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# Application of Risk Perception Theory to Develop a Measurement Framework for City Resilience: Case Study of Suita, Japan

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**Abstract**

Risk management has developed as an important aspect of sustainability. In order to manage risk more effectively, an overall evaluation of regional resilience needs to be performed. Therefore, this paper develops a framework to measure overall resilience in a community, focusing on risk perceptions of citizens of Suita City, Japan. The framework includes three main phases: (1) identifying multiple risks in the city through discussions with local experts and city workers; (2) prioritizing those risks by applying principal component analysis (PCA); and (3) understanding the relationships among them using decision-making trial and evaluation laboratory (DEMATEL) analysis. As a result, 21 risks were identified, and subsequently, four risks were prioritized: climate change, lack of self-sufficient energy, damage to the ecosystem, and natural disasters. Lastly, the application of DEMATEL analysis revealed that climate change and natural disasters have the greatest cause-effect relationships among the risks. The framework proves that multiple risks can be prioritized and gives overall suggestions on what kinds of risk a community is facing; where to start considering how to manage resilience; and which functions/services a community should improve to boost resilience. The identification, prioritization, and visualization of significant risk relationships completed in this study can support decision-making processes in strengthening community resilience.

**Keywords:** sustainability, risk perception, resilience, risk management

## 1. Introduction

Risk management has developed as an important aspect of sustainable development and sustainable resource management. In Japan, especially after the Great East Japan Earthquake, “resilience” has become a keyword in understanding how to manage risks and achieve a sustainable society (Baba, Masuhara, Tanaka, & Shirai, 2013). Several studies have measured resilience in cities, and it has become a key concept for operationalizing sustainability (Pickett, McGrath, Cadenasso, & Felson, 2014). For instance, Chen, Ferng, Y. Wang, Wu and J. Wang (2008) evaluated the resilience capacity of hillslope communities by assessing damage caused by two specific typhoons; Joerin, Shaw, Takeuchi and Krishnamurthy (2012) assessed the resilience of communities facing a higher probability of future disasters due to climate change; and Prashar, Shaw and Takeuchi (2012) assessed the resilience of urban areas to climate-related disasters. Most studies measuring community and urban resilience focused on disaster risks. However, these studies were limited to a specific risk each and failed to provide an overall consideration of resilience in the areas concerned. The difficulty lies in including every risk and addressing their relationships with limited resources and more diversified and complicated risks. To establish resilience in a community, a holistic assessment approach needs to be developed further.

With regard to the definition of resilience, it is generally stated as a system’s ability to respond and recover from disturbances (Fisher et al., 2010). Holling (1996) originally defined resilience in two ways, namely, engineering and ecological resilience. While engineering resilience is the more traditional of the two and focuses on recovery and constancy, ecological resilience focuses on system persistence and robustness to disturbance. Essentially, engineering resilience aims to maintain the *efficiency* of a function, whereas ecological resilience focuses on maintaining the *existence* of a function. These two contrasting approaches are fundamental paradigms of resilience (Holling, 1996). As the world faces more and more uncertain and interacting risks, it is desirable to pursue the dynamic challenge of integrating both paradigms to strengthen communities' capacity to manage resilience. Therefore, this study redefines resilience as a community's ability to cope with multiple risks that it might face.

To measure the resilience of a community, this paper aims to develop a framework by demonstrating the application of the theory of risk perception. It utilizes risk characteristics studied by Slovic (1987) to organize multiple risks. The study is customized for Suita City in the Osaka Prefecture of Japan. Thus, the specific objectives are to (1) identify multiple risks to Suita City by reviewing literature and holding discussions with local experts and city workers; (2) prioritize risks using principal component analysis (PCA) in conjunction with the experts' perceptions [these two steps are based on Slovic's theory of risk perception (1987)]; and (3) capture the causal relationships among risks by applying the decision-making trial and evaluation laboratory (DEMATEL) analysis technique. With the development of this framework, decision-makers will be able to understand the procedure for building community resilience in order to improve existing regulations and strategies.

