An Overview of Functional Damage and Restoration Processes of Utility Lifelines in the 2016 Kumamoto Earthquake, Japan

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Key Facts

- Hazard Type: Earthquake
- Date of the disaster: April 14th and 16th, 2016
- Location of the survey: Kumamoto Prefecture
- Date of the field survey: April 15th through June 7, when needed.
- Survey tools: Documents published via press release or related websites, Interviews
- Key findings: 1) Functional damage and restorations of electric power supply, water supply and city gas supply systems were compiled for the 2016 Kumamoto Earthquake, Japan.
  2) The number of customers or households without lifeline services were graphically illustrated.
  3) Supplying ratios were graphically and geographically illustrated.

Key Words : *The 2016 Kumamoto Earthquake, utility lifelines, functional damage, initial outage, restoration process*

1. INTRODUCTION

From April 14 on, a series of earthquakes hit the central Kyushu area in Japan causing major damage primarily to Kumamoto Prefecture. Those earthquakes were collectively named as “The 2016 Kumamoto Earthquake” by Japan Meteorological Agency (JMA)[1]. Seven earthquakes marked JMA seismic intensity I_{JMA}=6 lower or greater at least one observation station (See Appendix A for I_{JMA}). Among them, two earthquake events occurred on April 14 21:26 (M_{JMA}=6.5) and April 16 1:25 (M_{JMA}=7.3) marked I_{JMA}=7, the highest rank in the JMA scale. Especially, the latter event caused severe damage to lifeline facilities due to ground shaking and ground failures.

In this paper, functional damage and restoration processes of utility lifelines including electric power supply, water supply, city gas supply are compiled[2),3)] on the basis of documents published via press release or related websites by the central government office[4),5)], related supervisory authorities[6),7)], local government offices[8)-10)] and service providers[11)-14)] and related association[14),15)].

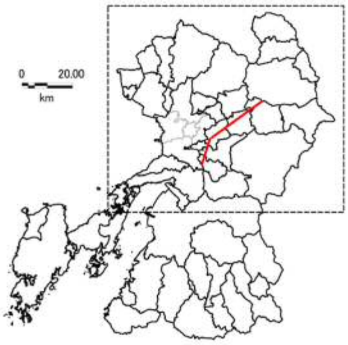
Figure 1 shows the location of Kumamoto Prefecture, its municipal boundary and the map focusing on the northern part mainly mentioned in this paper with the names of municipalities. Approximate locations of faults causing the two major events[16)] are also shown. The number of households and population (as of April 1, 2016) in selected municipalities in Kumamoto Prefecture are listed in Table 1.

Figure 2 shows the distribution of JMA seismic intensity, $I_{JMA.}$ The maximum value of observed seismic intensities throughout the seven earthquake events mentioned earlier was adopted as the representative intensity at each station. The maximum value of the representative intensities within in each municipality is shown in Fig.2.

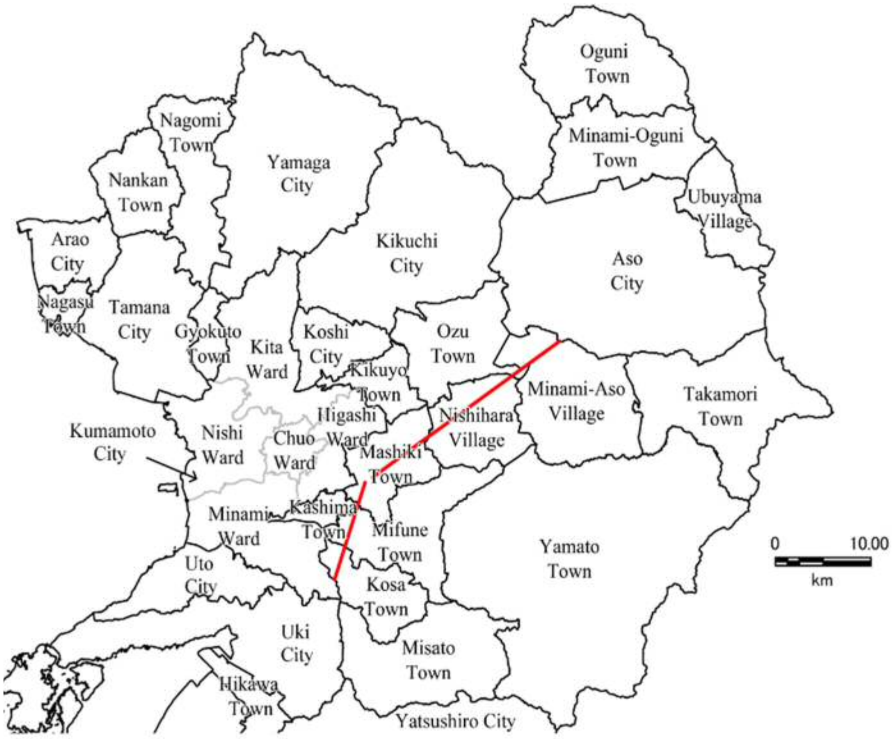
2. ELECTRIC POWER SUPPLY SYSTEM

The number of disrupted customers in terms of contracts of electric power supply compiled by

(a) Location of Kumamoto Prefecture



(b) Kumamoto Prefecture



(c) Municipalities around the source region

Fig.1 Kumamoto Prefecture and municipal boundary and approximate location of source faults of the 2016 Kumamoto Earthquake.

Table 1 The number of households and population in selected municipalities in Kumamoto Prefecture (April 1, 2016)[10].

