Development of Gross National Safety Index for Natural Disasters

O. Kusakabe[1], M. Kikumoto[2], K. Shimono[3], K. Itoh[4], H. Inagaki[5], S. Ohsato[6] and K. Watanabe[7]
[1]*International Press-in Association, 9F, Konan YK Bldg. 2-4-12 Konan, Minato-ku, Tokyo 108-0075, Japan*
[2]*Institute of Urban Innovation, Yokohama National University, Tokiwadai 79-5, Hodogaya-ku, Yokohama, Kanagawa 240-8501, Japan*
[3]*Graduate School of Urban Innovation, Yokohama National University, Tokiwadai 79-5, Hodogaya-ku, Yokohama, Kanagawa 240-8501, Japan*
[4]*Department of Urban and Civil Engineering, Tokyo City University, Tamatsutusmi 1-28-1, Setagaya-ku, Tokyo, 158-8557, Japan.*
[5]*Kankyo-Chishitsu Co.,Ltd, Kaiduka 1-4-15-203, Kawasaki-ku, Kawasaki, Kanagawa,210-0014, Japan.*
[6]*Doshitsu Research Co. Ltd, Oh-hara 2-27-31, Setagaya-ku, Tokyo, 156-0041, Japan.*
[7]*Technical Research Institute, Obayashi Corporation, Shimo-Kiyoto 4-640, Kiyose-shi, Tokyo, 204-8558, Japan.*
E-mail: ipa.kusakabe@press-in.org

ABSTRACT: After the Great East Japan Earthquake on March 11, 2011, it appeared that Japan was extremely vulnerable to natural disasters and lack of adequate social systems for mitigating natural disasters. The authors advocated a need for the development of safety index systems for natural disasters for policy makers and decision makers to prioritize mitigation measures to be implemented. The World Conference on Disaster Reduction in Kobe in 2005 adopted the Hyogo Framework for Action, which clearly states the urgent need for developing vulnerability index. An extensive literature survey was firstly conducted to find out the State of the Art regarding to the development of systems of indicators of disaster risk and vulnerability at national and sub-national scale. The survey indicates that the system of indicators such as World Risk Index (WRI) is widely accepted. By modifying the WRI index, a new index named GNS (Gross National Safety for natural disasters) was developed in this study. Risk in GNS is defined by Hazard x Exposure x Vulnerability. Five natural events are considered in 2015 version of GNS, including earthquake, tsunami, storm surge, sediment related disaster event, and volcanic activity. An initial calculation was carried out by using various big data available open to public. The results of disaster risk and vulnerability are presented in the prefectural scale in Japan. Our intension is not to provide the ranking of GNS but to offer the policy and decision makers a piece of scientific information for selecting highest priority measures for mitigation in a rational manner. A few commentary remark is added to include the impact of climate change on natural disasters in the safety index system.

KEYWORDS: Risk index, Natural hazard, Exposure, Vulnerability, Infrastructure

1. INTRODUCTION

Japan is prone to natural disasters. After the Great East Japan Earthquake on March 11, 2011, it appeared that Japan was extremely vulnerable to natural disasters and lack of adequate social systems for mitigating natural disasters. There is a fundamental need for creating a kind of safety index against potential natural disasters to guide us to transform our land to resilient land. The index must indicate how current hardware and software countermeasures effectively resist against potential natural disasters, and what measures are currently inadequate. Immediately after the Great East Japan Earthquake, the first author advocated to create such an index of nation-wide safety index, together with Gross Domestic Product (GDP) and Gross National Happiness (GNH), to steadily transform Japan to resilient land and coined GNS. GNS is an abbreviation of Gross National Safety for natural disasters, which is an index, expressing quantitative risks for natural disasters.

Roger Pulver (2012) showed his keen interest in GNS and wrote in his newspaper article on Japan Times on March 11, 2012, entitled "Japan's disaster must prompt a radical rethink of citizen's quality of life". In which, he stated that "Here's my point: The aftermath of the triple calamity in Tohoku has shown that Japan's government and industry has been neglecting the safety and the integrity of the people and the land. A paradigm of growth for the 21st century must take into account the kind of scientific methods advocated by Kusakabe.", "The creation of investment security and the husbanding of the land can bring about a merger of the three Gs: GDP, GNS and GNH. Any country or region striving for this would be a magnet for investment and a beacon of hope for the world."

A group of researchers was formed within the Japanese Geotechnical Society, with an aim of developing a safety index system for natural disasters for policy and decision makers to prioritize mitigation measures to be implemented.

Mitigation of natural disasters is closely related to the UN Millennium Development Goals (United Nations, 2000), in particular, "No.1 to eradicate extreme poverty and hunger", and "No.7 to ensure environmental sustainability". International community has been working towards creating an index of disaster risk and vulnerability, in accordance with the Hyogo Framework for Action 2005-2015 (UNISDR, 2007) from the both aspects of natural and social sciences.

This paper presents the concept of the GNS index and the way to calculate the 2015 version GNS, together with the calculated results of GNS in the prefectural scale. The authors hope that GNS can offer a scientifically sound index to assist the decision and policy makers to allocate proper and effective investment programs for mitigation of natural disasters, by showing how each prefecture annually progresses to upgrade the hardware and software countermeasures against natural disasters to a desirable level. To do so, the method and the range of application of GNS must be continuously improved and data available must be continuously updated.

2. GNS CONCEPT AND METHOD FOR CALCULATION

2.1 Basic concept

The World Conference on Disaster Reduction in Kobe in 2005 adopted the Hyogo Framework for Action (UNISDR, 2007), which clearly states the urgent need for developing vulnerability index. An extensive literature survey was firstly conducted to find out the State of the Art, regarding to the development of systems of indicators of disaster risk and vulnerability at national and sub-national scale. The survey indicates that the system of indicators such as World Risk Index (UNU-EHS, 2011-2015) is widely accepted.

Widely used risk indices for natural disasters adopt the following form of function.

$$R = f(H, E, V, Re) \quad (1)$$

where R: risk, H: hazard, E: exposure, V: vulnerability, and Re: resilience. In here, H x E means "exposure" in a broad sense, which can be determined by population distribution, geology, topography and climate. V and Re are values expressing the relationship between society and natural disasters. In the 2015 version GNS, Re is considered to be a dependent variable and $V = V(V, Re)$ is assumed. Thus the equation (1) yields

$$R = f(H, E, V) \quad (2).$$

The equation (2) is a form of function adopted in the GNS calculation. One of the simplest forms of the equation (1) may be

$$R = H \times E \times V \quad (3).$$

Equation (3) is the actual form of the equation used for the 2015 version GNS.

One of the features of the equation (3) is that the value of Risk (R) becomes null when one of the three parameters, H, E and V, is null. Namely in the cases where no physical event causing hazard occurs ($H = 0$), no people lives in the affected area caused by hazard ($E = 0$), and society is resilient enough against natural disasters ($\lim V = 0$), R becomes null.

In the course of development of the 2015 version GNS, the following points are taken into consideration in such a way that the decision and policy makers responsible for budge plan can easily access.

1. Data to be used should be free access for the purpose of continuous updating.
2. Data to be used should be available at the prefectural level.
3. Prioritizing items affecting for improving natural disaster measures and the items with higher propriety should be selected.
4. The values of hazard, exposure and vulnerability should be hierarchically calculated by weighted linear summation.