The paper is structured as follows: Section 2 presents an overview of risk perception theory. The methodology, assessment framework, and its application are described in Section 3. Lastly, a discussion of the results from PCA and DEMATEL is presented in Sections 4 and 5.

## 2. Risk Classification by the Theory of Risk Perception

Previous studies have attempted to classify new technologies and human activities that may generate new and unprecedented risks. Modern risk analysis employs a trio of risk characteristics to evaluate hazards: threat, vulnerability, and consequence (Linkov et al., 2014). The aim of risk management is to reduce the highest risk events by addressing one or all of the risk variables. In recent decades, the mechanisms underlying catastrophic damages have become more complex, along with developments that sometimes created new and unprecedented risks. Slovic (1987) argued that the most harmful consequences are rare and often delayed; therefore, they can be difficult to assess by statistical analysis. As such, he proposed an alternative method for risk assessment analysis, namely the measurement of "risk perceptions." This refers to the instinctive risk judgement that the majority of citizens depend upon. Since Slovic developed this idea, researchers have been attempting to invent techniques for assessing the opinions that people hold about risk.

The original research on risk perceptions was conducted by Starr (1969), who developed a method to weight technological risks against economic benefit. It explained systematic differences in the acceptability of risk and revealed patterns of risk acceptance. Starr's results suggested a classification of risks by applying the dichotomous trait of "voluntary" versus "involuntary" as a risk characteristic (Winterfeldt & Edwards, 1984). The study approach and conclusion have been developed by a number of researchers and have subsequently yielded nine risk characteristics: volition, severity, origin, effect manifestation, exposure pattern, controllability, familiarity, benefit, and necessity. These risk judgments were then evaluated statistically and used to rate various risks according to their risk characteristics. A factor analysis of the ratings and risks could largely be explained by two represented factors.

Slovic extended Starr's result to a broader set of risk characteristics. The extended study by Slovic, Fischoff and Lichtenstein (1980) designed 90 hazards (instead of 30) to cover a wide range of activities, substances, and technologies, and 18 risk characteristics. All risk characteristics were rated on a bipolar 1–7 scale, representing the range for which the characteristics described the hazard (Figure 1).

| Voluntariness of risk: Do people face this risk voluntarily? If some of the risks are voluntarily undertaken and some are not, mark an appropriate spot towards the center of the scale. |
|---|
| risk assumed voluntarily 1 2 3 4 5 6 7 risk assumed involuntarily |

Figure 1. Example of bipolar scale questionnaire

People's judgement ratings were evaluated by a statistical technique known as factor analysis, which indicated two underlying risk factors. As a result, based upon the nature of the characteristics, they labelled the first factor as "Dread" and the second factor as "Familiarity." Within the space of these factors, the designated hazards were plotted on a chart that indicated taxonomic significance. Slovic's study succeeded in applying psychophysical scaling and multivariate analysis to create quantitative representations of risk perceptions. Slovic et al. (1980) concluded that perceived risk was quantifiable and predictable and therefore suggested that the greater the perceived risk, the greater the desired reduction. Furthermore, they stated many of the 18 risk characteristics were presumed by the public to be essential and correlated greatly with perceived risk and preference for risk reduction.

## 3. Methodology

The fundamental framework approach draws upon the theory of risk perception discussed earlier. Referring to Slovic's original study, this study is composed of three phases.

### *3.1 Identification of Multiple Risks*

This study started by selecting potential risks within a community. A preliminary task entailed reviewing relevant literature to gather designated risks on a global level. Major articles referred to were the following: World Economic Forum (2014), UK Cabinet Office (2010), and Holzmann and Jørgensen (2000). These reports provided information on the environmental, technological, and societal aspects of global risks; World Economic Forum included a set of 14 major risks; the UK Cabinet Office presented 12 major risks; and Holzmann and Jørgensen addressed three significant risks. Referring to these as an initial list of existing risks, several workshops were held, involving local experts and city workers to discuss potential risks. Through this series of workshop discussions, multiple potential risks to Suita City were finally identified.