Municipalities	Households	Population
Chuo Ward	95,876	186,016
Higashi Ward	78,593	190,298
Nishi Ward	38,996	92,779
Minami Ward	47,762	128,355
Kita Ward	55,239	142,543
Kumamoto City total	316,466	739,991
Kikuchi City	17,015	47,942
Uto City	13,324	36,934
Uki City	21,485	59,489
Aso City	10,048	26,839
Koshi City	20,843	58,867
Misato Town	3,576	10,191
Gyokuto Town	1,818	5,253
Ozu Town	12,857	33,701
Kikuyo Town	16,088	41,197
Ubuyama Village	532	1,495
Takamori Town	2,442	6,243
Nishihara Village	2,358	6,792
Minami-Aso Village	4,693	11,453
Mifune Town	6,307	17,189
Kashima Town	3,198	9,049
Mashiki Town	11,534	33,748
Kosa Town	3,701	10,578
Yamato Town	5,549	14,939
Subtotal	157,368	431,899
Others	231,802	607,864
Prefectural total	705,636	1,779,754

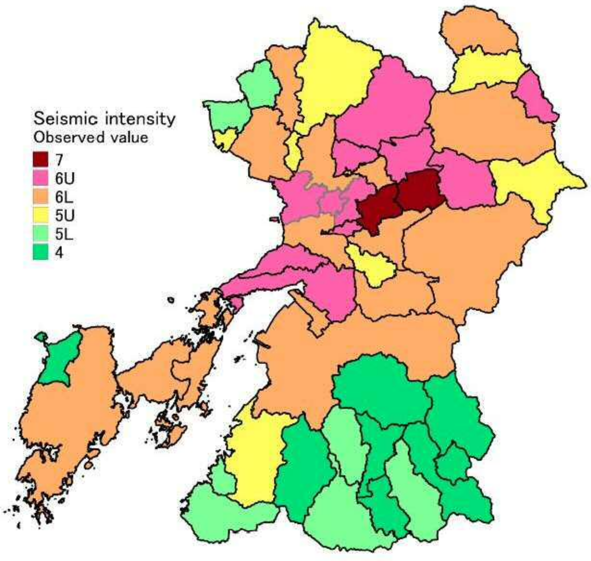


Fig.2 Distribution of JMA seismic intensity, I_{JMA}.

Kyushu Electric Power Co., Inc.[11] is employed in this paper. Figure 3 shows the relationship between the number of customers and that of households[10] in each municipality in Kumamoto Prefecture according to April 2016 statistics. It should be noted that the former is approximately 1.54 times as many as the latter.

Figure 4 shows the number of customers without electric power supply at each time point when data could be obtained. The data for the entire Kyushu Prefecture (partially including other surrounding prefectures at the peak of April 16, 2am) and the

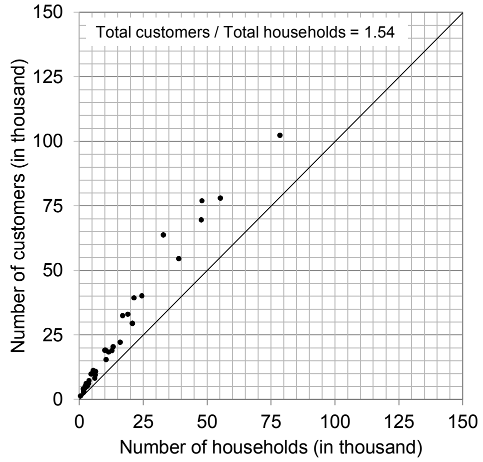
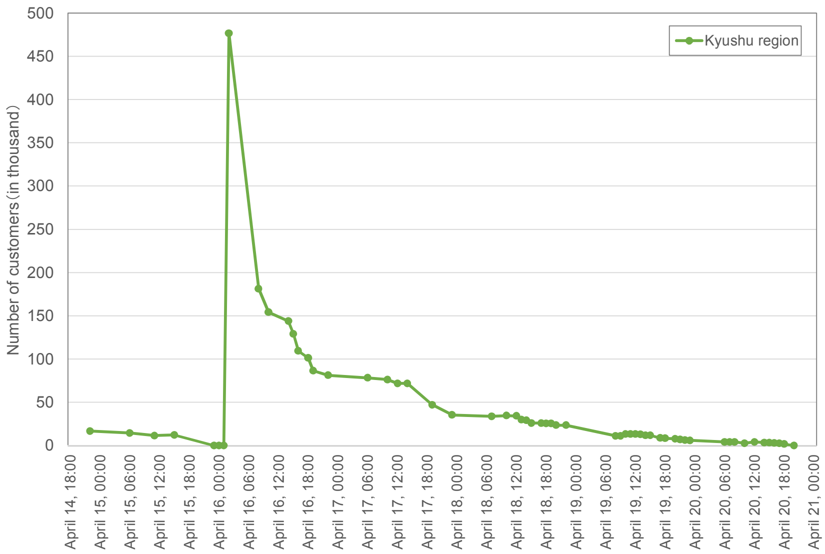
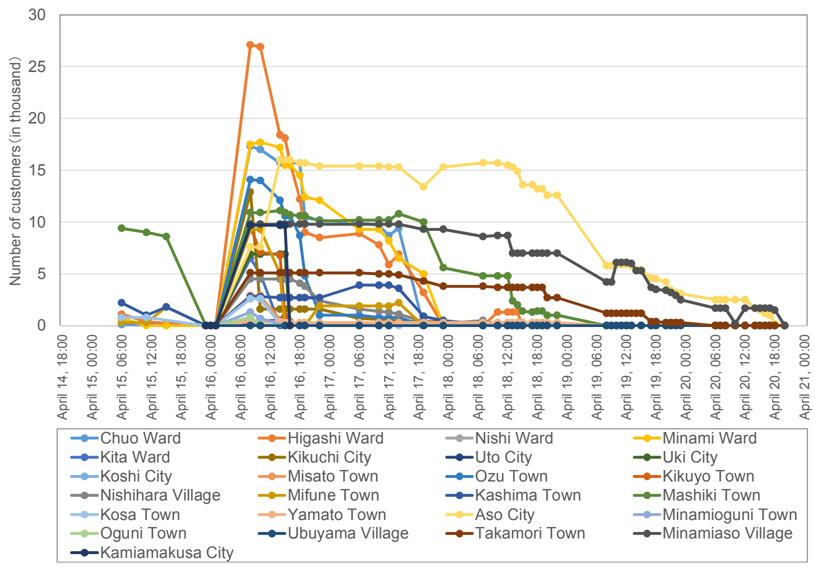


Fig.3 Relationship between the number of households and that of customers of electric power supply in municipalities in Kumamoto Prefecture.



