Review of restoration processes for damaged social infrastructures in Japan and building a performance indicator for designing disaster mitigation policy

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Abstract: Japan has experienced many large-scale natural disasters such as earthquakes, typhoons accompanied by heavy rain and landslides, and tornadoes. Based on the data of damage caused by four recent major earthquakes in Japan (the Hanshin-Awaji, Niigata-Chubu, Great East Japan, and Kumamoto earthquakes), we investigate the restoration processes of public utilities for major social infrastructure including electricity, gas, water, and communication lines by comparing the differences regarding the speed and trends. The results of various statistical data analyses and mathematical modelling analyses are used to make policy suggestions. In addition, we attempt to build performance indicators (PIs) for water supply businesses to measure the robustness of the water supply network system. Using actual data related to the water supply in Japan, we illustrate the numerical results for the PIs, which can be used to design natural disaster mitigation policies.

Keywords: earthquake; social infrastructure; restoration process; statistical data analysis; public utilities; mathematical model; robustness; water supply business; performance indicator; Japan.

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1 Introduction

Japan has experienced many severe natural disasters such as earthquakes, typhoons, floods, and landslides. The Hanshin-Awaji earthquake (January, 1995) resulted in 6,400 people being classified as either dead or missing. In March 2011, the Great East Japan Earthquake caused 16,000 deaths and 2,800 missing people. Moreover, as a result of this earthquake, more than 320,000 evacuees still have not returned to their homes (refer to Reconstruction Design Council, 2011; Suppasri et al., 2013; UNESCO, 2012). The East South Sea earthquake, which is predicted to occur in the near future, is expected to cause 25,000 dead or missing people, 960,000 damaged homes, and 50 trillion yen in economic losses. Moreover, earthquakes cause severe damage to public utilities such as electricity, gas, and water, which results in the interruption of services. This forces residents to evacuate to areas such as public schools and public halls, where they often must remain for long periods. In this study, we consider four recent major earthquakes in Japan that resulted in severe damage: Hanshin-Awaji (HNSA), Niigata-Chubu (NGTC), Great East Japan (GEJE), and Kumamoto (KMMT). Using data regarding deaths and missing people, evacuees and evacuation centres, water supply suspension and restoration, and other parameters, we apply statistical data analysis techniques to investigate these earthquakes with various corresponding mathematical models to derive more desirable and efficient mitigation policies for natural disaster preparation in Japan.

In Section 2, we show the suspension and restoration process of social infrastructures including electricity, gas, water and communication lines in Japan. In Section 3, we introduce how to build a performance indicator for the water supply businesses in Japan. We describe techniques for measuring the robustness of the water supply system. In Section 4 we provide summary and conclusion of this study.

2 Suspension and restoration of social infrastructure

In this section, we investigate the suspension and restoration processes of social infrastructure following the HNSA earthquake (17 January 1995); the NGTC earthquake

(23 October 2004); the GEJE earthquake (11 March 2011); and the KMMT earthquake (14 April 2014).

Table 1 Various public utility suspension and restoration rates for households (HH) affected by the 1995 Hanshin-Awaji earthquake in Japan

Public utility	*Suspension*	*Days required for restoration*
Electricity	2,600 HH	6
Gas	855.9 HH	84
Water supply	495.3 HH	90
Communication lines	101.66 LN	14

Notes: HH: households (unit: 1,000 homes) and LN: lines.

Table 1 indicates the number of households (HHs) with suspended public utilities including electricity, gas, water supply, and communication lines, and the number of days required to restore the services in Kobe city following the HNSA earthquake. Electricity was restored the soonest in six days followed by communication lines in two weeks; the gas and water supply required almost three months for restoration. These trends were similar for all of the studied natural disasters. Therefore, we sought to shorten the restoration period for gas and water supply, considering that restoration even a few weeks earlier would be extremely beneficial. In addition, we considered that their restoration trend curves differ among the public utilities. In particular, the cases for electricity and water supply showed convex forms, whereas those for gas and communication lines were rather concave form. Moreover, gas companies sometimes showed a convex-to-concave trend with a convex trend followed by a concave trend. Therefore, these properties need to be considered when developing natural disaster mitigation policies.

Table A1 indicates the restoration trend for public utilities such as water, gas, electricity, and communication lines following the HNSA earthquake, where cities and towns refer to those in which the water supply was disrupted.

Figure 1 Restoration trend for electricity and its approximation curve following the HNSA earthquake (see online version for colours)

