with small scale analysis is with census tracts and the lack of homogeneity in size.

Indicator Selection: Who Decides What is Important?

Once questions about the datasets have been resolved, attention is focused on the selection of variables from these datasets. In the case of vulnerability, to what extent will the variables and numbers selected for analysis represent reality? The selection of variables that will determine vulnerability for an index is a subjective process. Data collection and the acquiring of knowledge become subjective due to differing perspectives of the world that reflect ,nationality, gender, social and cultural identities. Communities are also unique and are influenced are many different factors such as history, politics, demographics, traditions, and similar developmental factors. These variations may affect the data and indicators that are selected. What one community may view as a critical indicator may not be viewed in the same way by a different community. If an indicator is derived from survey data, there may be issues with interpretation from different communities. For a variable to be a good indicator of vulnerability, there must be a clear theoretical foundation in order to measure what is intended.

Complexity and Measurement

The complexity of the issues of measuring a community's vulnerability to hazards has posed a series of problems. Hazard vulnerability can be viewed as the summation of a continuum that combines physical and social exposure, disaster resilience, preventive mitigation, and post event response. Because of this immense complexity and wide range of scope of the factors of vulnerability, it requires that data be used from multiple sources. Multiple sourcing represents another problem for data analysis, because of the variability of the data sources and the different methods used to collect them.

Another problem is that because there is a wide array of information there difficult to delve into any one particular aspect of vulnerability but rather to take a more general approach without detailed analysis . Another key concern arising from complexity is the interaction of the components of vulnerability in the context of multiple hazards and risk. As of yet, we are unable to fully grasp the nature of interactions that take place between risk and vulnerability, and this could be related to the fact that we as a community know the least about the social aspects of vulnerability and the quantification of vulnerability . The social aspects of vulnerability consist of the nature of people, social structures, and culture which inherently makes it geared towards a qualitative assessment. Complex interactions can take place between physical and social attributes along with living arrangements.

Compilation and Analysis

Once questions about the data have been resolved and decisions have been made on what variables to use, the next logical question will be how to compile the data into an index. The two main elements that comprise overall vulnerability, including social vulnerability and hazard vulnerability, are combined for two reasons. First an average of values will be more stable than a separate indicator and secondly there is a need to reduce the complexity of the data into a summary such as the Consumer Price Index. The integration the different vulnerabilities create methodological problems, as some combine by multiplying the two indices (hazard and social), whereas others sum the two indices.

Framing the Measurement: *Disaster Demands vs. Community Capacity*

One method of defining a disaster is based on the notion that a disaster is only a "disaster" if the demands created by the event exceed the community's capacity for dealing with it. Quarantelli calls this an "imbalance in the demand-capability ratio in a crisis situation". Other notable researchers have also considered the framing of a disaster as a crisis state, or social stressor, in particular, articulated that the impact of a disaster agent is not a sufficient enough characteristic to determine a disaster has occurred. Because community resources, commitment to preparedness, and other factors influence the ability to respond to disaster impacts, While the "demands exceeding capacity" proposition makes intuitive sense, it has not thus far been operationalized or empirically tested to examine its validity. In order to create a model for the creation of a Preparedness Index and Resiliency Index (CRI), we must formulate the indicators that will allow us to test the validity of the index, as well as how best to apply it in practice.

There have been some efforts in this area, such as the understanding of social vulnerability and vulnerable populations, the assessment of state and local vulnerability, the determination of community wide vulnerability, and the determination of loss potential. However, little has been done in the way of measuring resilience which is, in large part, linked to a community's preparedness, following tenets will help frame the development of a successful index and its deployment:

Proposed Modeling Framework

Various models exist to determine a community's exposure, but generically this can be described as:
Vulnerability = hazard * probability * frequency * Vulnerability measures (VM)

The **Disaster Resilience Index (DRi)** will be a composite result of the presumed relationship between community preparedness measures (Pi) and the derivation of a Vulnerability score. Only through testing can we determine the most appropriate mathematical relationship, but the initial working framework is that a meaningful DRi can be derived from:

$$DRI = \frac{\text{Preparedness Index (Pi)}}{\text{Vulnerability}}$$

Where:
DRi > 1, the community is more resilient
DRi < 1 the community is less resilient

This gives a broad indication of resilience. More detailed meaning will come from the manner in which the components are weighted, and the determination of a relative standard of resilience from which cross comparisons can be made. In effect, the Disaster Resiliency Index can be considered to be a function of a community's preparedness in a ratio to its relative exposure to a unique set of hazards in that community. The higher the Preparedness score, the higher the resiliency index. For a higher cumulative set of hazards and exposure (vulnerability), for a given level of preparedness, the lower the resiliency score.

Determining the key variables, measures and metrics

Using a collaborative and consensus-based process among identified experts in the field—the individual measures will be determined and weighted. These are identified below as functional measures of preparedness (FM), and vulnerability measures (VM). The functional measures (FM) will be based on measuring such spatial and non-spatial data items across a range of community assets, including physical, economic, sociocultural, and ecological dimensions of capital. The same will be true for community exposure and vulnerabilities (VM). The number of measures can be as extensive as feasible data collection and synthesis allows. Once the measures have been determined and agreed upon, they can then be scaled and normalized to fill in the following equations, first determining the preparedness index score. First, as an overall measure of community capacity, the derivation of a preparedness (Pi) score for a given location (x) will use the following:

Pix = (w1FM1 + w2FM2 + … wnFMn) Where:

Pi = community preparedness (P) index
x = location of community
wn = weight for a given measure
FMn = functional measure/indicator
n = number of measures

The next step is to determine the unique vulnerability of the community (located at x), by deriving a vulnerability score that measures hazards - including frequency and probability - as well as additional vulnerability measures (such as socially vulnerable populations):

Vx = [(Hapafa)+(Hbpbfb)+…] x [(w1VM1 + w2VM2 + … wnVMn)]

Where:
V = Community Vulnerability
x = location of community
Ha,b,c…. = Hazard agent (earthquake, hurricane….)
f = frequency of hazard
p = probability of hazard

w = weight
VM = Vulnerability measure/indicator
n = number of measures

Determining the ratio of capacity to vulnerability will give the Disaster Resiliency Index score. So that the Disaster Resiliency score will be:

$$DRix = \frac{Pix}{Vx}$$

$$\text{Disaster Resiliency Index} = \frac{\text{Community preparedness index}}{\text{Community vulnerability}}$$

Higher resilience scores will be determined by larger community capacity (measured as preparedness) versus the amount of vulnerability, or similarly if the community has low exposure (vulnerability) it will have a higher resilience score.

While this framework provides an overall structure to the model, the key factors (weighting, indicator development, data availability) will drive validity and model robustness.

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