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Disaster Risk Index: A Review of Local Scale Concept and Methodologies

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Abstract. Disaster Risk Index (DRI) is a tool for risk identification, risk management and risk exposure which measured at a different level of scales such as global, regional, trans-boundary or local. This paper reviews DRI and its developments at a local scale of nine countries. There are differences in the risk index components used. Some countries from the previous study such as China, Indonesia, Philippines, USA, and Brazil applied World Risk Index (WRI) concept while others use a combination of other risk components to define risk. The paper also reviews the methodologies used in terms of indicators' weight and the purpose of DRI development. The vulnerability component, which divided into six dimensions for assessment (social, environmental, economic, institutional, physical and economic) mostly focused on the social and physical dimensions. There is a limitation for the WRI concept at the local level in terms of data availability. The indicator used does not represent the local attribute of the countries or the community. Greater focus placed on an integrated approach for the development of DRI at the local level by considering the element of climate risk as an indicator. The development of DRI should consider an integrated approach that is focused on a certain dimension for future research for contribution to Disaster Risk Reduction (DRR).

Keyword: Disaster Risk Index, vulnerability, Risk Indicators, Local-scale

1. Introduction

Disaster always integrated with natural hazards, which is a natural phenomenon that might harm society and the environment [1]. Natural hazards include floods, earthquakes, landslide, hurricane, volcanic eruptions, wildfires, storms and drought. Hazards often cause an impact on loss of life and property. International Federation of Red Cross and Red Crescent (IFRC) reported that there are 1.4 million people affected by the disaster with an estimated 5 million US dollars in damages [2]. Therefore, a lot of effort taken to reduce the risk of disaster, especially to individuals. According to [3], disaster risk is the potential and probability of loss of lives, assets, health, and livelihoods that could occur to society in the future. Due to the vulnerability condition of the social-ecological system, there is a potential for loss in terms of physical, economic, social, and environmental [4].

Over the past decades, many efforts taken to reduce disaster risk. The Sendai framework has encouraged disaster risk reduction to be an indifferent organizational scale (world, regional, national, and local). The scale may refer to several dimensions. It may be in the form of organizational, space and time, therefore assessing risk in different scale are complicated as it may be dynamic (change in time) [5]. Reducing the disaster risk at the national and local level requires international, regional, sub-

regional, and transboundary cooperation [6]. Thus, the practice of disaster risk reduction is encouraged at all levels (world, regional national, local and transboundary) [7]. The method of disaster risk reduction also includes the development of disaster risk index in a different level of scale for risk assessment. Moreover, many countries and regional organizations have developed disaster risk index based on their specific region or country. An evaluation of risk and vulnerability including the assessment of institutional capacity is also one of disaster risk strategies (UNISDR, 2004).

Disaster risk index (DRI) also has different various scales and framework that has developed. The disaster risk index transformed and monitored to examine the relationship between the index area with the type of hazard (Islam, Swapan, & Haque, 2013). In the DRI conceptual model, vulnerability is a factor that defines why different people with the same exposure can have a high or low risk [9]. The indicator in the risk and vulnerability used to identify the leading cause of risk and vulnerability [10]. There is the various framework on measuring risk (hazard and vulnerability) with a different approach in terms of concept and operational scales (global, regional and local) in each country [11].

1.1 The Transformation of Risk Assessment

The term risk used to describe the possibility of losing something valuables and the probability threat of damage to lives, injury, and other negativities. In 1979, the United Nation Relief Organization (UNDRO) with the collaboration of United Nations Educational, Scientific and Cultural Organization (UNESCO) initiated the concept of risk, hazard, and vulnerability [12] (UNDRO, 1980). This proposed concept includes the following component: Hazard or Danger (H), Exposure (E) and Vulnerability (V), Specific Risk (Rs), Element at Risk (E) and Total risk (Rt): The equation (1) show the equation created for risk assessment by UNDRO:

$$R_t = E \times R_s = E \times (H \times V) \tag{1}$$

Cordona 1985 proposed at the Institute of Seismic Engineering and Seismology to remove the Exposure (E) component from the equation because implied in the vulnerability component. The actual concept of risk maintained without modifying the original concept made by UNDRO. Also, Cordona (1985) applies a hazard to a general formulation of the concept. Hazard (A_i), known as the possibility of the event with equal or greater intensity during the exposure time and Vulnerability (V_e) is known as the element that is susceptible and affected by the intensity on the occurrence of the event. Risk (Rie) perceived as the probability of the loss occurred to the element as consequences from the event. Eq.13 shows the risk equation based on Cordona in 1993[13]:

$$Rie = f(A_i, V_e) \tag{2}$$

The equation (2) shows that hazard (A_i) represents the natural phenomenon of floods, earthquakes, and hurricanes. While vulnerability (V_e) is the impact of natural phenomenon and represented by physical and social factors. This concept theoretically defines the area and the society affected by the natural hazard [13,14].

Further in time, Birkmann 2006 [10] defined risk as a possibility of a catastrophic event that causes the loss from the interaction of natural phenomena and vulnerability conditions. A hazard is then determined based on the location, magnitude, frequency, and probability. The hazard potentially gives a negative impact on the cultural, environmental, social, and economic aspects. Then, the growing use of a composite and synthetic indicator used in the indicator system has acquired interest as a tool for measurement, identification, and management of policies. The practice of the indicator system has become a powerful tool for disaster risk reduction.

Currently, based on the report from United Nations Office for Disaster Risk Reduction (UNISDR) there is three standard risk assessment methodology used in disaster risk management (probabilistic risk analysis, risk matrix or multi-criteria impact and likelihood analysis, and the index-based approach [15]. In this study, the reviews focused explicitly on the index approach. In the index approach, the hazard, vulnerability or subcomponent in the vulnerability presented in simple index scores. Then all components of risks combine to describe it in a single index score.

A review of previous research on the current disaster risk index approach practised by various countries at a local scale was conducted. The study focuses on the concept of each framework. Besides, the study reviews the changes from the past to the current framework. The review also includes the component and the indicator of each framework used in various countries. At the end of this paper, the paper discusses the current issues regarding DRI and future suggestions for improving DRI.

2.0 An overview of the risk index objectives

This section provides an overview of the purpose of DRI from various countries. From literature, nine states identified to develop its DRI at a local scale. However, all the states have a different purpose when producing the DRI. Most of the DRI approach is based on the World Risk Index by comparing the disaster risk sub-components and indicators among the countries. For local scales, the risk index development depends on the country's perspective on their local definition of the risk indicators.

In the last 20 years, the risk and vulnerability assessment within a different level of scale is an important issue and discussed in various studies in several previous studies. All discussions mainly focused on the importance of specific indicators for different scales. At the local scales, commonly the main objectives are to analyse the risk within the small organisational level, spatial area or hazard event. There is evidence showing that the successful result by conducting risk assessment at local scales [15]. Providing balanced bottom-up with top-down processes in disaster risk assessment and establishing stronger linkages between the national assessment and local-level, community-level and sectoral catastrophe threat assessment practices should enrich both techniques.

Table 1 shows the main objective of DRI development. Most of the disaster risk index used to identify hazard exposure and vulnerability. Countries such as the USA, Brazil, Indonesia, Pakistan, China and the Philippines elucidate vulnerability into several components (sensitivity, susceptibility, coping and adaptive capacity). The downscaling of disaster vulnerability can provide different results when compared in terms of global or regional scale. For example, living costs for an individual at a city might be different from an individual in the countryside, whereby the value of living costs might be different. The indices of the living expense in each country may vary.