### *3.2 Prioritization of Risk Characteristics*

This step followed the identification of multiple risks by principal components analysis (PCA). PCA is a statistical technique used to analyze data sets by several inter-correlated quantitative dependent variables. In order to identify patterns of perception and highlight similarities and differentiations, PCA has been deemed an effective tool for analyzing data (Smith, 2002).

In order to prioritize the multiple risks, a questionnaire survey was provided to academic individuals with an understanding of risk management, in order to reveal patterns of risk perception. The survey was conducted with five Master's students, one Lecturer, and two Professors in the Department of Environmental Engineering at Osaka University, Japan.

Both implementation and procedure followed Slovic et al. (1980), and 14 risk characteristics were applied (Table 1). Questionnaire respondents were asked to rate each of the characteristics, and each item was scaled from -2 to 2, with 0 as neutral. An example risk characteristic, "controllability," is shown in Figure 2 below.

| Do you think this risk is controllable? (Please mark a score as appropriate). | | | | | | |
|---|---|---|---|---|---|---|
| Controllable | -2 | -1 | 0 | 1 | 2 | Not controllable |

Figure 2. Questionnaire for "controllability" in a risk characteristic

Average scores were calculated and input to a statistics processing tool, in this case, IBM's SPSS Statistics, Version 22.

Table 1. Risk characteristics rated by academic individuals

| | |
|---|---|
| Controllability | Reduction ability |
| Delay effect | Voluntariness |
| Catastrophic | Observability |
| Critical | Notice to exposure |
| Even Exposure | Acute effect |
| Personal exposure | Familiarity |
| Future generation | Scientifically unknown |

### *3.3 Visualization of Cause-Effect Relationships*

Another questionnaire was distributed to the same eight experts, this time to capture causal relationships among risks. Respondents were asked to evaluate an item's impact among the others using an integer scale from 0 to 8.

(0: no direct influence; 2: moderate direct influence; 4: strong direct influence; 8: very strong direct influence). The data were processed by using DEMATEL analysis.

The DEMATEL analysis offers a method to visualize problems by isolating related variables into cause and effect groups, which can provide greater understanding of any causal relationships among the examined variables (Wang, H. Lin, L. Lin, Chung, & Lee, 2012). Utilizing the survey scores, the first step is to find the average matrix. The assigned scores yield an $n \times n$ answer matrix $X^k$. The $n \times n$ average matrix $A$ was computed by averaging the $h$ experts' score matrices. The $(i, j)$ elements of the average matrix $A$ is denoted as $a_{ij}$ as follows:

$$a_{ij} = \frac{1}{h}\sum_{k=1}^{h} X_{ij}^{k} \tag{1}$$

The second step calculates the direct influence matrix $D$, which is obtained from normalizing the average matrix $A$, where $s$ is a constant:

$$D = sA \tag{2}$$

The third step calculates the indirect influence matrix. The indirect influence of division $i$ on division $j$ declines as the power of the matrix increases. The indirect influence matrix $ID$ is obtained from the values in the direct influence matrix $D$, where $I$ is the identity matrix:

$$ID = D^2(I - D)^{-1} \tag{3}$$

The fourth step derives the total influence matrix $T$:

$$T = D(I - D)^{-1} \tag{4}$$

The $(i, j)$ elements of matrix $T$ is $t_{ij}$: the sum of the $i$th row and the sum of the $j$th column:

$$d_i = \sum_{i=1}^{n} t_{ij} \tag{5}$$

$$r_j = \sum_{j=1}^{n} t_{ij} \tag{6}$$

The last step is to obtain the cause-effect impact-relationships map (IRM). The map can be developed from the values of $d + r$ and $d - r$, represented on the $x$-axis and $y$-axis. These values demonstrate the degree of effectiveness among risks. The horizontal axis vector $(d + r)$ was labelled as "Prominence" and the vertical axis $(d- r)$ as "Relation." Prominence indicates the importance of each factor. Relation divides factors into two groups: a cause group and effect group. Using the dataset of the $(d + r, d- r)$, the causal diagram demonstrates the IRM in graph form.