(a) Kumamoto Prefecture (Including surrounding prefectures only at the peak at April 16, 2 am).



(b) Selected municipalities in Kumamoto Prefecture (Data not available at several data points including the peak at April 16, 2 am).

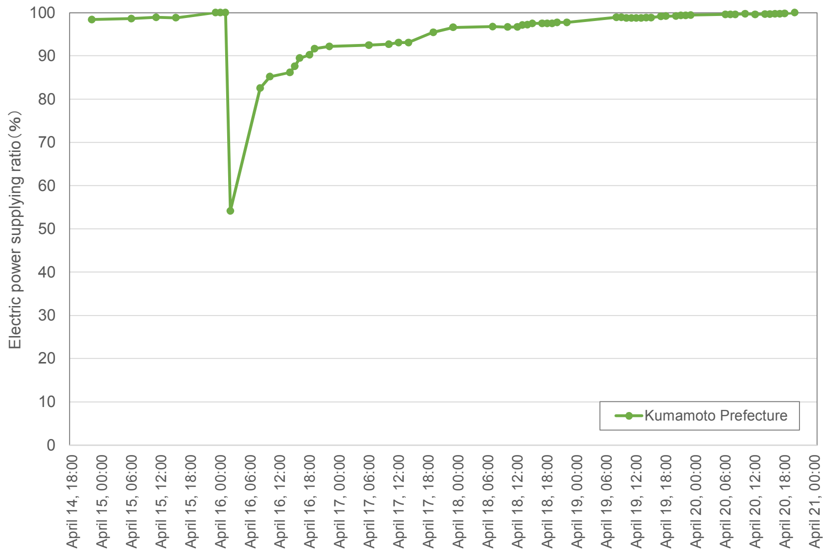
Fig.4 Number of customers without electric power supply in Kumamoto Prefecture.

breakdown for selected municipalities in Kumamoto Prefecture are shown.

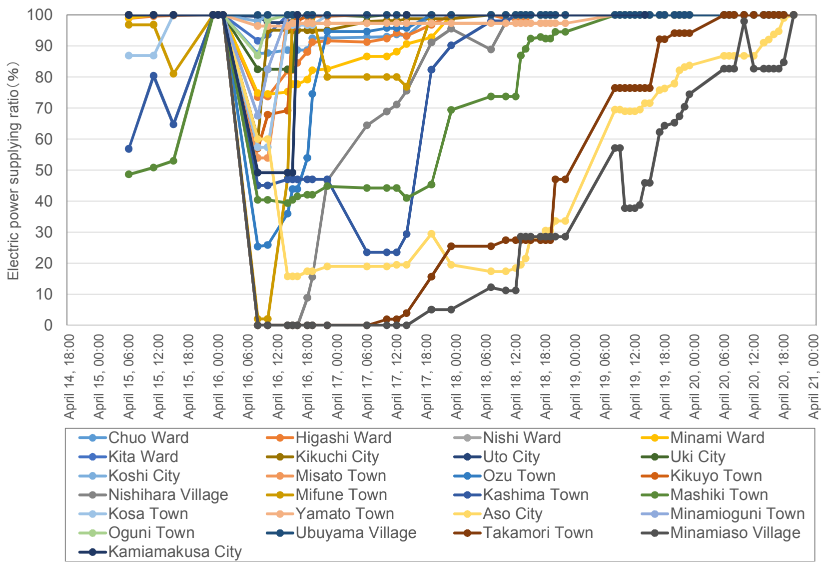
Figure 5 shows the electric power supplying ratios. The electric power supplying ratio was calculated as the fraction of the number of customers with electric power supply to the total number of customers. Figure 6 shows the spatial distribution of the electric power supplying ratios.

The maximum number of disrupted customers by the earthquake event on April 14 was 16.7 thousand (as of April 14, 22:00). At this point, the affected area was limited to near-source region. The earthquake event on April 16, however, caused power outage of 476.6 thousand customers (as of April 16, 2:00). Detailed data with regard to prefectural and municipal breakdown of initial power outage have not been reported, although the most part is considered to be in Kumamoto Prefecture.

As of April 16, 8:00 (6.5 hours after the event), the number of customers without power supply was rapidly reduced to 181.3 thousand (Kumamoto Prefecture: 180.4 thousand, Oita Prefecture: 0.7 thousand, Miyazaki Prefecture: 0.2 thousand) by rerouting operation. Twenty-four municipalities in Kumamoto Prefecture account for 99.5% of the total outage. The principal municipalities suffering power outage were Higashi Ward, Minami Ward and Chuo Ward of Kumamoto City, followed by Aso City, Ozu

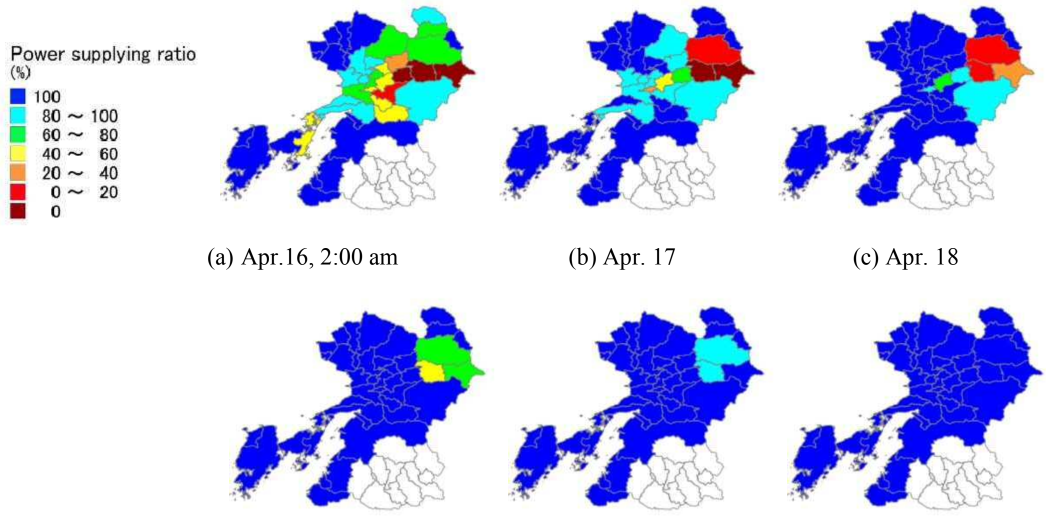


(a) Kumamoto Prefecture (Including surrounding prefectures only at the peak at April 16, 2am).