Three layered hierarchy system is used in the 2015 version, which is basically the similar system adopted in WRI, as is shown in Figure 1. The Risk components at the first top layer compose of Exposure (H x E) and Vulnerability (V). The vulnerability is a summation of the weighted hardware countermeasures Sub-goals and the weighted software countermeasures Sub-goals. The Exposure and the hardware and software countermeasures Sub-goals are calculated from the corresponding weighted Sub-goals. The Sub-goals are determined by the corresponding weighted Normalized indicators, which are obtained by a cluster of free access data base, named Original data in this paper.

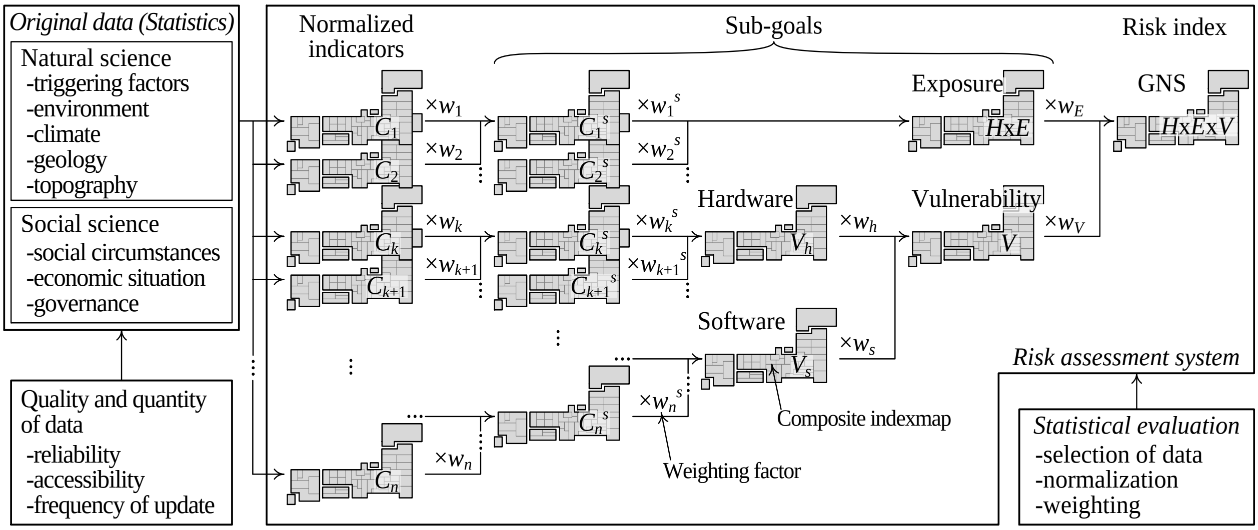

Figure 1 Hierarchical assessment system of GNS

Table 1 lists Original data, Normalized indicators, Sub-goals and Risk components with the weight at each level. Two types of statistical and scientific data are available for Original data. One group of data is given in a form of dimensionless number such as %, while another group of data has a certain dimension. In order to equally handle with the two groups of the data in a single formulation, the latter must be normalized to give a value in the range of 0 to 1. Figure 2 shows the relationship between original data and the normalized index C linked by an exponential normalizing function.

2.2 GNS framework for 2015 version

The authors have decided to adopt the simplest framework of GNS by the multiplying "vulnerability" and "exposure" as a simple, yet clear indicator. In the "vulnerability" calculation, available data are categorized into two; hardware countermeasures and software countermeasures, because this categorization is commonly adopted in civil engineering fields. GNS is hierarchically calculated as shown in Figure 1.

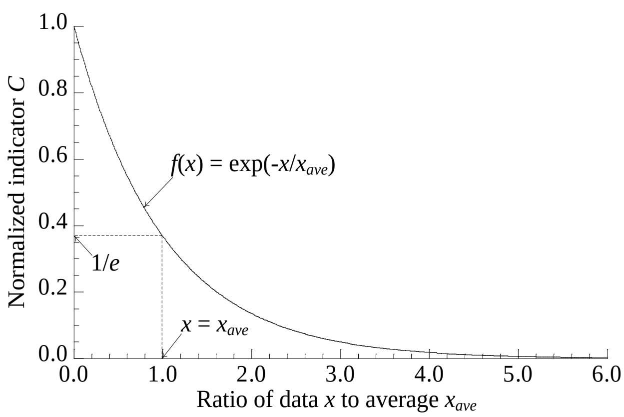

Figure 2 Normalizing function for calculating frequency coefficient

Table 1 Source data, normalized indicators, subgoals and weighting coefficients for the calculation of GNS

Original data	Normalized indicators	weight w_i	Subgoals	weight w_i	Subgoals	weight w_i	Risk components	weight w_i	Risk index
J-SHIS Map (Disaster-affected people)	Interplate earthquake	0.500	Earthquake	0.200			Exposure	0.500	GNS
Total length of active faults [km]	Epicentral earthquake	0.500							
Number of tsunami disasters	Tsunami	1.000	Tsunami	0.200					
Pupulation rate in the area of 3m above sea level or less [%]									
Number of tidal wave disasters	Storm surge	1.000	Storm surge	0.200					
Pupulation rate in the area of 3m above sea level or less [%]									
Number of sediment disasters	Sediment disaster	1.000	Sediment disaster	0.200					
Population rate in sediment disaster prone area [%]									
Number of volcanic disasters	Volcano	1.000	Volcano	0.200					
Pupulation rate in volcanic area [%]									
Rate of earthquake resistant private buildings [%]	Rate of earthquake resistance of buildings	0.330	Buildings	0.250	Hardware	0.500	Vulnerability	0.500	
Rate of earthquake resistant public buildings [%]									
Rate of non-fireproof wooden houses [%]	Rate of non-fireproof houses	0.330							
Rate of damaged buildings [%]	Rate of damaged buildings	0.330							
Rate of earthquake resistant main pipelines [%]	Rate of earthquake resistance of water supply and drainage facilities	0.500	Lifelines	0.250					
Rate of earthquake resistant purification plants [%]									
Rate of earthquake resistant service reservoirs [%]									
Rate of decrepit pipelines (over 40 years) [%]	Percentage of decrepit pipelines	0.500							
Total length of road [km]	Road density index	0.500	Infrastructures	0.250					
Repair rate of bridges [%]	Repair rate of bridges	0.500							
Rate of development of broadcast communication equipment system [%]	Rate of development of radio communication facilities for disaster prevention	0.500	Information, networks	0.250					
Rate of development of prtable broadcast communication system [%]									
Rate of development of J-alert system [%]	Rate of development of J-alert system	0.500							
Rate of development of J-alert automatic system [%]									
Number of stockpiling hardtacks [meals]	Stockpiling foods	0.200	Emergency stockpile	0.225	Software	0.500			
Number of stockpiling instant noodles									
Amount of stockpiling rice [kg]									
Number of stockpiling canned staple foods									
Number of stockpiling side dishes									
Amount of stockpiling water [l]	Stockpiling water	0.200							
Number of stockpiling blankets	Stockpiling blankets	0.200							
Number of supermarket store	Supermarket store index	0.200							
Number of convenience store	Convenience store index	0.200							
Number of physicians	Number of physiciams per 100,000 population	0.500	Medical services	0.225					
Number of hospital beds	Number of hospital beds per 100,000 population	0.500							
Financial capability index	Financial capability index	0.250	Economy and population	0.225					
Gini coefficient	Gini coefficient	0.250							
Old-age index [%]	Old-age index	0.250							
Rate of persons who received public aid [%]	Rate of persons who received public aid	0.250							
Rate of participation in earthquake insurance [%]	Rate of participation in Earthquake Insurance	1.000	Insurance	0.100					
Number of dangerous sites subject to sediment disaster	Rate of specification of sediment disaster prone areas	0.333	Regulations and governance	0.225					
Number of sediment disaster prone areas									
Number of municipals publishing hazard maps for tsunami disaster	Rate of publication of hazard maps	0.333							
Number of municipals publishing hazard maps for floods disaster									
Number of municipals publishing hazard maps for sediment disaster									
Rate of households covered by voluntary disaster prevention organization [%]	Coverage rate for the voluntary organization for disaster prevention	0.333							