## 4. Results and Discussion

This section discusses the findings from the application of the developed framework.

### *4.1 Selecting Multiple Risks*

From the literature review, an initial list of 29 risks was developed: 14 risks from World Economic Forum, 12 risks from the UK Cabinet Office, and 3 risks from Holzmann and Jørgensen, as follows:

(1) World Economic Forum (2014)

In terms of environmental global risks, the following were listed: extreme weather events, natural catastrophes, man-made environmental catastrophes, biodiversity loss and ecosystem collapse, water crises, and climate change mitigation and adaptation. Secondly, the paper listed societal risks, including food crises, pandemic outbreak, chronic disease, severe income disparity, antibiotic-resistant bacteria, mismanaged urbanization, and profound political and social instability. Finally, technological risks were mentioned: the breakdown of critical information infrastructure and networks, cyber-attacks, and data fraud/theft.

(2) The UK Cabinet Office (2010)

The type of risks summarized by the National Risk Register are catastrophes, human disease, flooding, severe weather, animal disease, major industrial accidents, major transport accidents, attacks on crowded places, attacks on infrastructure, attacks on transport systems, non-conventional attacks, and cyber security.

(3) Holzmann and Jørgensen (2000)

The report discussed social risks that arise from biased social protection and the negative impact of economic development and growth. In view of social risk management, an aging population, rising international competition, and income insecurity were particularly of concern.

These key risks were included in a draft version of the workshop discussion itinerary. Several workshops were held with local experts and city workers to particularize the risk to Suita City. As a result, 21 multiple risks were selected, which were presented in Table 2.

Table 2. The 21 multiple risks identified by workshops

| | | | |
|---|---|---|---|
| 1. | Climate change | 12. | Social strain |
| 2. | Lack of self-sufficient energy | 13. | Population density |
| 3. | Damage to ecosystem | 14. | Obstacles to human security |
| 4. | Natural disaster | 15. | Lack of preparation by corporations |
| 5. | Development of city infrastructure | 16. | Economic crisis |
| 6. | Daily life inconvenience | 17. | Intentional harmful activities by individuals or groups |
| 7. | Lifestyle changes | 18. | Dependence on a single energy source |
| 8. | Amount of pollution | 19. | Energy supply instability |
| 9. | Change of environmental quality | 20. | Over-investing in infrastructure development |
| 10. | Availability of natural resources | 21. | Disruption to essential utilities |
| 11. | Change in availability of natural benefit | | |

Comparing this with the study by Slovic et al. (1980), the number of risks was lower but more focused on a larger scale. In this study, global-scale risks, such as climate change, ecosystem damage, population density, and economic crisis were on the list, while in 1980, risks were more localized and on an individual basis, such as nuclear power, DDT, herbicides and pesticides, food coloring, and radiation therapy. Slovic et al. (1980) explained their result as reflecting the news media's presentation of these issues at the time. Natural disasters were not mentioned as a risk in the former study. This can be explained by the lack of first-hand exposure to natural disasters at that time as compared to the present day group; disaster and natural catastrophes are more likely to be recognized as risks when more people experience them. The same is true of energy issues, which are now regularly faced. Additionally, in the present study, the onset of urbanization, infrastructure, pollution, and quality of life/lifestyle were identified as risks.

The multiple risks identified cover a wide range of fields and reflect a range of perspectives; however, further discussion is still required for further specification. For instance, with regard to natural disasters, the issues of damage to ecosystems and environmental quality should be more specific based on actual disaster experiences and regional geographic information. For Suita City, earthquakes, damage from torrential rainfall, wind, and floods can be listed as particularly relevant natural disaster risks. Similarly, some of the risks might overlap each other, and further clarification is needed for this. Future research will face the challenge of reflecting regional geological information and clarifying the description of each risk in the list.