(b) Selected municipalities in Kumamoto Prefecture (Data not available at several data points including the peak at April 16, 2 am).

Fig.5 Electric power supplying ratios in Kumamoto Prefecture.



(a) Apr.16, 2:00 am (b) Apr. 17 (c) Apr. 18

(d) Apr. 19 (e) Apr. 20 (f) Apr. 21

Fig.6 Distributions of electric power supplying ratios in Kumamoto Prefecture.

Town, Kikuchi City and Mashiki Town.

Functional recovery was relatively rapid at Kumamoto City and the municipalities far away from the source region. The number of customers without power supply as of April 17, 23:00 was 38.4 thousand in eight municipalities including Aso City, Minami-Aso Village, Mashiki Town, Takamori Town, Kashima Town and Nishihara Village in descending order of the number of disrupted customers. In Kumamoto region, it was reported that functional recovery was completed at 22:00 of April 18 in Yamato Town and Mashiki Town except for hardest-hit area where recovery works cannot be conducted due to damage to dwelling houses or surface road[11].

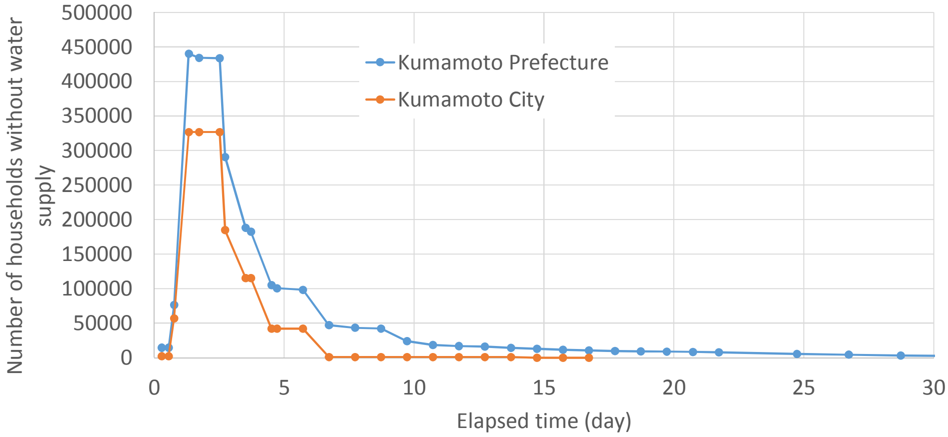
On the contrary, in some part of Aso region (Aso City, Takamori Town and Minami-Aso Village), functional recovery was further delayed because of damage to 66KV transmission line caused by massive landslides and ground failures in Minami-Aso Village. Provisional recovery was completed at 19:10 of April 20 using high voltage electric power generating vehicles. In total, 162 cars (52 cars owned by Kyushu Electric Power Co., Inc. and 110 cars provided by nine other electric power companies) were prepared and 148 cars were directly connected to high voltage distribution line[11]. Construction works of temporary transmission lines were conducted in parallel and completed on April 27. As a result, electric power supply via transmission lines as usual was finally established at 21:36 of April 28.

3. WATER SUPPLY SYSTEM

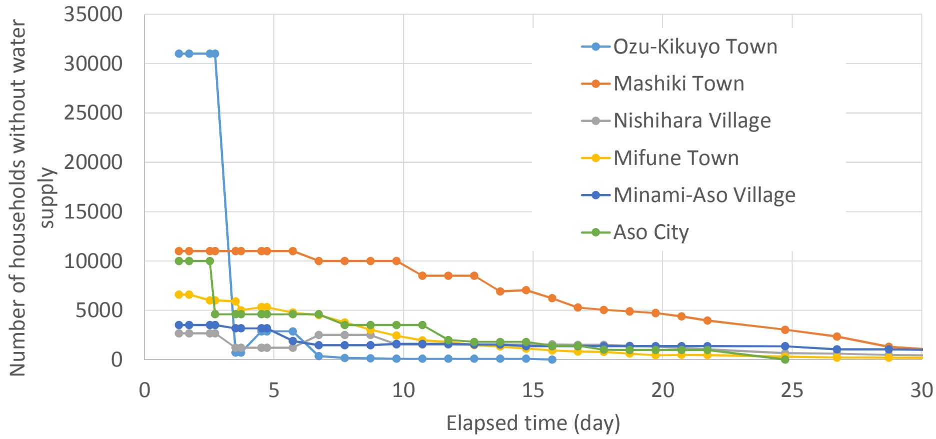
The number of disrupted households compiled by Kumamoto Prefectural Government[8] is graphed with respect to the elapsed time after the earthquake on April 14. The maximum number of disrupted households, the expected restoration time, and the number of emergency water tank trucks complied by the Ministry of Health, Labour, and Welfare (MHLW)[6] are also considered in this paper. Similar to the electric power supply system, the water supplying ratio was calculated using the number of households with water supply and the total number of households based on data compiled by Kumamoto Prefecture[10] as of April 2016.

According to the MHLW, the water supply system was interrupted for approximately 445 thousand households in total, and 97% of them were concentrated in Kumamoto Prefecture (Kumamoto Prefecture: 432 thousand, Oita Prefecture: 10 thousand, Miyazaki Prefecture: 2.8 thousand, etc.). The principal municipalities of water supply disruption were Kumamoto City (327 thousand), Ozu-Kikuyo Town (31 thousand), Mashiki Town (11 thousand), and Aso City (10 thousand).

Figures 7 and 8 show the number of households without water supply, and the water supplying ratios with respect to the elapsed time after the earthquake event on April 14, respectively. Figure 9 shows the spatial distribution of the water supplying ratios. The water supplying ratio increased rapidly in Kumamoto City and Ozu-Kikuyo Town. It should be noted that the households where the water was supplied on a trial basis were excluded from the number of households without water supply in Kumamoto City. Hence, the water supplying ratio in Kumamoto City might show some differences from the actual situations. Night-time water cut was conducted to cope with water leakage and shortage of water thereby in several municipalities.