2.2.1 Vulnerability

The vulnerability is given by a summation of the weighted hardware countermeasures and the weighted software countermeasures Sub-goals. In here, the hardware countermeasures mean physical disaster prevention methods such as aseismic methods of structures, and upgrading of aged infrastructures to mitigate against natural disasters. The hardware countermeasures Sub-goals are classified into a group of Sub-goals. Four Sub-goals are selected: (a) buildings, (b) lifelines such as gas, water and sewage network, (c) infrastructures, (d) information and networks. The hardware countermeasures Sub-goals are determined by 9 Normalised indictors based on 14 different Original data bases (Fire and Disaster Management Agency, 2015a; Japan Water Research Center, 2012a, b; Ministry of Internal Affairs and Communications, 2008; Ministry of Land, Infrastructure, Transport and Tourism, 2015a, b; New Supermarket Association of Japan, 2015; Nippon Telegraph and Telephone Corporation, 2015; Statistics Bureau, 2015a,b). Figure 3 shows the calculated vulnerability of the hardware countermeasures from the Normalized indicators. Numerical data of the results are given in the Appendix as Table A1.

The software countermeasures means a measures other than the hardware countermeasures, including a social system of conducting frequent disaster education, stocking food for emergency and preparing manuals at the time of disasters. Five Sub-goals are selected. (a) emergency stockpile, (b) medical services, (c) economy and population, (d) insurance, (e) regulations and governance. The process of calculation, software countermeasures Sub-goals is basically the same as those of the hardware countermeasures. 22 Original data bases (Cabinet Office, Government of Japan, 2015b; Fire and Disaster Management Agency, 2015b; General Insurance Rating Organization of Japan, 2015; Ministry of Health, Labour and Welfare, 2015a,b,c; Ministry of Internal Affairs and Communications, 2015a,b; Ministry of Land, Infrastructure, Transport and Tourism, 2015c) are utilized. Figure 4 presents the calculated result of software countermeasures from the Normalised indicators. Numerical data of the results are given in the Appendix as Table A2.

2.2.2 Exposure

In the 2015 version GNS, five natural disaster types are considered, namely earthquake, tsunami disasters, storm surge disasters, sediment related disaster, and volcanic disasters. For the earthquakes, a further grouping is required. There are two types of earthquake; trench type earthquakes and earthquakes located directly above the focus. In the 2015 version GNS, the data are normalized by different methods for each type of earthquake. Exposure Sub-goals are determined by 6 Normalised indictors based on 10 different Original data bases (Abe, 2006; Active faults research group, 1991; Arakawa et al., 1961; Cabinet Office, Government of Japan, 2015a; Geospatial Information Authority of Japan, 2015; Japan Meteorological Agency, 2015; Jiban-net, 2015; Ministry of Internal Affairs and Communications, 2015c; Miyazaki, 1956; Nakata and Imaizumi, 2002; Japan Meteorological Agency and Volcanological Society of Japan, 2003; National Research Institute for Earth Science and Disaster Prevention, 2015; National Land Information Division, National Spatial Planning and Regional Policy Bureau, MLIT, 2015; Statistical Information Institute Consulting and Analysis, 2015; The Headquarters for Earthquake Research Promotion, 2015).

For the trench type earthquakes, J-SHIS Map prepared by National Research Institute for Earth Science and Disaster Prevention (2015) is utilized. The Map provides the distribution of population (population seismically exposed; PSE) in the areas, of which seismic intensity exceeds a certain value, for a given focus and a given magnitude of earthquake. In the 2015 version GNS calculations, equal or over the seismic intensity of 6 caused by the above 13 earthquakes is taken as "Exposure" for the trench type earthquakes. For the earthquakes located directly above the focus, extended lengths of active faults are used and the extended lengths are divided by the total area of the prefecture, which is equivalent to a density of active faults. Because a clear separation of exposure calculated due to these two types of earthquake is not straightforward, the average value of the two exposures is used in the calculation. For other four types of natural disasters, the exposure was obtained from available data regarding the number of occurrence during a certain period time.