### *4.2 Prioritizing Multiple Risks*

The questionnaire survey was provided to the experts, and all of the selected 21 risks were rated in terms of 14 risk characteristics. The average scores were calculated and transferred to the statistical analysis software, SPSS. Table 3 shows the analysis results. Application of the PCA statistical technique showed four primary characteristics in the first factor: acute effect (risk decreasing or increasing), delay effect (effect immediate or effect delayed), notice to exposure (known to those exposed or unknown to those exposed) and familiarity (old risk or new risk). By referring to the theory of risk perception, these four factors have been labeled as "Unknown." The second factor primarily reflects six characteristics: reduction ability (easily or not easily reduced), catastrophic (not global catastrophic or global catastrophic), personal exposure (individual or catastrophic), future generation (low risk or high risk to future generations), controllability (controllable or uncontrollable) and criticality (consequences not fatal or fatal). The nature of these characteristics suggests that this factor can be called Dread.

Table 3. Result from principal components analysis (PCA)

| Variable | Factor | |
|---|---|---|
| | 1 | 2 |
| Acute effect | 0.907 | 0.282 |
| Delay effect | 0.883 | 0.316 |
| Notice to exposure | 0.840 | 0.012 |
| Familiarity | 0.763 | -0.238 |
| Future generation | 0.567 | 0.741 |
| Observability | 0.352 | 0.007 |
| Catastrophic | 0.285 | 0.817 |
| Personal exposure | 0.261 | 0.773 |
| Even Exposure | -0.240 | -0.603 |
| Reduction ability | -0.257 | 0.854 |
| Scientifically unknown | -0.361 | 0.201 |
| Critical | -0.507 | 0.653 |
| Controllability | -0.598 | 0.663 |
| Voluntariness | -0.765 | 0.451 |

Each of the 21 risks has a mean score for each of the 14 characteristics, which also has a score on each factor. These scores give the location of each risk within the factor space, and Figure 3 shows such plots for Factors 1 and 2. The high end of risks on the horizontal dimension (Factor 1) were identified to be unfamiliar, not to be noticeable, or for people to take time to realize their exposure. The risks in this dimension, such as the lack of self-sufficient energy, indicate the necessity to educate people to increase their awareness. Items at the high end of Factor 2 are highly dreaded: climate change and damage to ecosystem. Their characteristics also have unknown risks. Natural disasters are also highly dreaded but are, on the other hand, well known. At the negative end of Factor 2, items are posing risks to individuals and are limited in scale in terms of impact on daily life, corporations, and infrastructure.