Table 1. Objectives of DRI by various countries

Country	Main Objectives	References
Philippines	Focus on local or smaller scale risk assessment	[16]
Taiwan	Evaluating flood-prone areas for disaster mitigation	[17]
USA	Providing a method to assess risk at the subnational level	[18]
Brazil	Capturing hazard, susceptibility exposed to the community, coping and adaptive capacities for community	[19]
Vietnam	Identify flood hazard information within the context of flood exposure and vulnerability	[20]

Pakistan	Providing clear concept and methodologies for risk assessment based on several components (hazard, vulnerability (sensitivity and exposure), coping and adaptive capacity)	[21]
Bangladesh	Developing methodologies that consider hazard and vulnerability	[8]
Indonesia	Assessing the aspect of disaster risk exposure, susceptibility, adaptive and coping capacity at a local scale	[22]
China	Producing a risk map for design and implementation of disaster risk mitigation	[23]

2.1 Conceptual Framework and Methodologies

Most of the countries except Taiwan employ the risk concept introduced by United Nation [24] to define risk, which includes two main components; hazard and vulnerability in calculating risk. The idea has then been expanded mainly in the vulnerability component. As for Vietnam, the indices for the risk model consist of hazard and vulnerability elements without dividing them into sub-components. To quantify hazard and vulnerability, indicators are used. Table 2 shows a summary of the risk conceptual framework for various countries reviewed.

Pakistan's DRI concept combines hazard and vulnerability [25]. The method expands the vulnerability component into three main sub-components, namely, exposure, sensitivity and capacity. Exposure and sensitivity in this method mainly to describe vulnerability in the climate change context. This component describes the function of exposure, sensitivity and capacity [26].

WRI concept is the most common concept used by several countries. The approach of WRI is an effort from the Alliance Development Work as a new disaster risk and vulnerability assessment at the country scale. WRI approach is not primarily the impact of a disaster, or the event of the effects of mortality and economic losses but focuses on human exposure and vulnerability towards catastrophe [14].

Susceptibility is one of three subcomponents in the vulnerability component in WRI's conceptual framework. The subcomponent defined as the condition of the element that is exposed (societies or other exposed element) during natural hazard event that has a high risk to be affected [26, 29-30]. Coping capacity is one of the subcomponents in the vulnerability component. The component used in the WRI conceptual framework. Coping capacity is the ability to cope and manage during disaster events using available resources and skills for individuals, organisation or systems [31]. Adaptive capacity is also one of the subcomponents of the vulnerability component for the WRI concept. The use of adaptive capacity is to define the capability to develop, change, adjust and respond from the effect caused by stress [22, 32]. The subcomponent used in the conceptual framework for Pakistan, sensitivity referred to as a level of the system that is affected or benefitted caused by climate change and variability [33-34]. Susceptibility is also one of the terms chosen as alternatives words [20].

From the literature reviews, the main risk component used is a hazard, exposure, vulnerability, susceptibility, adaptive capacity, coping capacity, sensitivity and capacity. Hazard described as a phenomenon, condition or human activity that might cause loss of life, damage to property, social, economic and environmental damage [1]. Some countries conduct an assessment on a single hazard while some use multi-hazard. Multi-hazard is a combination of multiple disaster events that occurred inside the states and may coincide, whereby, the potential effect is considered [15]. In WRI, exposure referred to as an existence (peoples, infrastructure, resources, goods, services and ecosystem exposed and prone to natural hazards [27]. However, as for the concept that relates to climate change, exposure

is defined as an annual average percentage of people who are exposed to climate-related hazards either sudden-onset hazards or slow-onset hazards [28].

In this study, vulnerability is circumstances determine by a social, economic, environmental and physical element that increase the susceptibility for individual or community to the impact of hazard [10,15,29]. All countries except Taiwan has an input of vulnerability component into the DRI concept for risk assessment.

Table 2: The conceptual framework for each country

Conceptual Framework	**Country**	**References**
World Risk Index (WRI) Exposure × Vulnerability Vulnerability = (Susceptibility + (1 – Adaptive Capacity) + (1 – Coping Capacity)	Brazil, Philippines, Indonesia, USA, China	[25], [7]
R = H × V Where R risk, H hazard, and V vulnerability $V = \frac{E \times S}{C}$ Where E exposure, S sensitivity, and C capacity $DRI = \frac{Hazard \times (Exposure \times Sensitivity)}{Capacity}$	Pakistan	[25] [30]
DRI = Hazard Index + Vulnerability Index	Bangladesh	[8]
DRI = Hazard × Vulnerability	Vietnam	[25]
$DRI = \sum W_i X_i$	Taiwan	[17]

3. Vulnerability Dimension, Subcomponent, and Indicator

DRI contains several layers of assessment combined to analyze the level of risk. Vulnerability contains the most subcomponents with a mixture of indicators. The subcomponents might vary from one approach to another based on the objective of the studies and the indicators used are based on the subcomponents, which some are similar. Table 3 shows the summarise of nine countries subcomponents, weighted approach (equal or different weighted) and several indicators used for risk assessment.