(a) Kumamoto Prefecture and Kumamoto City



(b) Selected municipalities in Kumamoto Prefecture

Fig.7 Number of households without water supply in Kumamoto Prefecture with respect to the elapsed time after the earthquake on April 14.

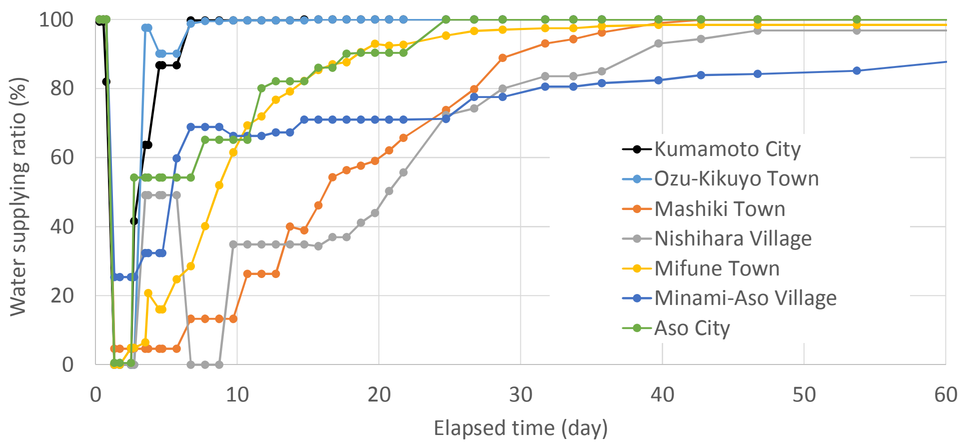


Fig.8 Water supplying ratios in selected municipalities in Kumamoto Prefecture with respect to the elapsed time after the earthquake on April 14.

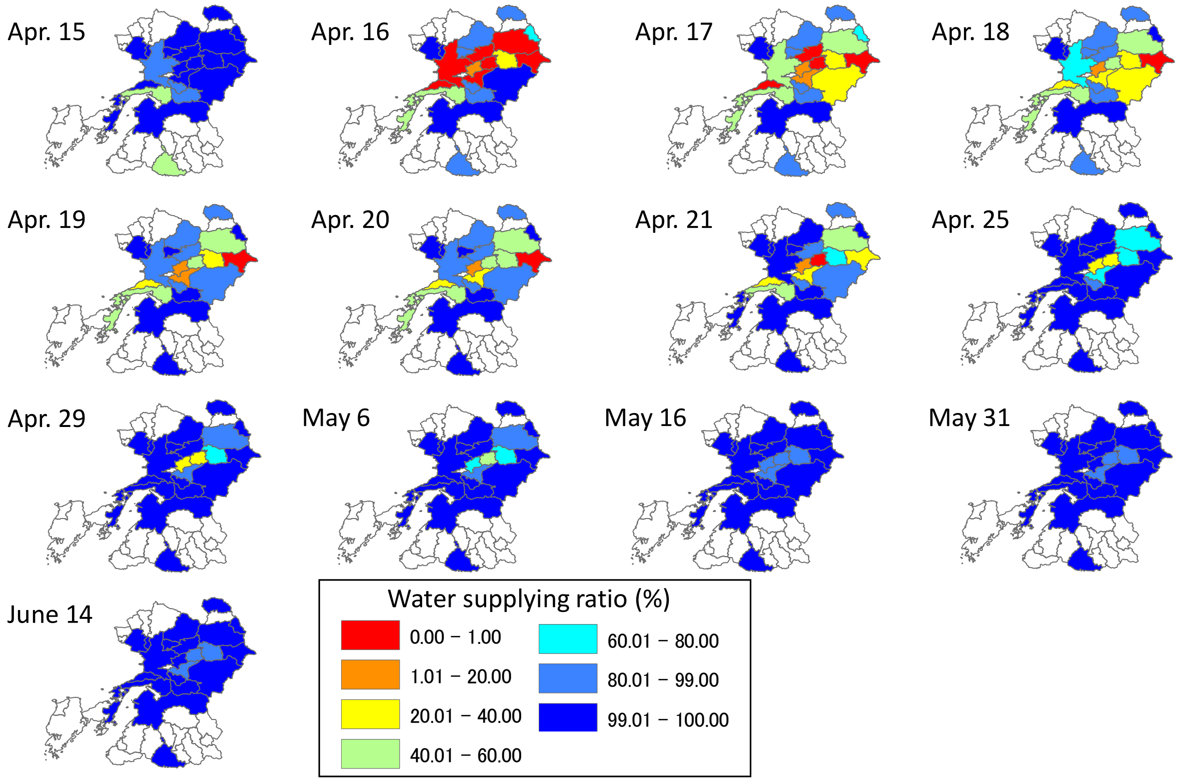


Fig.9 Spatial distribution of water supplying ratios in Kumamoto Prefecture.

Also in Ozu-Kikuyo town, water supply function was instable due to reduced water pressure during the restoration process.

Turbid water of water resources was another problem. Eleven municipalities in Kumamoto region take underground water usually potable without filtration process. There are cases that people were cautioned that delivered water was not necessarily adequate for potable use.

The severely affected municipalities, which are Mashiki Town, Nishihara Village, Mifune Town, Minami-Aso Village, and Aso City, show lower supplying ratios with respect to the elapsed time after the earthquake.

The MHLW[6)] started reporting the expected restoration time on April 23 (Fig.10). They set the three classifications: short term (approximately a week), mid-and-long term (more than two weeks) and temporary exclusion from restoration plan. The water supply for 740 households in Mashiki Town, 706 households in Minami-Aso Village, 140 households in Nishihara Village, and 98 households in Mifune Town (accounting for 6.5%, 20.3%, 5.3% and 1.5% of the total disrupted households, respectively) was planned to be restored in accordance with the reconstruction of the stricken areas because they were built in the heavily affected areas by the earthquake (as of May 18).