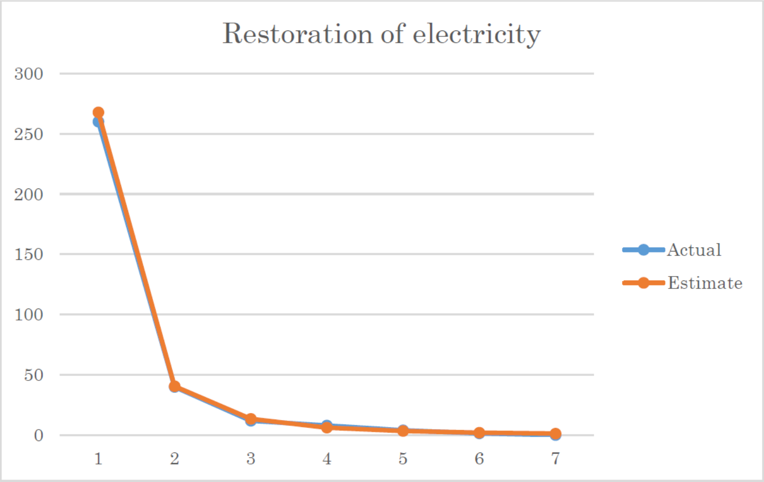
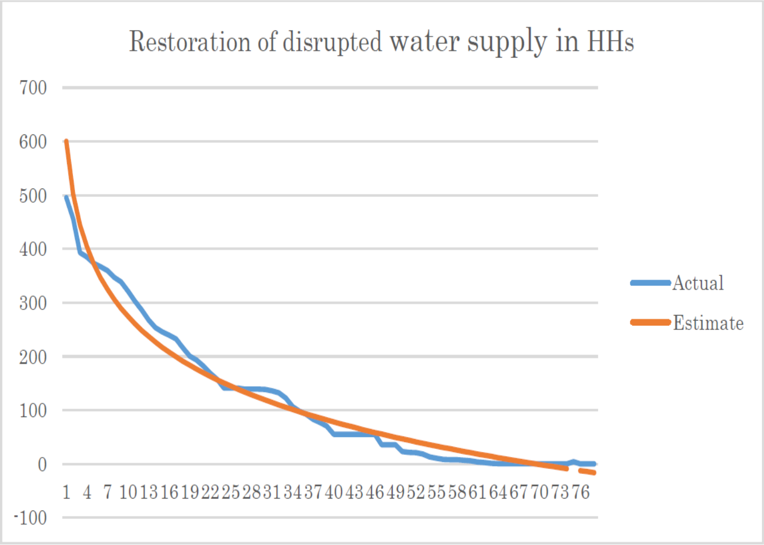


Figure 2 Restoration trend of disrupted water supply for HHs and its approximation curve following the HNSA earthquake (see online version for colours)



Figures 1 and 2 indicate the curves expressing the restoration trend for electricity and water supply corresponding to the data shown in Table A1 in the Appendix. By approximating the actual data shown by the blue points in these figures, we obtained the approximation function forms as shown in the following equations. The approximation curves for the restoration processes based on these functions are represented by the red lines in Figures 1 and 2.

The mathematical model expressing an approximating function for the restoration trend of electricity can be given as the following polynomial function:

$$y = ax^b \quad a, b\text{: parameter} \tag{1}$$

Thus, the parameters for the above mathematical model can be estimated by using the following transformation:

$$\log y = \log \; a + b \; \log x \tag{2}$$

The mathematical model expressing an approximating function for the restoration trend of the water supply can be given as the following nonlinear function:

$$y = c \log x + d \quad c, d\text{: parameter.} \tag{3}$$

The parameter estimates for *a* and *b*, *c* and *d* corresponding to the restoration process of electricity and the water supply, respectively, are shown in Table 2. Thus, the restoration process of electricity for the case of Kobe can be given using parameters *a* and *b* by the following mathematical model:

$$y = 2.589x^{-2.726} \tag{4}$$

The parameter estimates for c and d corresponding to the restoration process of disrupted water supply for the HHs of Kobe give the following mathematical model as shown in Figure 2.

$$y = 600.15 \log x - 141.47. \tag{5}$$

Table 2 Parameter estimates for electricity and water supply restoration model

Electricity		*Water supply*	
Parameter	*Disrupted HHs*	*Parameter*	*Disrupted HHs*
log a	5.5902 (28.93) (0.00)	c	600.1533 (56.80) (0.00)
b	–2.7261 (17.668) (0.00)	d	–141.47 (47.067) (0.00)
R^2	0.9842	R^2	0.9664
n	5	n	77

Notes: R^2: adjusted R^2 and n: number of data. Figures in parentheses indicate t-value (upper) and P-value (lower).

Figures 1 and 2 show that the actual and estimated values for expressing the restoration processes of both electricity and the water supply in Kobe are very close. The actual and estimated values coincide in Figure 1. In Figure 2, the number of HHs with disrupted water supply becomes zero when $y = -141.47 \log x + 600.153 = 0$, i.e., $x = \exp(4.243) = 69.57$. Thus, the number of HHs with disrupted water supply becomes zero almost 70 days after the occurrence of the disaster.

Figure 3 Trend of the number of HHs with disrupted water supply (HNSA) (see online version for colours)

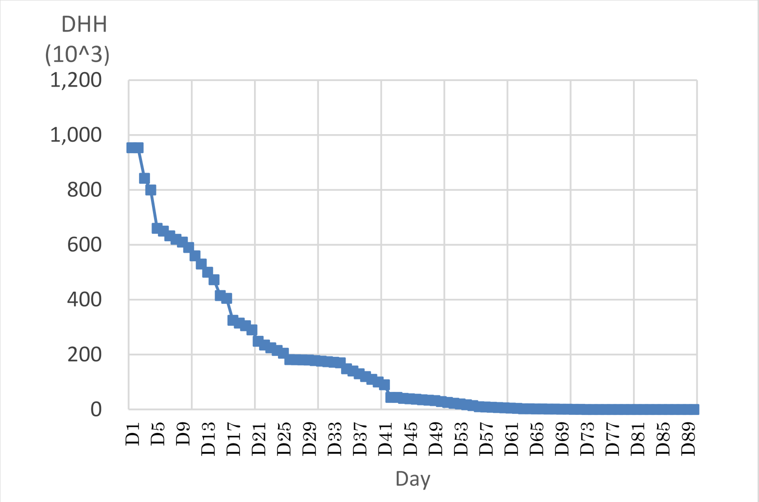


Figure 3 shows the trend of the number of HHs with disrupted water supply following the HNSA earthquake. The figure shows that almost 1.3 million HHs were disrupted. The restoration speed was very fast during the first month after disruption. After that period, it took two to three months for the water supply to be restored in all HHs.