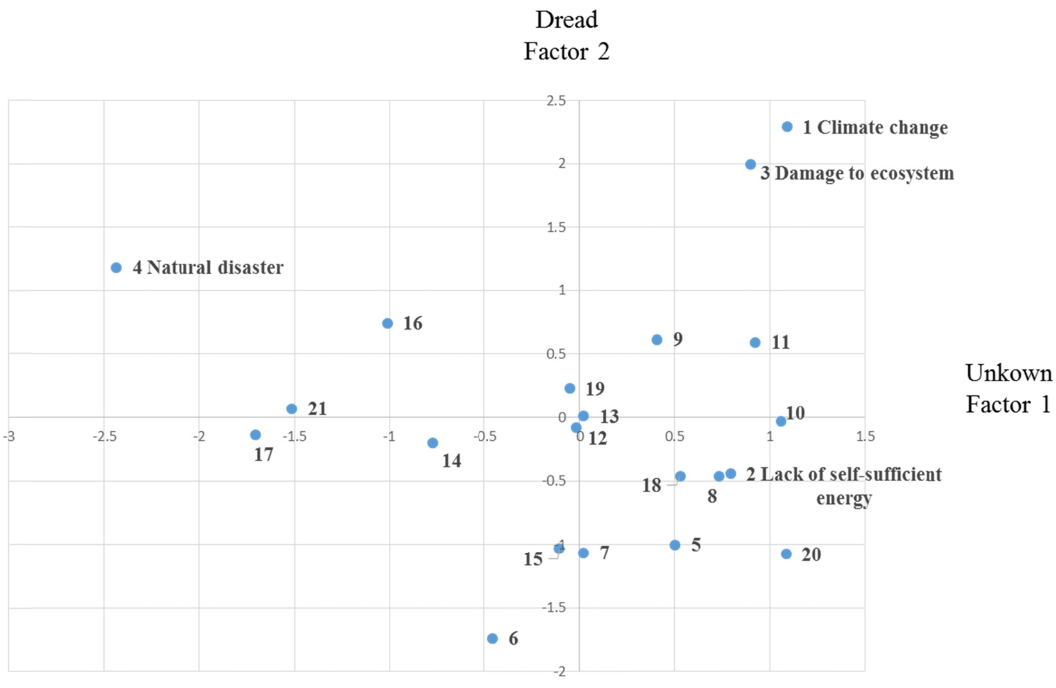


Figure 3. Location of 21 risks on Factor 1 and 2

The results suggest that judgements of multiple risks are related more to characteristics such as Unknown and Dread. These two factors should be considered when thinking about risk management. This intuitive judgement indicates the degree of desire to reduce a risk. The Unknown factor is related to knowledge about a risk, as risks that scored highly on Unknown can be seen as those on which further education is required in order to reduce the risk. The Dread factor was considered as catastrophic, not easily avoided, and posing high risk to future generations. People have stronger desires to reduce occurrence of risks scoring higher in this factor; as such, stronger, more specific regulations related to these may need to be implemented.

Hence, the risk at the higher end of both factors can be identified as most critical, which in turn implies the preference of appropriate countermeasures as part of a community's strategy. As Slovic (1987) suggested, psychometric analysis of questionnaire data in which preferences and perceived risks are identified are useful in quantifying and predicting risk perception. Application of psychometric techniques tends to be well-suited to identifying similarities and differences among groups in terms of risk perceptions. This study identifies four preferential risks among the examined multiple risks: climate change, damage to ecosystems, natural disasters, and lack of self-sufficient energy are thought to be the most significant in the utilized two-dimensional structure.

This study targeted a group of experts as academic individuals and the result came from the perceived risk as expressed by them. To further expand on these results, the same questionnaire could be implemented to undertake comparisons among different groups, which could include public workers, experts, and college students in different areas of the community.

*4.3 Demonstrating Cause-Effect Relationships*

To understand the relationship among the examined risks, DEMATEL methodology was applied. The values of $d + r$ and $d - r$ were calculated to produce an IRM (Figure 4). This map visualizes the difference between cause groups and effect groups. Climate change and natural disasters are identified as causes, while damage to ecosystems and lack of self-sufficient energy are effects.