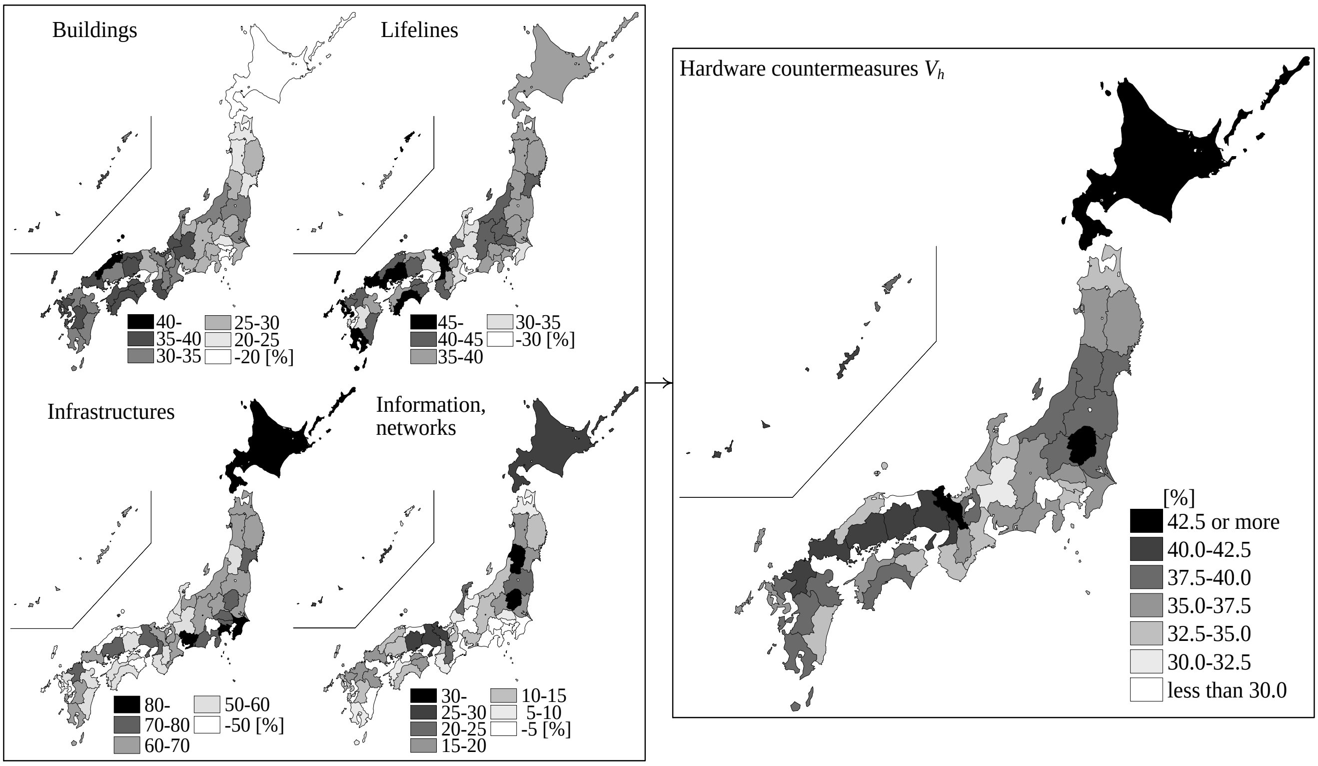

Figure 3 Calculation of vulnerability of hardware countermeasures from normalized indicators

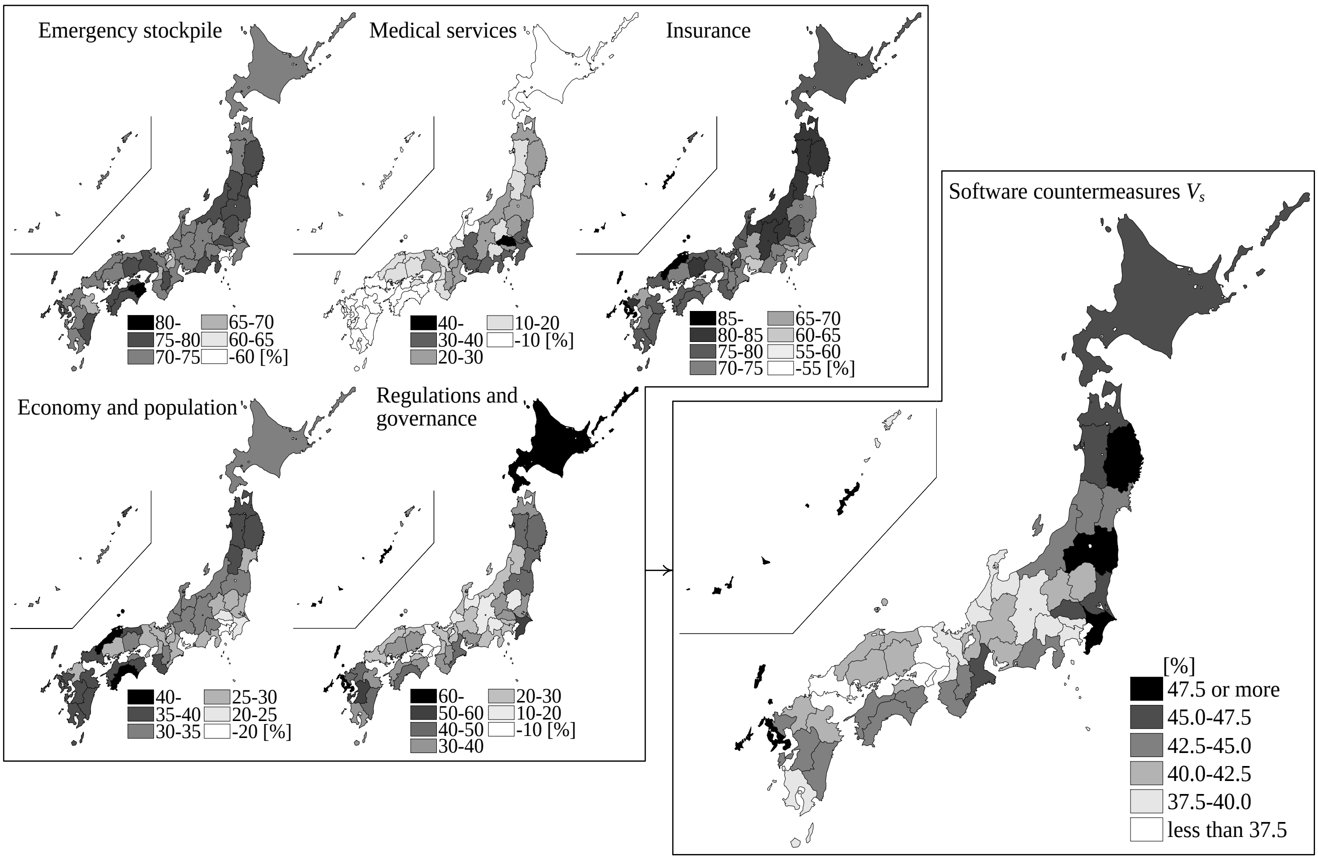

Figure 4 Calculation of software countermeasures from normalized indicators

Frequency coefficient F_i is calculated in the following equation.

$$F_i = f(R) = 1 - \exp(-N_i / N_m) \quad (4)$$

Here N_i, the number of occurrence in a prefecture, N_m, the average number of occurrence in 47 prefectures.

For tsunami disasters, data from 1498 to 2006 (Abe, 2006) was used to determine the frequency coefficient. Exposure is calculated by multiplying the number of people living less than 3m above the sea level and the frequency coefficient. For storm surge disasters, data from 701 to 1961 (Arakawa et al., 1961) was used. Exposure is calculated by multiplying the number of people living less than 3m above the sea level and the frequency coefficient. The difference between the exposure due to tsunami and the exposure due to storm surge is only the location and the frequency of occurrence.

For the sediment related disasters, including debris flows, steep slope failure and landslide, and the frequency coefficient is determined by the ratio of the number of occurrence to the number of site identified as the sediment related disaster dangerous site. Exposure is calculated by multiplying the percentage of people living in the sediment related disaster dangerous sites.

For volcanic disasters, the data are used in the chronological table of volcanic disaster from the year of 1600 onwards published by the Meteorological Agency (2003). Exposure for volcanic disaster is multiplying the percentage of people living the volcanic areas and the frequency coefficient. Figure 5 shows the calculated Exposure from the normalized indicators. Numerical data of the results are given in the Appendix as Table A3.

GNS is finally obtained by multiplying the values of Vulnerability and the values of Exposure, as is shown in Figure 6. Numerical data of the results are given in the Appendix as Table A4. It should be stressed that the author's intension is not to provide the ranking of GNS but to offer the policy and decision makers a piece of scientific information for selecting highest priority measures for mitigation in a rational manner.

3. DISCUSSIONS

Table 2 lists the correlation coefficients obtained by the correlation analysis between Exposure and Normalised indicators, indicating that earthquakes, in particular, the trench type earthquakes are strongly correlated with Exposure, while tsunami and storm surge has some positive correlations. In contrast, sediment related disaster and volcano activities has a negative coefficient. Although population and population density are not directly related to Exposure, the results shows that they have some correlations with Exposure, implying that Japanese large cities have been historically developed in low land areas along coastal areas.