The most subcomponents used are social, demographic characteristics and economical. Although the approach is similar between the countries using WRI, their numbers of indicators are different. The limitation of data availability at the local scale causes a different number of indicators used. However, countries using the WRI approach has extensive subcomponent assessments compared to others. The number of subcomponents used is twelve while others only provide two or up to four subcomponents. All the subcomponents are essential for disaster risk management and provide information for mitigation. However, the number of indicators used in Pakistan is the highest where it shows details of vulnerability assessment for each subcomponent.

Table 3: Subcomponents, Weighted, and Number of Indicators used for vulnerability

Country	Subcomponents	Weighted (Each indicator has weighted)	Number of Indicators
China	Public infrastructure, Poverty, economic capacities, health status, government and authorities, medical services, financial coverage, education and research, gender equity, environmental condition and protection, and financing	Equal	33
USA		Both	17
Indonesia		Equal	20
Philippines		Equal	26
Brazil		Equal	32
Pakistan	Socio-economic, demographic characteristics, flood frequency, and disaster preparedness	Different	47
Bangladesh	Social factor and geographical factor	Different	10
Vietnam	Land-use, Distance to rivers, Population density, Poverty rate, Road density and Number of doctors and nurses	Different	6
Taiwan	Flood factor, Land use, and adaptation and response capability	Yes	18

In terms of vulnerability, several definitions are being proposed by different researchers. [31], suggests that there are nine dimensions of vulnerability, which are social, physical, economic, institutional, cultural, environmental, educational, political and ideology that tightly integrated between each other. All the methodologies consist of indicators to measure the disaster risk. The number of indicators used also differ among countries. The European research project Methods for The Improvement of Vulnerability Assessment (MOVE) have proposed the different dimension of vulnerability. MOVE framework defined vulnerability into six dimensions (physical, institutional, social, economic, cultural and environmental) [11]. Figure 1 shows the overall concept of the MOVE framework. The original of hazard is from the socio-natural origin. The vulnerability consists of several components with six dimensions (physical, social, ecological or environmental, cultural, economic, and institutional).

The six dimensions are the core of the concept and critical factors to show the difference in vulnerability. The social dimension is the tendency for people to be damaged by disruption to an individual or collective social system and their characteristics[32-33]. The component includes the level of organisation, limitation of access and internal solidarity communities that restrain the capability to respond and cope during a disaster. The physical dimension is the physical impact on the built environment, critical infrastructure or open spaces that have the potential to damage during an emergency [32–34]. Economic dimension: is the inclination to lose the economic value and productivity capacity disturbance [32,35]. Environmental or ecological dimension is the potential ecological, biophysical system and other different function to be affected during the disaster [32,36]. The cultural dimension is the possibility to damage hidden values such as communities' customs, artifacts, habitual practices and natural or historical landscapes [33,37]. Institutional dimension is potentially detrimental to the system and function of governance including formal or informal customary rules, which may need to change due to disaster [33,37-38].