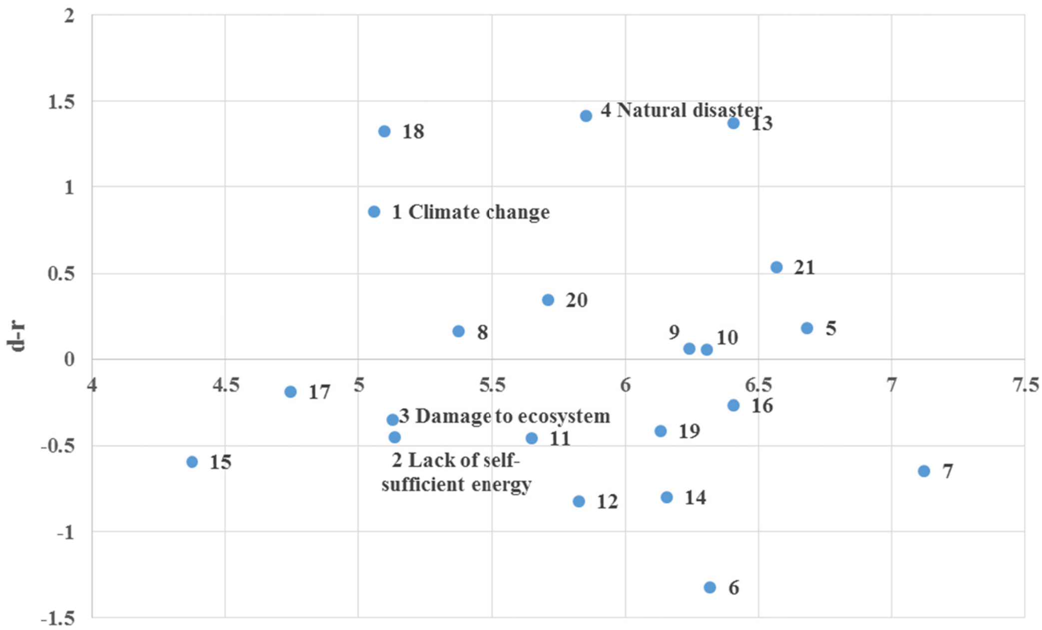


Figure 4. A cause-effect impact-relationships map (IRM)

Furthermore, the net influence matrix $N$ can be used to identify the strength of impact on each item. Using each value calculated for the total influence matrix $T$ (Equation 4), the net influence matrix $N$ is given by the following:

$$N = Net_{ij} = t_{ij} - t_{ji} \tag{7}$$

For example, Table 4 is the matrix $N$, which presents the degree of relationship between (1) climate change, (2) lack of self-sufficient energy, (3) damage to ecosystem, and (4) natural disaster. "Climate change" influences all the others, and "natural disaster" highly affects self-sufficient energy (=0.103). Through understanding these relationships, it can be seen that effective countermeasures to climate change and natural disasters will also have a positive impact on reducing other risks.

Table 4. Net influence matrix $N$ of the risk (No. 1–4)

| Divisions | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 Climate change | | | | |
| 2 Lack of self-sufficient energy | -0.0444 | | | |
| 3 Damage to ecosystem | -0.0666 | 0.0030 | | |
| 4 Natural disaster | -0.0406 | 0.1030 | 0.0468 | |

## 5. Conclusion

By understanding resilience as the ability to cope with comprehensive risks, this study proposed a framework applying Slovic's risk perception theory integrated with the PCA and DEMATEL statistical techniques. The study succeeded in organizing multiple risks for resilience management. As a framework of each assessment, the study was composed of three phases, with the outcome of each summarized as follows:

(1) To identify multiple risks, an initial list of potential risks was provided by reviewing global reports and discussing the topic with local experts and city workers to particularize the risks to Suita City. As a result, 21

multiple risks were identified for Suita City.

(2) In order to prioritize multiple risks, the application of risk perception theory is recognized as a practical approach to identifying and revealing the characteristics of multiple risks facing a community. In the case of Suita City, the 21 multiple risks were characterized by the nature of risk perception: Dread and Unknown. This was demonstrated by applying the PCA statistical technique. The greater the degree of Dread and Unknown, the greater the desire to reduce that risk. Among the 21 multiple risks, four particular risks—climate change, damage to ecosystem, natural disaster and lack of self-sufficient energy—were prioritized as having the greatest degree of Dread and Unknown in Suita City. This information proves effective for helping policy makers redefine local policies.

(3) To understand the internal relationships among the 21 multiple risks, DEMATEL analysis was used to produce a map that visualizes the relevant cause-effect relationships. The result indicates that climate change influences all the others and that natural disasters highly impact the risk of lacking self-sufficient energy. It elucidates the structure of multiple risks, which is useful information for policy makers to draw upon when activating existing management with the aim of increasing community resilience.

The framework proves that multiple risks can be prioritized and gives overall suggestions to decision-makers: what kinds of risk a community is facing; where to start considering how to manage resilience; and which functions/services a community should improve to boost resilience.

For further development of these findings, a follow-up study must engage in further discussion about multiple risks, the group and number of research participants, and include regional characteristics (i.e., natural resources). Through compiling and utilizing a series of datasets, more holistic, accurate information for policy makers will be obtained, and the process will become a suitable tool to integrate into existing decision-making processes.

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