Table 2 Correlation coefficients between exposure E and Normalized indicators

Earthquake	0.924
Tsunami	0.586
Storm surge	0.393
Sediment disaster	-0.199
Volcano	-0.056
Population	0.457
Population density	0.489

Table 3 shows the result of the correlation analysis between vulnerability of hardware countermeasures and Normalised indicators. As is expected, items of infrastructures and information / networks are appreciable correlations with the vulnerability. Building are, however, virtually no correlation, which may suggest that the selection of the values of weight needs to be carefully examined.

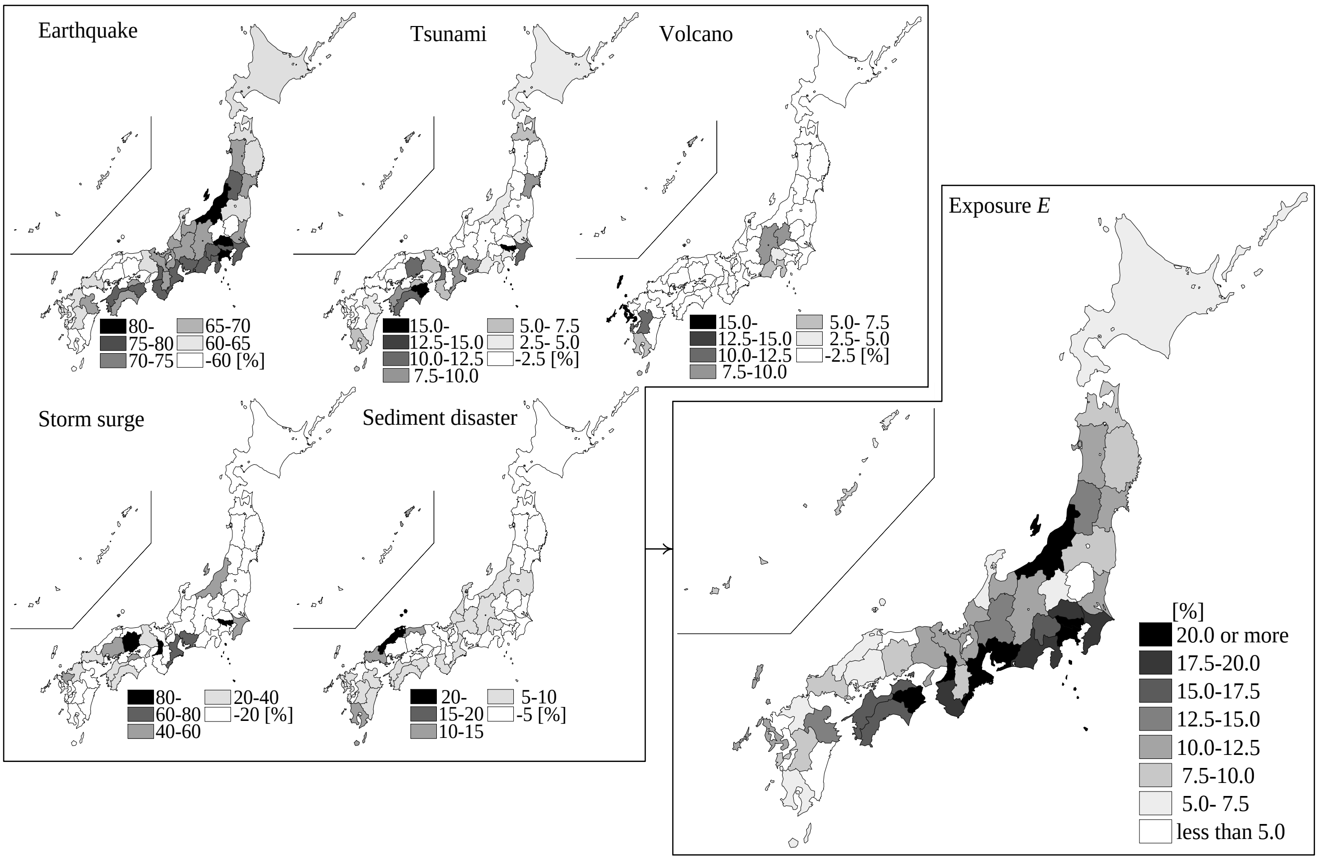

Figure 5 Calculation of exposure from normalized indicators

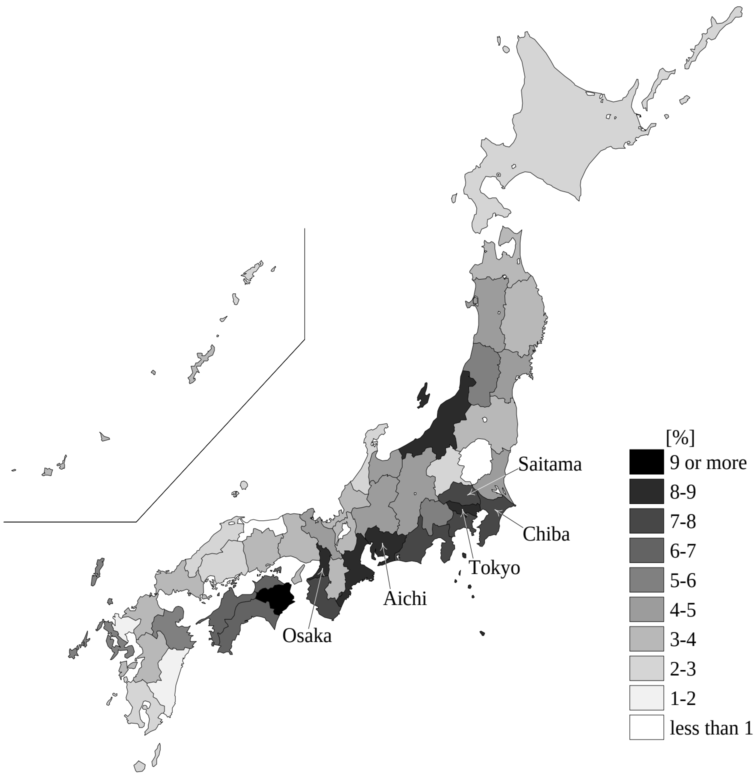

Figure 6 Contour map for Gross National Safety index for natural disasters (GNS)

The result of the correlation analysis between vulnerability of software countermeasures and Normalised indicators is given in Table 4. The highest correlation with vulnerability is seen in the regulation and governance. Weak negative correlation is noticed in the population density, which may indicate that software countermeasures may be insufficient in some rural areas.

Table 3 Correlation coefficients between vulnerability of hardware countermeasures V_h and Normalized indicators

Buildings	-0.005
Lifelines	0.310
Infrastructures	0.533
Information, networks	0.752
Population	0.137
Population density	0.010

Table 4 Correlation coefficients between vulnerability of software countermeasures V_s and Normalized indicators

Emergency stockpiling	0.326
Medical services	0.154
Economy and population	0.209
Insurance	0.192
Regulation and governance	0.815
Population	-0.148
Population density	-0.250

Figure 7 is the plots of Vulnerability against Exposure for various prefectures. Horizontal and vertical dotted lines indicate each mean value. The numerical value of the parenthesis is the ranking of GNS for a particular prefecture. It is readily noticed that the values of exposure are widely scatter, while the values of vulnerability fall in a relatively narrow range. Some features in Figure 7 are that Okinawa Prefecture and Hokkaido are the largest in Vulnerability with smaller values in Exposure, while Tottori and Yamanashi prefecture are the smallest in vulnerability. Three prefectures having the largest population (Tokyo, Osaka, Aichi) show larger values of exposure with some discrepancy in the values of vulnerability among them.