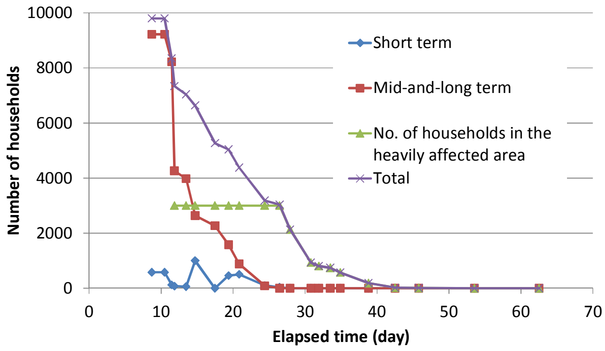
Figure 11 shows the number of emergency water tank trucks deployed in the affected areas[6)]. 108 water tank trucks were operated from April 21 to April 26, and the number of trucks decreased in accordance with the recovery of water supply.

4. CITY GAS SUPPLY SYSTEM

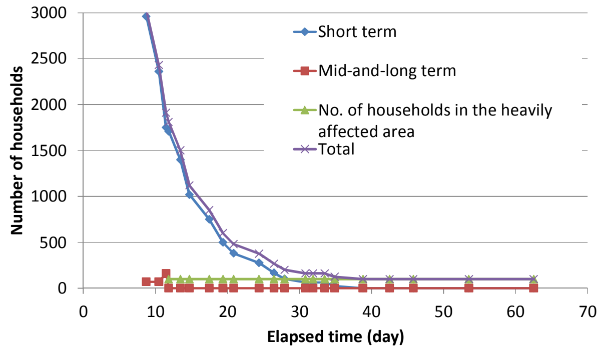
The number of disrupted houses compiled by Saibu Gas Co., Ltd. [12)] is employed in this paper. The number of customers of Saibu Gas Co., Ltd. in Kumaoto Prefecture is 112,771 (Household: 105,167, Commercial: 5,743, Industrial: 122, Others: 1,739) as of 2014. The locations of gas-supply blocks were also available at the web site of Saibu Gas, Co., Ltd. [12)] (Fig.12). The gas-supply area in Kumamoto Prefecture is divided into the seven blocks. The gas-supply area covers a small part of Mashiki Town, where severe ground motion of I_{JMA}=7 was observed. In the heavily affected area in Mashiki Town, the LP gas is supplied.

The gas supply was disrupted for 1,123 households after the earthquake on April 14. The gas supply was recovered for 645 households at 20:00 on April 15, and the associated recovery rate was 57.4%. The gas supply was interrupted for 100,884 households after the earthquake on April 16. There are 16 SI sensors equipped with city gas supply facilities. SI values at fifteen of them exceeded 60 kine which is a criterion for emergency shutoff of city gas supply[9),13)].

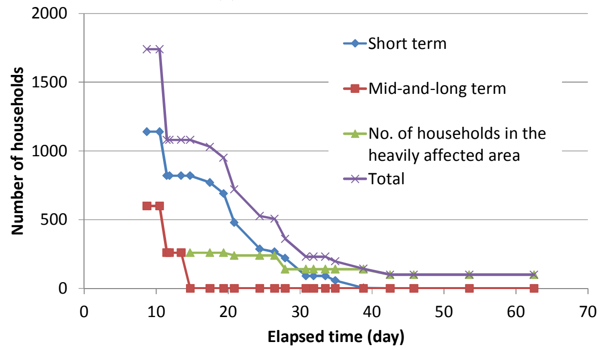
Figure 13 shows the number of disrupted households with respect to the elapsed time after the event on April 14. The gas supplying ratios were



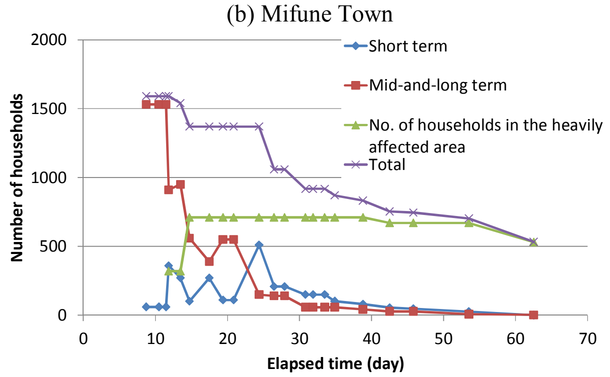
(a) Mashiki Town



(b) Mifune Town



(c) Mishihara Village



(d) Minami-Aso Village

Fig.10 Expected restoration time of water supply and the number of households whose water supply was planned to be restored in accordance with the reconstruction of the stricken areas.

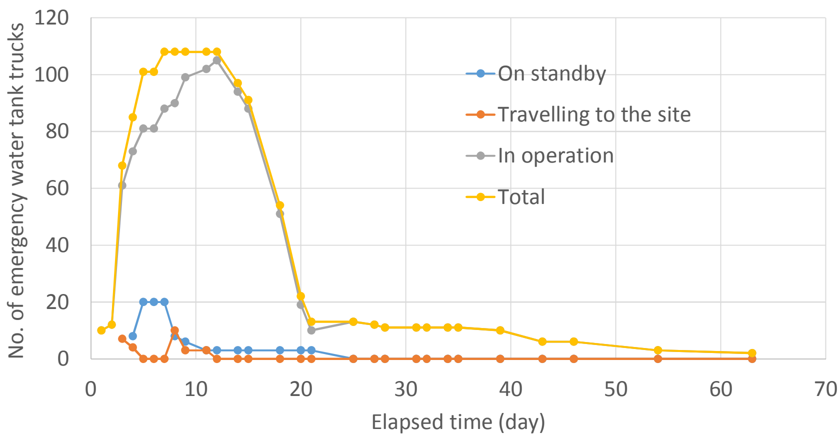


Fig.11 Number of emergency water tank trucks deployed in the affected areas.

calculated with respect to the elapsed time. According to Saibu Gas Co., Ltd. and the Japan Gas Association (JGA)[14], the gas supply was not disrupted for the approximately 1,100 households in Block 201, and 500 households in Block 207. These are special district where gas shutoff is conducted at SI value over 80 kine. It is considered that city gas supply can be supplied safely enough because both gas pipelines and buildings in these districts are earthquake-resistant. The gas supply was totally interrupted in other gas-supply blocks after the earthquake on April 16 (Figs.14 and 15).