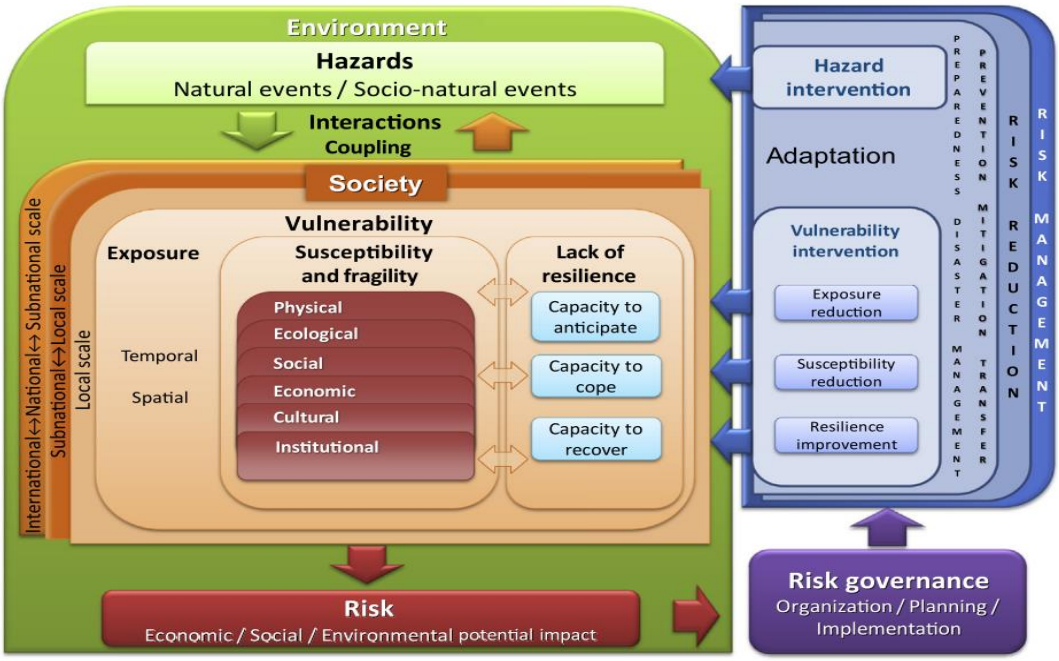

Figure 1. The MOVE conceptual framework. Figure concept based on [10,37,39–42]

Therefore, based on the concept of the MOVE framework for vulnerability, this study divides the indicator to be used in each country into six parts (economic, social, environmental, physical, institutional, and cultural. Figure 2 shows the number of indicators of each country used based on six dimensions. The highest number of indicators used in Pakistan with 47 number of indicators. However, the method does not include environmental indicators in their methodologies. The nine countries studied show that the highest is only five dimensions as contained in the indicator (Philippines, Pakistan, USA, China, Indonesia, and Brazil).

The countries that used the WRI conceptual framework (China, USA, Philippines, Indonesia, and Brazil) have missing cultural dimensions in their concept. The number of indicators for countries that used the WRI conceptual framework is China (32), Philippines (26), USA (16), Indonesia (20) and Brazil (32) with 23 indicators for vulnerability. China, the Philippines, and Brazil added more indicators that are suitable to analyze vulnerability in their countries. However, for Brazil and Indonesia, there is a lower number of indicators compared to WRI because some indicators are not relevant, nor suitable for social attributes and the indicators used by WRI are only for a national level. The lowest number of indicators used in Vietnam with six indicators and divided into four dimensions (social, institutional, physical and economic), while Taiwan and Bangladesh have 13 and 10 indicators, respectively.