Just after the HNSA earthquake, the water supply was cut off in 1,265,730 HHs in ten cities and seven towns. This corresponds to almost 90% of the total number of HHs in these areas, moreover in five cities and four towns. However, the restoration was very quick in these areas, with the water restored in one town the day of incident, in one city and one town the next day, and in two cities and four towns within a week. After one week, the percentage of HHs with suspended water supply was 45.1%, which is almost half of that on the first day. After two weeks, the total was 3.2%, which means the water supply was restored in almost all HHs. In the entire Hyogo prefecture, the percentage of HHs with suspended water supply was 33.7%. We used these statistical data to develop various types of mathematical models to evaluate their relationships and processes.

Figure 4 Numbers of cities and towns with disrupted for water supply (GEJE) (see online version for colours)

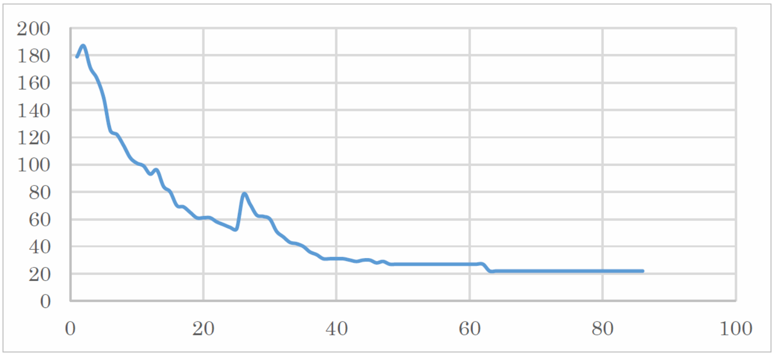


Figure 4 shows the numbers of cities and towns with disrupted for water supply following the GEJE earthquake, and Figures 5 and 6 show the restoration trends for HHs with disruptions in the gas supply and communication lines, respectively, following the HNSA earthquake. Based on these results, the approximation curves for these restoration processes can be expressed by concave forms for the gas supply and convex forms for the communication lines. This fact implies that the approximate curves can be expressed by the following function, which is referred to as the survivability function what we call:

$$f(x) = \frac{(1-x^p)^q}{x^{pq} + (1-x^p)^q} \quad p, q\text{: parameter} \tag{6}$$

We have been considering the application of the above survivability function to explain various events occurring in our social system. We believe that the restoration process of the social infrastructures could be one of such applications (refer to Oyama and Kobayashi, 2015a, 2015b; Oyama, 2020). Social infrastructures include electricity, water supply, gas supply and communication lines. According to our data analyses using available data we collected, being related with social structures, we consider that their restoration processes can be divided into two types. The first group consists of electricity and gas, which shows a convex restoration process curve. The second group includes the gas supply and communication lines, which show the form of a concave function or a concave function following a convex curve.

Figure 5 Restoration trend for disrupted gas supply for HHs (HNSA) (see online version for colours)

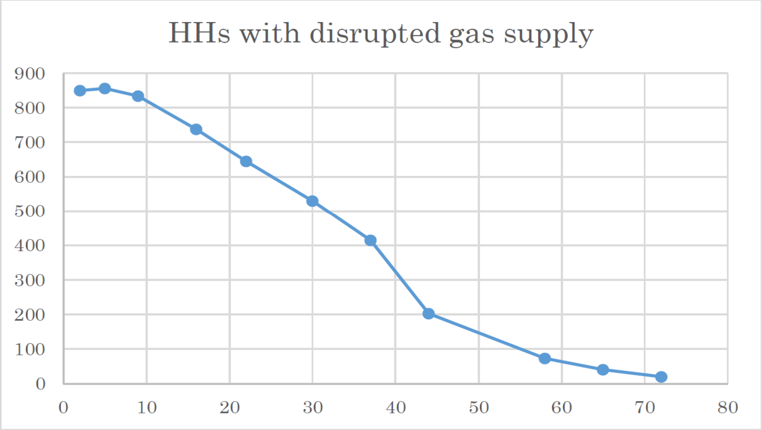
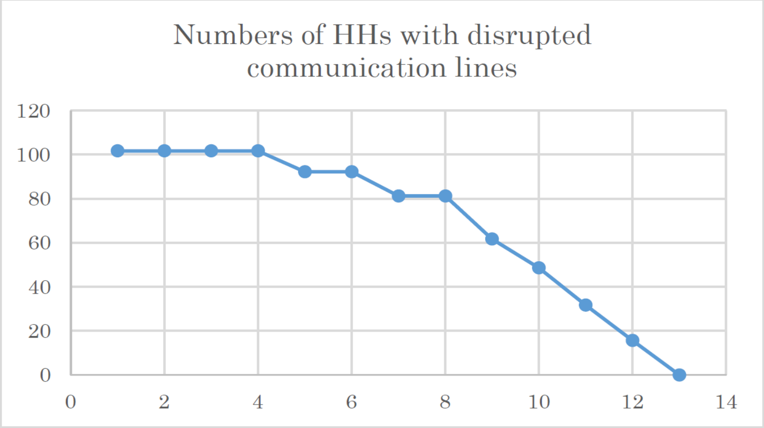


Figure 6 Restoration trend for disrupted communication lines for HHs (HNSA) (see online version for colours)



3 Building performance indicators (PIs) for the water supply businesses

We attempted to measure the PIs for public utilities, focusing on water supply businesses. The PI is based on three types of factors, which in this case include management, facility/equipment, and utility operation. There may be considered some other factors to express the status of the water supply businesses, however, we consider that those three aspects could be major factors at least to represent the current activities and potential capabilities of their businesses. Table 3 shows these factors and their evaluation criteria used to evaluate the PI for each water supply business. In Table 3 diffusion rate is defined to be the ratio between water supply population and the total population. The PI is measured for each component, such as the size of the business and its location, depending upon the data availability. Thus, for each component, we measured the PI corresponding to each category and each evaluation criterion.