The eight major hospitals where gas is supplied through middle pressure pipelines received priority responses, and they were restored on April 16 and 17. After completing restoration work of mid-pressure B pipelines on April 18, prioritized restorations were conducted for customers supplied via mid-pressure line: 24 facilities, 7 facilities and 4 facilities on April 18, 19 and 20, respectively. In total, supply to 43 facilities were completed by April 20.

The number of disrupted households decreased rapidly because the damage to gas pipes was not extensive. Saibu Gas Co., Ltd. initially expected to complete restoration work on May 8. The restoration time was shortened, and the gas supply was totally recovered at 13:40 on April 30. According to the JGA, the number of emergency response workers

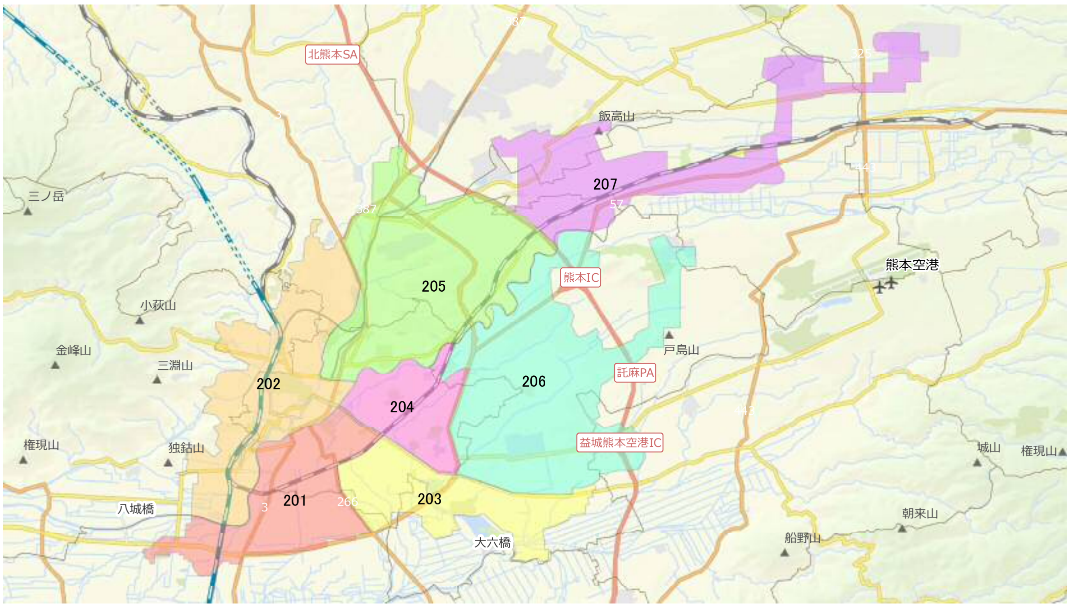
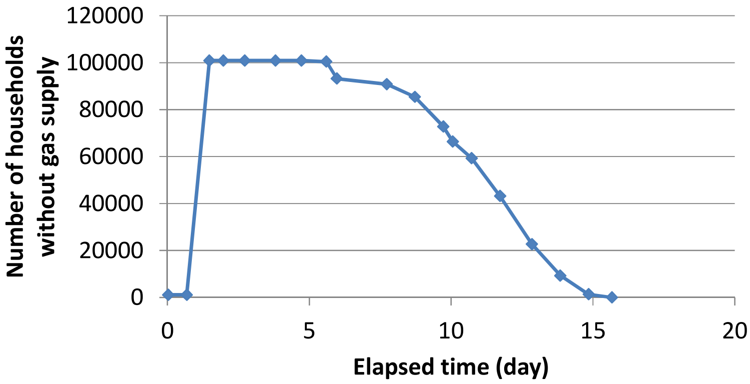
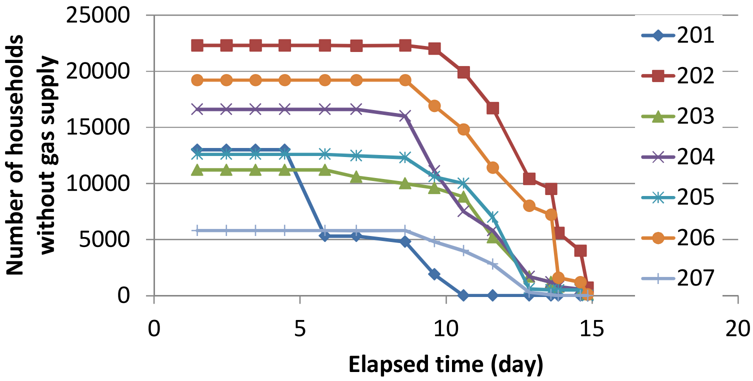


Fig.12 Locations of gas-supply blocks in Kumamoto Prefecture deployed by Saibu Gas Co., Ltd.



(a) Entire of the area supplied by Saibu Gas Co., Ltd.



(b) Gas-supply blocks

Fig.13 Number of disrupted households with respect to the elapsed time after the event on April 14

increased gradually, and it shows the largest value of 4,641 (Saibu Gas Co., Ltd.: 1,965, Assistance from other gas companies organized by JGA: 2,676) on April 25 (Fig.16).

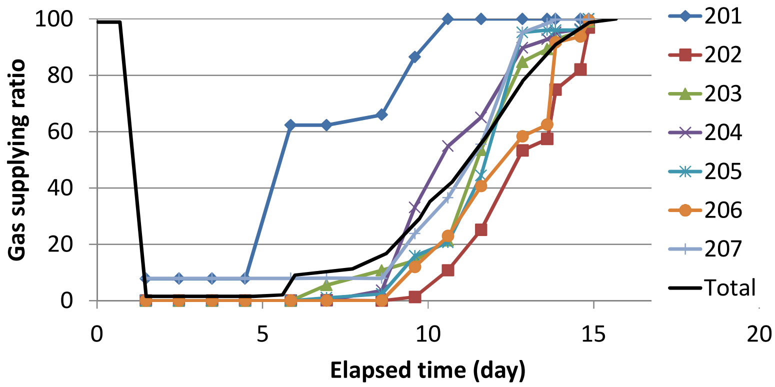


Fig.14 Gas supplying ratios with respect to the elapsed time after the earthquake on April 14.