In order to further examine the content of the vulnerability, the relationship between vulnerability for hardware and that for software is given in Figure 8. It is seen that the values of vulnerability for software countermeasures fall in the range of 37% to 50%, while the values of vulnerability for hardware countermeasures are plotted in a slightly wider range of 28% to 44%. Horizontal and vertical dotted lines indicate each mean value. The mean value for software is slightly larger than that for hardware. From the figure, it is obvious that Okinawa prefecture and Hokkaido are vulnerable both in the hardware and software countermeasures. In contrast, the values of vulnerability of Tottori and Yamanashi prefecture are small both in the hardware and software countermeasures.

Further discussions are given for five selected prefectures, including Tokyo, Osaka, Aichi, Saitama and Chiba. Figure 9 presents the values of GNS, Exposure (E), Vulnerability (V), together with V_h and V_s, normalized by the corresponding national average value. It is clear from the figure that larger values of GNS in the selected prefecture are largely due to the larger values of exposure. As is indicated earlier, people tends to live in the lower land along coastal areas because of convenience, although vulnerability in these areas are high. The value of vulnerability for hardware countermeasures in Osaka is larger than the national average, while the values of vulnerability for software countermeasures in Chiba and Saitama is larger than the national average.

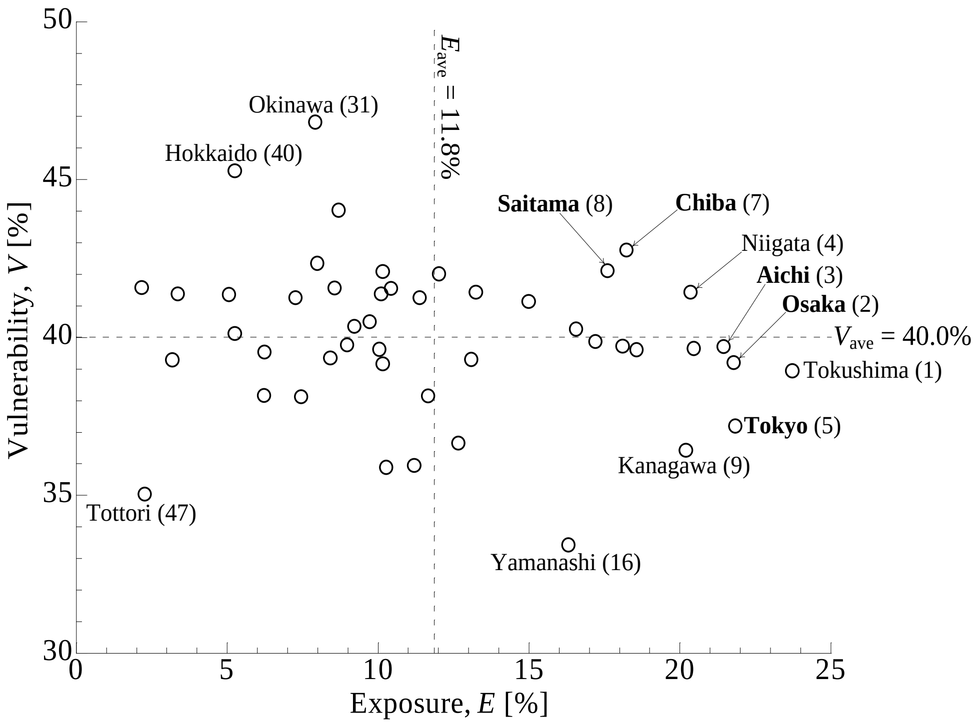

Figure 7 Relationship between exposure E and vulnerability V

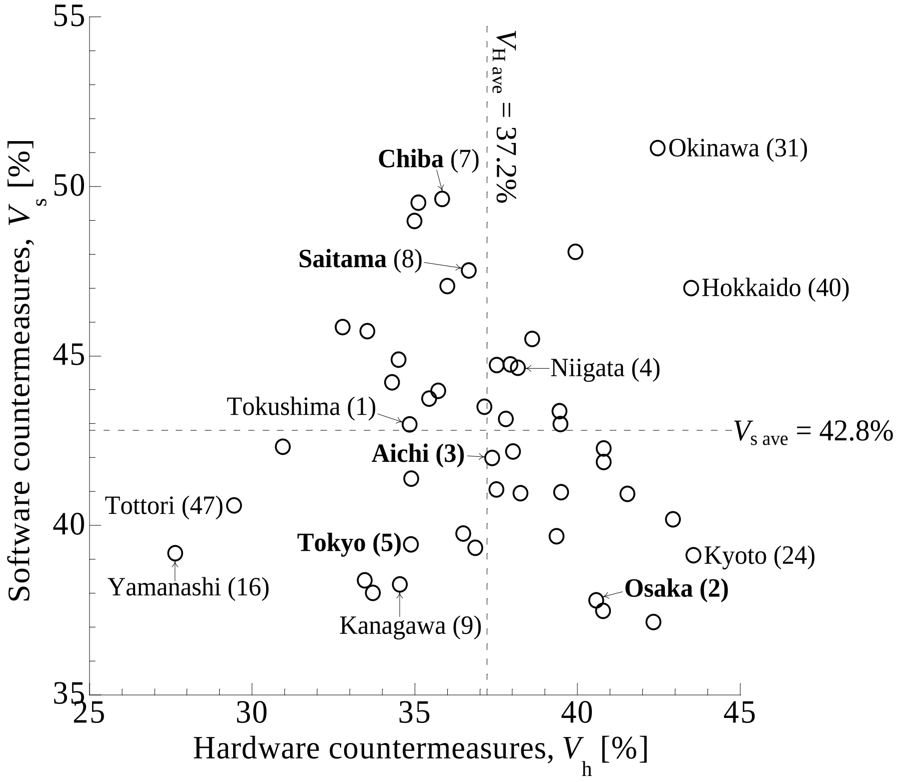

Figure 8 Relationship between vulnerability for hardware V_h and that for software V_s

Figure 10 shows which natural event affects the value of vulnerability for the selected five prefectures, indicating that earthquake, tsunami and storm surge are main disaster types. Since Saitama prefecture does not face to the sea, the major natural event must be earthquakes.

There are four Sub-goals in the vulnerability for hardware countermeasures. Figure 11 indicates which Sub-goals are inadequate relative to the national average. According to the 2015 version GNS, infrastructures per population are inadequate in all the prefectures and lifelines is also inadequate in Osaka.

There are five Sub-goals in the vulnerability for software countermeasures. Figure 12 indicates that vulnerability in medical services in all the prefectures are larger than the national average, in particular, Saitama and Chiba is almost twice the national average.