Table 3 Category and evaluation criteria used for determining the PI

Category	*Evaluation criteria*
Management	Total budget, number of employees
	Total revenue (1×10^8 yen), total cost (1×10^8 yen)
	Total revenue/total cost, water supply revenue (1×10^3 yen)
Facility/ equipment	Total pipeline length (main pipe), transmission pipeline length, distribution pipeline length; km)
	Facility capacity (1,000 m^3/day), earthquake-resistant pipe ratio (%), pipe ratio exceeding the durability period (%)
Utility operation	Population, water supply population, diffusion rate (%)
	Unit supply cost (yen), unit water supply cost (yen)
	Technical staff ratio (%)

The following computational procedure was used for measuring the PI for the water supply businesses. First, we defined sets to include a set of components I, set of evaluation items J, and set of components K as $I = \{1, 2, \ldots, n_i\}$, $J = \{1, 2, \ldots, n_j\}$, and $K = \{1, 2, \ldots, n_k\}$, respectively.

Step 1 Calculate mean μ_{ij} and standard deviation (SD) σ_{ij} using index value x_{ijk} for each category $i \in I$, evaluation item $j \in J$, and component $k \in K$.

$$\mu_{ij}^{x} = \frac{1}{n_k}\sum_{k=1}^{n_k} x_{ijk} \qquad i \in I,\ j \in K \tag{7}$$

$$\sigma_{ij}^{x} = \sqrt{\frac{\sum_{k=1}^{n_k}\left(x_{ijk} - \mu_{ij}^{x}\right)^2}{n_k - 1}} \qquad i \in I,\ j \in K \tag{8}$$

μ_{ij} mean value for each factor $i \in I$ and evaluation item $j \in J$

σ_{ij} SD or each category $i \in I$ and evaluation item $j \in J$.

Step 2 Using index value x_{ijk}, mean μ_{ik}^{x}, and SD σ_{ik}^{x}, we normalised the data for each category $i \in I$, evaluation item $j \in J$, and component $k \in K$ as follows:

$$z_{ijk} = \frac{x_{ijk} - \mu_{ij}^{x}}{\sigma_{ij}^{x}}, \qquad i \in I,\ j \in J,\ k \in K \tag{9}$$

x_{ijk} index value for category $i \in I$, evaluation item $j \in J$, and component $k \in K$

z_{ijk} normalised index value for category $i \in I$, evaluation item $j \in J$, and component $k \in K$.

Step 3 Define the index value w_{ik} for category $i \in I$ and component $k \in K$ as follows:

$$w_{ik} = \frac{1}{n_j}\sum_{j=1}^{n_j} Z_{ijk} \qquad i \in I,\ j \in J \tag{10}$$

Based upon the above algorithm and using index value x_{ijk} for category $i \in I$, evaluation item $j \in J$, and component $k \in K$, we calculate index values w_{ik} for category $i \in I$ and component $k \in K$.

Table 4 Management data (1) by size of the water supply business

Division		*WSP*	*NSF*	*PEX*	*AWS*	*WSR*	*FCP*
Water supply		84,532	31	447,921	10,444	1,626,817	47,987
Population	More than 1×10^6	2,645,918	1,028	6,876,117	315,493	53,762,606	1,472,233
	$5 \times 10^5 - 10^6$	652,716	224	2,995,654	78,344	11,025,227	324,227
	$2.5 \times 10^5 - 5 \times 10^5$	345,380	128	1,733,242	41,858	6,346,678	185,045
	$1 \times 10^5 - 2.5 \times 10^5$	148,463	50	842,132	18,208	2,706,351	79,762
	$5 \times 10^4 - 1 \times 10^5$	69,081	23	509,354	8,763	1,353,593	40,607
	$3 \times 10^4 - 5 \times 10^4$	38,474	14	321,100	5,046	741,554	23,886
	$2 \times 10^4 - 3 \times 10^4$	24,604	10	233,295	3,206	476,808	16,061
	$1 \times 10^4 - 2 \times 10^4$	14,551	6	155,816	2,057	286,346	10,268
	$5 \times 10^3 - 10^4$	7,206	4	95,395	1,040	154,109	5,644
	Less than 5×10^3	3,164	3	65,292	614	74,616	4,509

Notes: WSP: water supply population; NSF: number of staff; PEX: pipe extension (m); AWS: annual water supply (1×10^3 m^3); WSR: water supply revenue (1×10^3 yen) and FCP: facility capacity (1,000 m^3/day).

Table 5 Management data (2) by size of the water supply business

Division		*NB*	*NSC*	*PLC*	*WRC*
Water supply			0.37	5.30	19.24
Population	More than 1×10^6	93	0.39	2.60	20.32
	$5 \times 10^5 - 10^6$	261	0.34	4.59	16.89
	$2.5 \times 10^5 - 5 \times 10^5$	274	0.37	5.02	18.38
	$1 \times 10^5 - 2.5 \times 10^5$	146	0.33	5.67	18.23
	$5 \times 10^4 - 10^5$	201	0.34	7.37	19.59
	$3 \times 10^4 - 5 \times 10^4$	209	0.35	8.35	19.27
	$2 \times 10^4 - 3 \times 10^4$	144	0.39	9.48	19.38
	$1 \times 10^4 - 2 \times 10^4$	56	0.41	10.71	19.68
	$5 \times 10^3 - 10^4$	11	0.57	13.24	21.39
	Less than 5×10^3	15	1.02	20.64	23.58

Notes: NSC: number of staff per 1,000 WSP; PLC: pipe length per capita (m); WRC: water supply revenue per capita (1×10^3 yen) and NB: number of businesses.