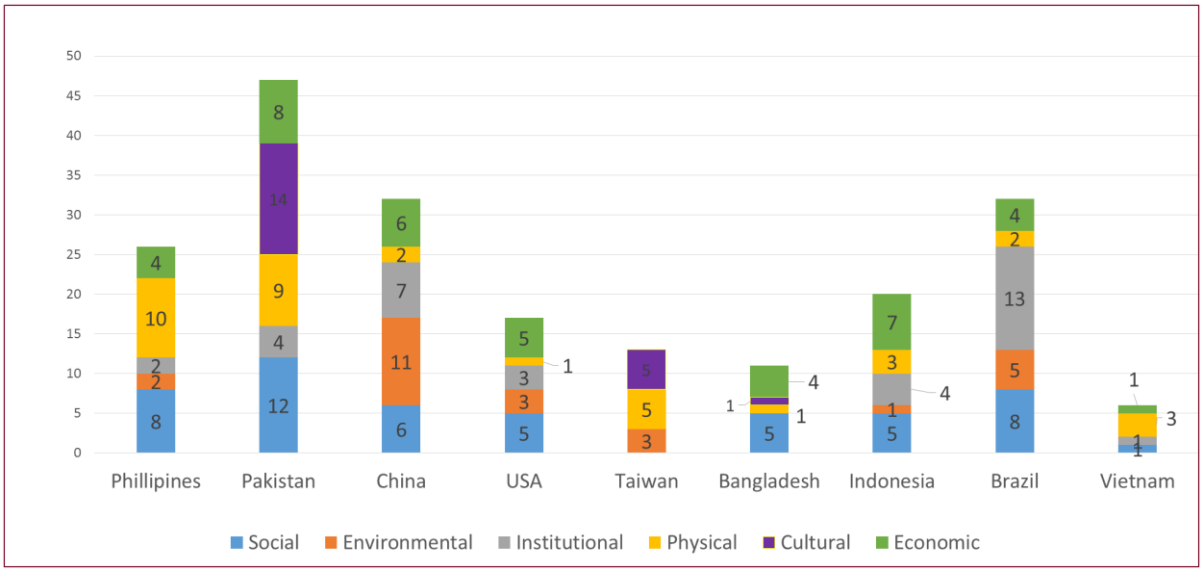

Figure 2: Number of indicators of each country divided into six dimensions based on the MOVE framework

4. Discussion

The modular structure of the Work Risk Index component allows the separate analysis of each component. However, this method only focuses on the country's scale than on a local scale. The indicator used based on the large scale size assessment that depends on the availability of the data for the same country to apply it at the national scale. The capabilities of these tools to evaluate the local level risk are limited, and therefore there is a need for the second layer of indicator that shows the local attributes [43]. Several elements considered to improve the vulnerability component in this method are social networks, local culture, and knowledge on the disaster, the experience of disaster, the capability of local government and others. The weight of the indicator used on these methodologies can be a potential of error if used in the lower than global scale because of the expert judgment based on a different scale [18]. If the weight is similar across sub-components, for a component having the least number of indicators, it will be the most influential component.

The climate risk is also among the topic and elements discussed lately. Currently, there are fewer studies that integrate disaster risk with climate risk. In terms of DRI at the local level, only Pakistan combines with climate change elements. The impact of climate is likely to increase the magnitude, frequency and spatial distribution of hazardous [44]. The adaptation to climate change impact becomes decisive especially at the local level because of the effect, which is affected at the local level and urban area [45]. The climate risk assessment also includes vulnerability and resilience by integrating climate change with disaster risk. The obstacle to implementing the integrated risk assessment and management is due to the dependence between risks and attributes (social, physical, geographical, economic and policy) of the area [46]. Linkage dependency assessed by exposure, vulnerability, and resilience [47].

Every country is not homogenous and has it's unique; therefore, the local attribute or cultural invulnerability should be considered [48]. Moreover, consider the integrated disaster risk index approach for improvement. Integrated disaster risk research engages multiple scales (local to global), stakeholders (experts, professionals, officials, etc.), knowledge (scientific, local), disciplines (physical, social, human sciences, etc.), methodological approaches, areas of application/implementation (planning, sustainable development, policy, etc.) and real-world experiences [49]. There are dimensions

of vulnerability from the social, economic, physical, cultural, environmental and institutional aspects [32].

5. Conclusion

In conclusion, most of the countries place greater emphasis on social and physical vulnerability in terms of dimension. For the conceptual model, most of the studies use the WRI concept at the local level. However, the idea shows some limitations for application at local in terms of vulnerability indicator. The data used in the WRI are not available at the local level. Then, the data used should be considered either using the same weight or different weights to show the importance of one indicator as compared to another indicator. Consideration should be given to integrating the multi-dimension aspect in the vulnerability indicator in the DRI at the local level. In addition, all dimensions should consider local attributes. Pakistan is the only country that has integrated disaster risk and climate risk at the local level. The contribution of the DRI for DRR also should be focused in the future to determine the degree of success of the implementation of DRI into disaster management at the local level.

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