The number of physicians and hospital beds per population should be increased. Chiba is high in regulations and governance. A close look at the calculated results reveals that the rate of specification of sediment disaster prone areas is extremely low in Chiba prefecture. Improvement of this item would lower the value of vulnerability in this respect. Doing such visualization of insufficient Sub-goals would help decision and policy makers to prioritize mitigation measures, which is a beneficial merit of GNS.

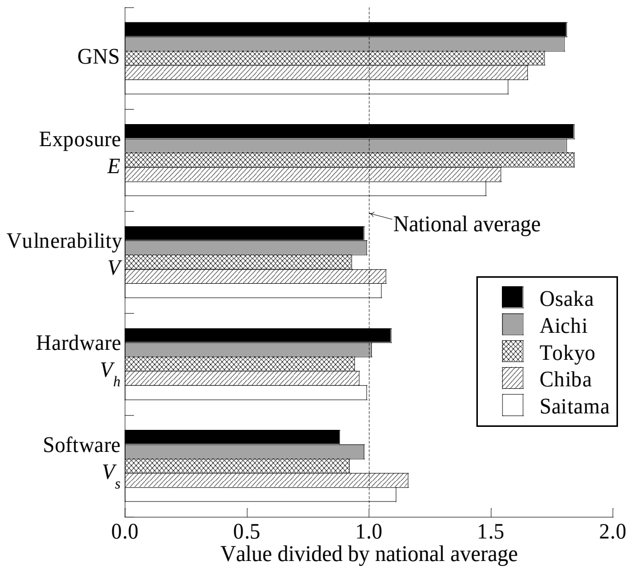

Figure 9 Relative values of GNS, exposure and vulnerability indices of five prefectures.

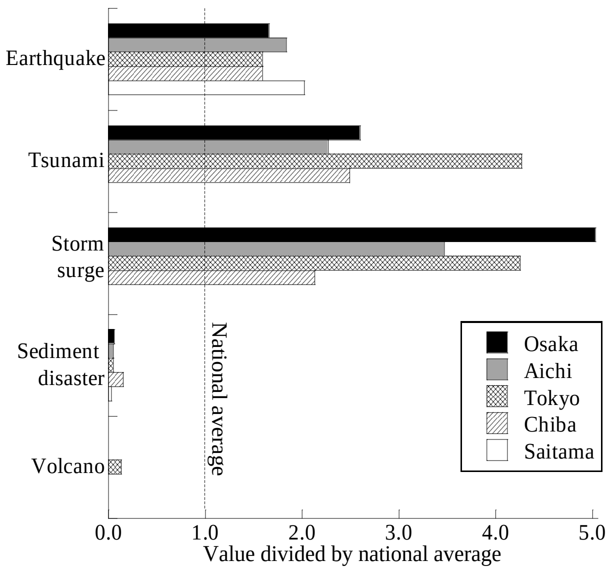

Figure 10 Relative values of indices composing exposure E

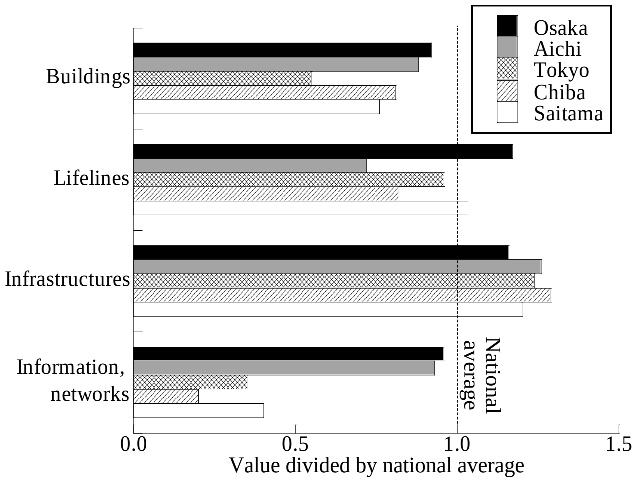

Figure 11 Relative values of indices composing vulnerability of hard ware countermeasures V_h

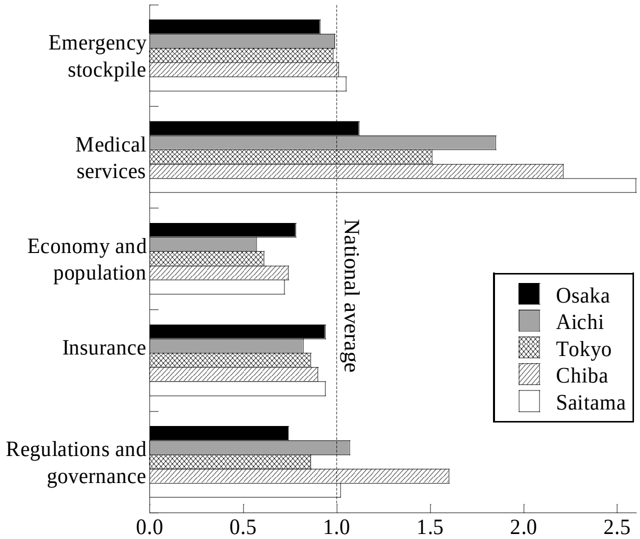

Figure 12 Relative values of indices composing vulnerability of software countermeasures V_s

4. CONCLUDING REMARKS

The concept and the assessment method of Gross National Safety for natural disasters were introduced and the initial calculation results were presented as the 2015 version GNS in this paper.

The authors are a group of geotechnical engineers & geologists. From our professional view of impact of climate change on natural disasters, we are aware of two aspects: sea water level rise related disasters and rainfall related disasters. The sea water lever rise results in possible erosion of coastal areas as well as river embankments, which may be included in current GNS framework. Rainfall related disasters may not be simple, because the accuracy of the data of rainfall of intensity and duration may be insufficient, even down scaling techniques are applied to current global models. This must be overcome by the collaboration between the research group of climate change and the authors.

Finally, the authors would like to emphasize that the concept of the GNS can be applied to other countries or regions in the similar way as the present paper. However, in assessing the risk index against natural disasters, it is essential to adjust the assessment system of the disaster risk by selecting regional natural disasters as fundamental indices composing hazard H. It is also quite important to consider the difference of the quality and quantity of the statistical data on the social and economic issues in including them as indices composing vulnerability V.

5. PPENDIX DETAILED RESULTS OF THE 2015 VERSION GNS

Detailed results of the calculation of the 2015 version GNS are provided here. Numerical data of the vulnerability of hardware and software countermeasures and their Sub-goals for worst ten and best five prefectures are given in Table A1 and A2, respectively. Calculation results of the exposure and its Sub-goals are given in the Table A3. Final results of the calculation of GNS, vulnerability and exposure are given in Table A4.