Tables 4 and 5 indicate business-related evaluation criteria for the water supply business whereas Table 6 shows the water supply cost data. In Table 4 and 5, the following abbreviations are used: WSP: water supply population; NSF: number of staff;

PEX: pipeline extension (m); AWS: annual water supply (1×10^3 m^3); WSR: water supply revenue (1×10^3 yen); FCC: facility capacity (1,000 m^3/day); NSC: number of staff per 1,000 water supply population; PLC: pipeline length per capita (m); WRC: water supply revenue per capita; NB: number of water supply businesses by size of water supply population. In Table 6, water supply costs are shown for 2011 and 2012.

Table 6 Water supply cost

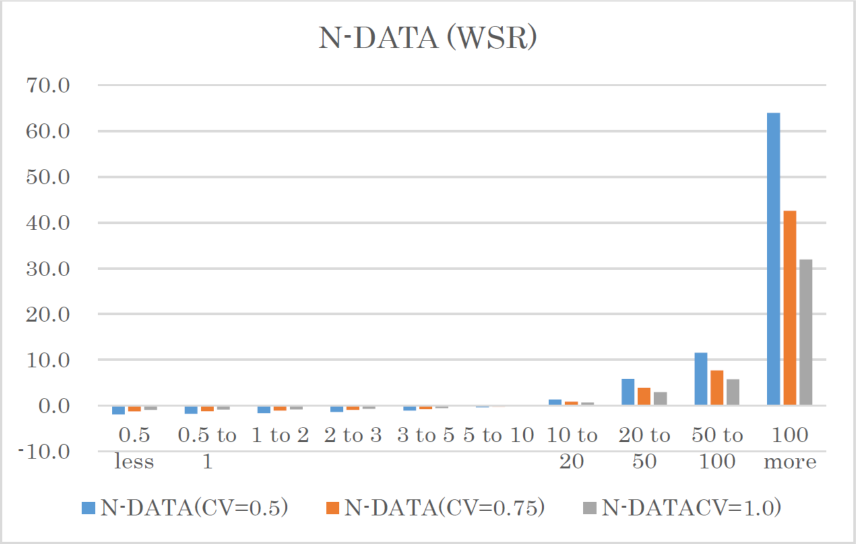
Division		*WSC (2012)*	*WSC (2011)*
Water supply		176.26	176.78
Population	More than 1×10^6	189.67	190.32
	$5 \times 10^5 - 10^6$	153.23	154.48
	$2.5 \times 10^5 - 5 \times 10^5$	164.07	165.27
	$1 \times 10^5 - 2.5 \times 10^5$	165.67	166.10
	$5 \times 10^4 - 10^5$	176.32	177.55
	$3 \times 10^4 - 5 \times 10^4$	176.92	175.84
	$2 \times 10^4 - 3 \times 10^4$	180.28	184.79
	$1 \times 10^4 - 2 \times 10^4$	174.52	174.84
	$5 \times 10^3 - 10^4$	200.97	194.85
	Less than 5×10^3	252.58	265.97
Water supply business		77.41	82.13

Note: WSC: water supply cost (yen).

The data in Tables 4, 5, and 6 are shown by the population size for the water supply businesses in Japan being categorised into ten groups. Thus, by using additional data such as the number of water supply businesses for each group corresponding to the size of water supply population, we can obtain the mean of each evaluation criterion while we cannot obtain the SD. Because we need the SD data in order process the data for the normalisation, we estimate the SD values based on different values of the coefficient of variance (CV), such as 0.5, 0.75, and 1.0. Based on these estimating assumptions, we obtain the estimated PI values for the normalised data (N-DATA) of WSR, NSF, and PPL, as shown in Figures 7, 8, and 9, respectively.

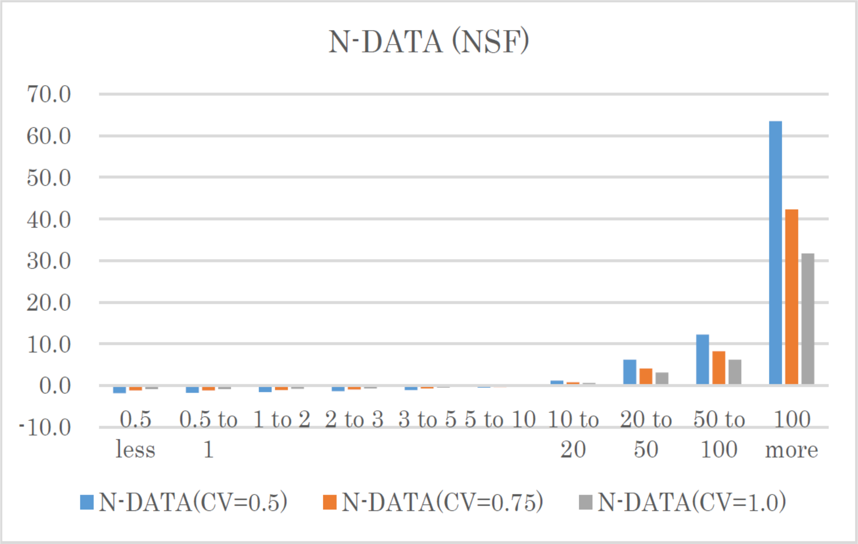
Figures 7 and 8 show that the PI values for both normalised variables WSR and PPL are positive only for water supply businesses with sizes larger than the population value of 10^6; PPL in Figure 9 is positive only for water supply businesses with water supply population sizes larger than the value of 20 × 10^4. Moreover, the largest size group with the population value larger than 10^6 shows much larger positive PI values than the other groups. This means that the water supply businesses can be profitable in Japan only when the water supply population is larger than 20 × 10^4, among them only when it exceeds 10^6 or more. Based on the estimation processes mentioned above, we obtain numerical results for the PIs for WSR, STF, and PPL according to the size of water supply businesses in Japan, as given in Figure 10. The graphs of WSR and STF almost coincide because their corresponding PI values were almost the same for all sizes of water supply businesses.

Figure 7 Distribution of normalised WSR data for each CV value (see online version for colours)



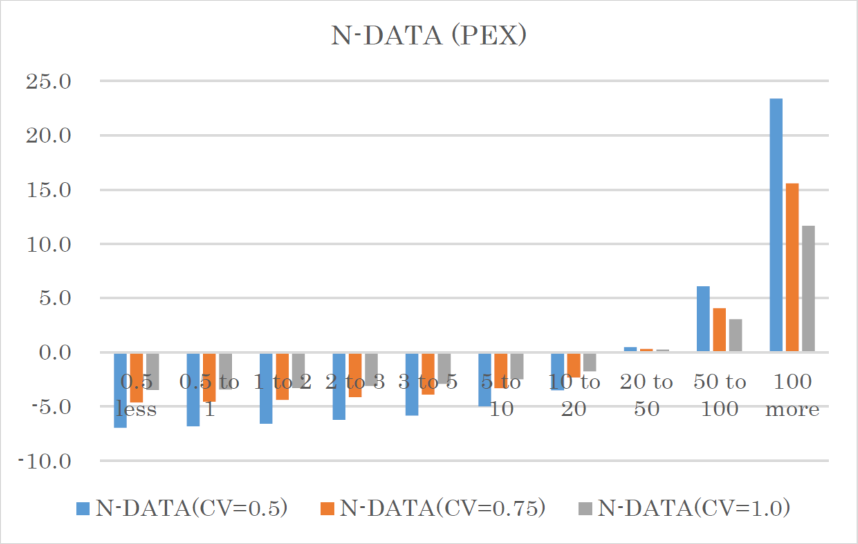
Source: Japan Water Works Association (2019)

Figure 8 Distribution of normalised STF data for each CV value (see online version for colours)



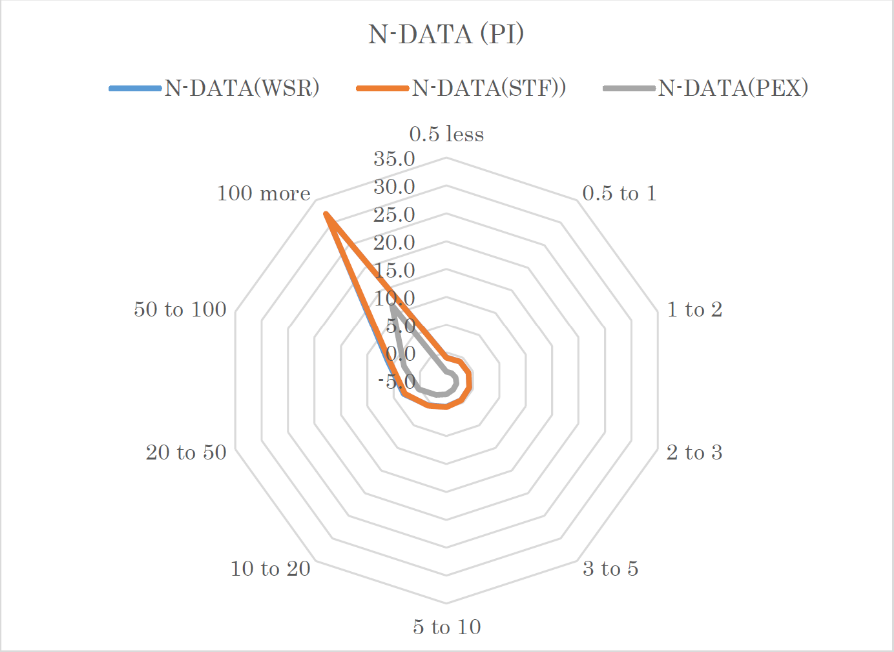
Source: Japan Water Works Association (2019)

Figure 9 Distribution of normalised pipe length data for each CV value (see online version for colours)



Source: Japan Water Works Association (2019)

Figure 10 PIs for WSR, STF, and PPL by the size of the water supply business in Japan (see online version for colours)



Notes: WSR: water supply revenue per person (1 × 10^3 yen); NSF: number of staff per 1 × 10^3 person and PEX: pipeline extension (m).