Table A1 Vulnerability of hardware countermeasures V_h and Sub-goals (worst ten and best five prefectures)

Rank	Prefecture	Hardware [%]	Buildings [%]	Lifelines [%]	Infrastructures [%]	Information, networks [%]
1	Kyoto	43.6	31.1	47.1	69.2	26.9
2	Hokkaido	43.5	17.5	38.9	89.9	27.8
3	Tochigi	43.0	26.9	39.8	74.4	30.8
4	Okinawa	42.5	37.4	36.7	68.5	27.4
5	Yamaguchi	42.4	39.6	47.7	66.4	15.8
6	Fukuoka	41.6	33.5	42.3	72.6	17.9
7	Hiroshima	40.8	31.3	46.8	73.3	12.0
8	Okayama	40.8	36.9	41.3	58.4	26.9
9	Hyogo	40.8	28.0	32.8	75.6	26.8
10	Osaka	40.6	28.3	46.5	74.2	13.4
⋮	⋮	⋮	⋮	⋮	⋮	⋮
43	Toyama	33.5	28.1	34.5	63.0	8.3
44	Aomori	32.8	22.8	36.8	64.2	7.5
45	Gifu	31.0	35.9	31.4	55.4	1.2
46	Tottori	29.5	37.7	37.4	41.4	1.3
47	Yamanashi	27.7	27.3	39.8	40.8	2.8
	Average	37.2	30.9	39.9	64.1	14.0

Table A2 Vulnerability of software countermeasures V_s and Sub-goals (worst ten and best five prefectures)

Rank	Prefecture	Software [%]	Emergency stockpile [%]	Medical services [%]	Economy and population [%]	Insurance [%]	Regulation and governance [%]
1	Okinawa	51.1	72.9	16.5	34.1	86.6	65.1
2	Chiba	49.6	74.4	38.1	23.9	68.4	53.7
3	Iwate	49.5	75.3	21.8	37.7	80.8	49.3
4	Nagasaki	49.0	76.7	1.5	38.1	86.8	62.7
5	Fukushima	48.0	75.8	25.0	33.6	74.0	46.2
6	Saitama	47.5	77.1	44.8	23.4	71.0	34.3
7	Akita	47.0	71.5	14.4	39.7	82.0	46.9
8	Hokkaido	47.0	72.2	5.1	33.7	77.9	63.1
9	Aomori	45.8	73.4	23.2	37.1	81.4	33.8
10	Mie	45.7	72.6	27.1	29.2	74.0	41.4
:	:	:	:	:	:	:	:
43	Kanagawa	38.2	57.8	35.7	18.8	66.9	28.0
44	Fukui	38.0	73.9	14.5	35.0	77.1	11.2
45	Osaka	37.8	67.1	19.4	25.2	71.0	24.7
46	Hyogo	37.5	76.3	21.3	27.9	76.7	6.8
47	Yamaguchi	37.1	71.8	2.0	35.4	78.8	20.8
	Average	41.8	73.6	17.2	32.3	75.7	33.5

Table A3 Exposure E and Sub-goals (worst ten and best five prefectures)

Rank	Prefecture	Exposure [%]	Earthquake [%]	Tsunami [%]	Storm surge [%]	Sediment disaster [%]	Volcano [%]
1	Tokushima	23.7	49.1	0.0	0.1	1.3	0.0
2	Tokyo	21.9	24.5	0.6	7.9	11.9	0.0
3	Osaka	21.8	20.3	3.0	1.6	0.9	0.6
4	Aichi	21.5	9.8	0.0	0.0	1.2	0.0
5	Mie	20.5	26.8	0.6	7.2	1.9	0.0
6	Niigata	20.4	31.1	4.8	2.6	1.2	0.0
7	Kanagawa	20.2	39.0	5.2	5.3	1.3	0.0
8	Sizuoka	18.6	72.1	11.1	25.4	0.3	0.0
9	Chiba	18.2	7.8	1.0	12.4	4.2	0.0
10	Wakayama	18.1	36.5	1.5	0.0	5.1	0.4
:	:	:	:	:	:	:	:
43	Hiroshima	5.1	46.1	0.7	4.9	4.4	0.0
44	Saga	3.4	30.1	6.9	2.5	2.1	0.6
45	Miyazaki	3.2	57.8	0.0	0.0	5.3	0.2
46	Tottori	2.3	70.8	0.0	0.0	6.2	4.6
47	Tochigi	2.2	0.0	0.8	0.0	10.6	0.0
	Average	11.9	43.5	4.3	5.1	5.0	1.6

Table A4 GNS, exposure and vulnerability

Rank	Prefecture	GNS	Exposure	Vulnerability	Hardware	Software
1	Tokushima	9.2	23.7	38.9	34.9	43.0
2	Osaka	8.5	21.8	39.2	40.6	37.8
3	Aichi	8.5	21.5	39.7	37.4	42.0
4	Niigata	8.4	20.4	41.4	38.2	44.6
5	Tokyo	8.1	21.9	37.2	34.9	39.4
6	Mie	8.1	20.5	39.6	33.6	45.7
7	Chiba	7.8	18.2	42.7	35.9	49.6
8	Saitama	7.4	17.6	42.1	36.7	47.5
9	Kanagawa	7.4	20.2	36.4	34.6	38.2
10	Sizuoka	7.4	18.6	39.6	35.5	43.7
11	Wakayama	7.2	18.1	39.7	34.5	44.9
12	Ehime	6.9	17.2	39.8	35.7	43.9
13	Kagawa	6.7	16.6	40.2	39.5	41.0
14	Kochi	6.2	15.0	41.1	37.5	44.7
15	Yamagata	5.5	13.3	41.4	39.5	43.3
16	Yamanashi	5.5	16.3	33.4	27.7	39.2
17	Oita	5.1	13.1	39.3	37.5	41.0
18	Nagasaki	5.1	12.0	42.0	35.0	49.0
19	Miyagi	4.7	11.4	41.2	39.5	43.0
20	Gifu	4.6	12.7	36.6	31.0	42.3
21	Nagano	4.4	11.7	38.1	36.5	39.7
22	Akita	4.3	10.4	41.5	36.0	47.0
23	Ibaraki	4.3	10.2	42.1	38.6	45.5
24	Kyoto	4.2	10.1	41.3	43.6	39.1
25	Toyama	4.0	11.2	35.9	33.5	38.4
26	Shiga	4.0	10.1	39.6	38.3	40.9
27	Hyogo	4.0	10.2	39.1	40.8	37.5
28	Kumamoto	3.9	9.7	40.5	37.8	43.1
29	Fukushima	3.8	8.7	44.0	40.0	48.0
30	Nara	3.7	9.2	40.3	37.2	43.5
31	Okinawa	3.7	7.9	46.8	42.5	51.1
32	Fukui	3.7	10.3	35.9	33.7	38.0
33	Yamaguchi	3.6	9.0	39.7	42.4	37.1
34	Okayama	3.6	8.6	41.5	40.8	42.3
35	Iwate	3.4	8.0	42.3	35.1	49.5
36	Aomori	3.3	8.4	39.3	32.8	45.8
37	Fukuoka	3.0	7.3	41.2	41.6	40.9
38	Ishikawa	2.8	7.5	38.1	36.9	39.3
39	Kagoshima	2.5	6.3	39.5	39.4	39.7
40	Hokkaido	2.4	5.3	45.2	43.5	47.0
41	Shimane	2.4	6.2	38.1	34.9	41.4
42	Gunma	2.1	5.3	40.1	38.1	42.2
43	Hiroshima	2.1	5.1	41.3	40.8	41.8
44	Saga	1.4	3.4	41.3	38.0	44.7
45	Miyazaki	1.3	3.2	39.3	34.3	44.2
46	Tochigi	0.9	2.2	41.6	43.0	40.2
47	Tottori	0.8	2.3	35.0	29.5	40.6
	Average	4.7	11.9	40.0	37.2	42.8

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