Figure 11 PIs for POP, DIF, and PPL by prefecture in Japan (see online version for colours)

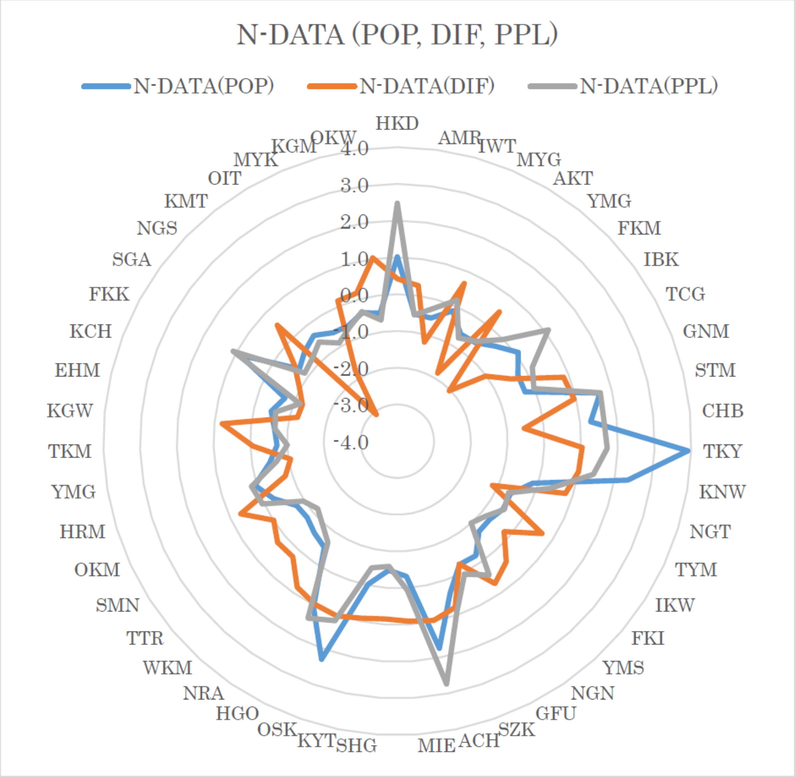


Figure 11 indicates similar PIs for the water supply population, denoted by POP, and the diffusion rates, denoted by DIF, corresponding to prefectures in Japan. The most urbanised prefectures, such as TKY, KNW, AIC, and OSK, show high PI values of POP larger than 2. Thus, we can say that the POP PI values indicate the degree of urbanisation almost proportionally. We see that low PI values for POP are noted for remote areas such as IWT, AKT, and YMG in Tohoku; TYM, ISK, and FKI in Hokuriku; KCH, KGW, and TKS in Shikoku; and SAG, MYZ, and OIT in Kyushu. However, high PI values are noted for most prefectures with values of about 1, whereas IWT and AKT in the Tohoku area, TYM and FKI in the Hokuriku area, EHM and KCH in the Shikoku area, and KMM and OIT in the Kyushu area show rather lower DIF PI values, at less than –1.1. Among them, KMMT shows an exceptionally lower value of –3.7. This result implies that lower DIF PI values occur for prefectures with rich underground water resources.

4 Summary and conclusions

The International Disaster Database (EM-DAT, 2019) and the NGDC/WDC (2019) reported that between 1970 and 1979 and between 2000 and 2012, the number of global natural disaster events increased significantly from 837 to 4,939, or almost six-fold. Over the entire period of 1970–2012, 40.8% of these natural disasters occurred in Asia. Japan has experienced numerous severe natural disasters resulting in huge amounts of damage.

Based on the statistical data analyses regarding the four major earthquakes evaluated in the present study, we applied mathematical modelling techniques to investigate the restoration processes of major social infrastructure (refer to Oyama and Kobayashi, 2015a, 2015b; Parwanto and Oyama, 2013, 2014, 2015; Parwanto et al., 2015; Oyama, 2020). To improve this research, the restoration trends for public utilities could be studied more carefully and generalised further with more details to facilitate comparison with the proposed mathematical models.

The restoration process for public utilities such as electricity, water, gas, and communication lines can be expressed by various types of mathematical models. Those for the former two can be expressed by convex polynomial functions given as $y = ax^b$ and $y = a \log x + b$, respectively. However, those for electricity and water can be expressed by the combined function of concave function following a convex function, such as the so-called survivability function. By proposing PIs for the water supply businesses, we evaluated the status of the each business from management, facility/equipment, and utility operation perspectives. Further, numerical experiments were conducted by using the 2012 earthquake data available in Japan. In future work, we plan to compare the statuses and investigate the changes occurring before and after the GEJE earthquake.

Finally, we believe the approaches discussed in the present study will contribute to the development of effective mitigation policies for natural disaster preparation in Japan.

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Appendix

Table A1 Restoration processes for water supply, gas, electricity, and communication lines following the HNSA earthquake

Date	*No.*	*Water*	*Gas (1,000)*	*Electricity*	*Telephone line*	*Date*	*No.*	*Water*	*Gas*
1/17/1995				2,600,000	101,660	3/20/1995	61	3,520	
1/18/1995				400,000	101,660	3/21/1995	62	2,600	
1/19/1995	1	495,300		120,000	101,660	3/22/1995	63	1,300	
1/20/1995	2	456,300	849.5	80,000	101,660	3/23/1995	64	650	
1/21/1995	3	393,250		40,000	101,660	3/24/1995	65	650	40.95
1/22/1995	4	384,800		15,000	101,660	3/25/1995	66	650	
1/23/1995	5	373,100	855.9	0	92,160	3/26/1995	67	650	
1/24/1995	6	367,250			92,160	3/27/1995	68	650	
1/25/1995	7	359,450			81,160	3/28/1995	69	650	
1/26/1995	8	347,100			81,160	3/29/1995	70	130	
1/27/1995	9	338,650	834.1		61,660	3/30/1995	71	130	
1/28/1995	10	321,100			48,660	3/31/1995	72	130	20.25
1/29/1995	11	302,900			31,660	4/1/1995	73	130	
1/30/1995	12	286,650			15,660	4/2/1995	74	130	
1/31/1995	13	267,800			0	4/3/1995	75	130	
2/1/1995	14	253,500				4/4/1995	76	130	
2/2/1995	15	245,700				4/5/1995	77	130	
2/3/1995	16	239,200	737.8			4/6/1995	78	130	
2/4/1995	17	232,700				4/7/1995	79		
2/5/1995	18	216,450				4/8/1995	80		
2/6/1995	19	200,850				4/9/1995	81		
2/7/1995	20	193,050				4/10/1995	82		
2/8/1995	21	182,000				4/11/1995	83		
2/9/1995	22	168,350	644.8			4/12/1995	84		
2/10/1995	23	157,300				4/13/1995	85		
2/11/1995	24	141,500				4/14/1995	86		
2/12/1995	25	141,500				4/15/1995	87		
2/13/1995	26	141,400				4/16/1995	88		
2/14/1995	27	139,100				4/17/1995	89		
2/15/1995	28	139,100				4/18/1995	90		
2/16/1995	29	139,100				4/19/1995	91		
2/17/1995	30	138,450	529.9			4/20/1995	92		
2/18/1995	31	135,850				4/21/1995	93		
2/19/1995	32	132,600				4/22/1995	94		
2/20/1995	33	122,850				4/23v	95		

Table A1 Restoration processes for water supply, gas, electricity, and communication lines following the HNSA earthquake (continued)

Date	*No.*	*Water*	*Gas (1,000)*	*Electricity*	*Telephone line*	*Date*	*No.*	*Water*	*Gas*
2/21/1995	34	106,600				4/24/1995	96		
2/22/1995	35	98,150				4/25/1995	97		
2/23/1995	36	92,300				4/26/1995	98		
2/24/1995	37	83,200	415.1			4/27/1995	99		
2/25/1995	38	77,350				4/28/1995	100		
2/26/1995	39	70,200				4/29/1995	101		
2/27/1995	40	55,250				4/30/1995	102		
2/28/1995	41	55,250				5/1/1995	103		
3/1/1995	42	55,250				5/2/1995	104		
3/2/1995	43	55,250				5/3/1995	105		
3/3/1995	44	55,250	203.1			5/4/1995	106		
3/4/1995	45	55,250				5/5/1995	107		
3/5/1995	46	55,250				5/6/1995	108		
3/6/1995	47	35,750				5/7/1995	109		
3/7/1995	48	35,750				5/8/1995			
3/8/1995	49	35,750				5/9/1995			
3/9/1995	50	23,350				5/10/1995			
3/10/1995	51	21,450				5/11/1995			
3/11/1995	52	20,800				5/12/1995			
3/12/1995	53	18,550				5/13/1995			
3/13/1995	54	13,000				5/14/1995			
3/14/1995	55	10,400				5/15/1995			
3/15/1995	56	8,450				5/16/1995			
3/16/1995	57	7,800				5/17/1995			
3/17/1995	58	7,800	73.359			5/18/1995			

Table A2 Normalised PI values (WSR, STF, PEX)

SIZE	*N-DATA (WSR)*	*N-DATA (STF)*	*N-DATA (PEX)*
Less than 0.5	–0.9045	–0.9543	–3.4873
0.5 to 1	–0.8727	–0.9055	–3.4203
1 to 2	–0.8090	–0.8245	–3.2857
2 to 3	–0.6817	–0.7077	–3.1132
3 to 5	–0.5544	–0.5454	–2.9176
5 to 10	–0.2679	–0.1702	–2.4984
10 to 20	0.5914	0.6591	–1.7573
20 to 50	3.0740	2.8907	0.2272
50 to 100	6.1296	5.7588	3.0386
More than 100	31.7196	31.9583	11.6803

Table A3 Normalised PI values (POP, DIF, PPL)

PREF.	*POP*	*DIF*	*PPL*	*PREF.*	*POP*	*DIF*	*PPL*
HKD	5.444	98.0	34,868	SHG	1.419	99.4	8,715
AMR	1.337	97.5	9,161	KYT	2.622	99.6	9,586
IWT	1.305	92.7	11,568	OSK	8.851	100.0	23,680
MYG	2.318	98.8	15,181	HGO	5.556	99.8	25,664
AKT	1.053	90.6	7,471	NRA	1.385	99.3	8,062
YMG	1.149	98.2	9,157	WKM	1.003	97.4	5,559
FKM	1.950	90.0	13,504	TTR	0.588	97.5	3,798
IBK	2.934	93.3	23,196	SMN	0.703	96.6	5,443
TCG	2.011	95.1	15,297	OKM	1.930	98.9	14,121
GNM	1.985	99.4	13,609	HRM	2.875	94.0	14,998
STM	7.208	99.7	28,044	YMG	1.422	93.2	8,039
CHB	6.185	94.9	27,857	TKM	0.771	96.4	5,159
TKY	13.237	100.0	28,387	KGW	0.984	99.2	8,101
KNW	9.061	99.9	25,751	EHM	1.441	92.7	8,647
NGT	2.332	99.2	16,701	KCH	0.756	92.6	3,780
TYM	1.077	92.9	8,049	FKK	5.076	93.5	23,072
IKW	1.158	98.8	9,043	SGA	0.853	94.9	6,260
FKI	0.811	96.0	6,465	NGS	1.396	98.4	7,079
YMS	0.864	98.0	5,165	KMT	1.801	86.6	8,913
NGN	2.119	98.9	17,247	OIT	1.179	90.9	6,071
GFU	2.056	95.8	14,208	MYK	1.123	97.1	8,215
SZK	3.717	99.2	21,692	KGM	1.702	97.2	10,786
ACH	7.416	99.8	37,142	OKW	1.408	100.0	7,955
MIE	1.872	99.6	14,259				

Notes: POP: water supply population (1×10^3); DIF: diffusion (%) and PPL: pipeline length (m).