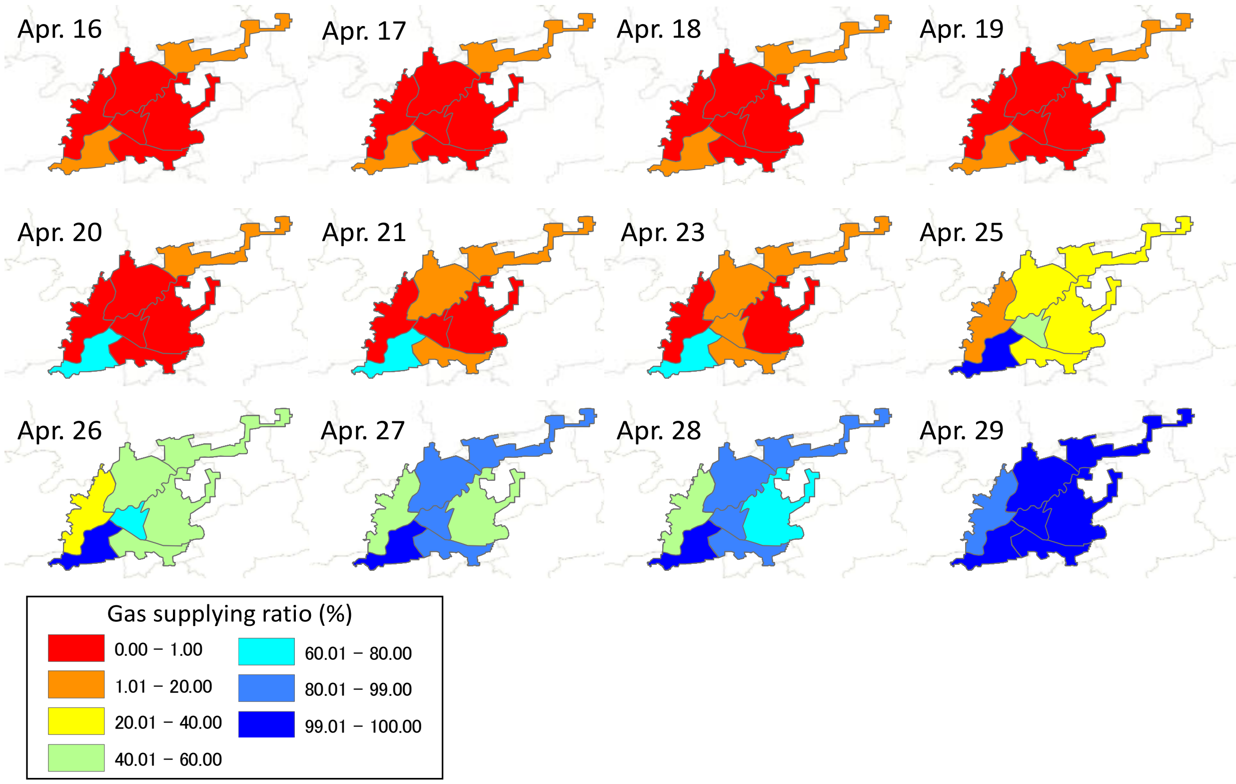


Fig.15 Spatial distribution of gas supplying ratios in the area supplied by Saibu Gas Co., Ltd.

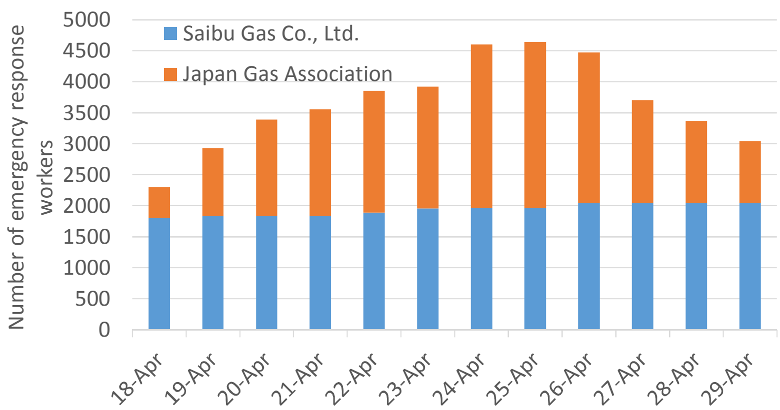


Fig.16 Number of emergency response workers of Saibu Gas Co., Ltd. and those sent off by Japan Gas Association.

5. CONCLUDING REMARKS

In this paper, functional damage and restorations of three utility lifelines, i.e., electric power supply system, water supply system and city gas supply system in Kumamoto Prefecture were compiled for the 2016 Kumamoto Earthquake, Japan. Major outputs of this study are listed below.

1) The number of customers or households without lifeline services were graphically illustrated on prefectural and municipal basis.
2) Supplying ratios defined as the fraction of the number of customers or households to the total were graphically and geographically illustrated on prefectural and municipal basis.
3) Spatial distributions of supplying ratios on municipal basis were also illustrated by geographical maps.

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APPENDIX A JMA SEISMIC INTENSITY

JMA seismic intensity, I_{JMA}, is calculated based on two horizontal and vertical components of strong motion accelerograms processed with the band-pass filter prescribed by JMA[17]. Discrete ranks of the JMA seismic intensity are derived by rounding the continuous values into the 10-fold intensity scale ranging from 0 to 7. **Figure A1** compares I_{JMA} and I_{mm} (Modified Mercalli intensity) using the Eq.(A1) proposed by Shabestari and Yamazaki[18] and Eqs. (A2) and (A3) proposed by Wald et al.[19].

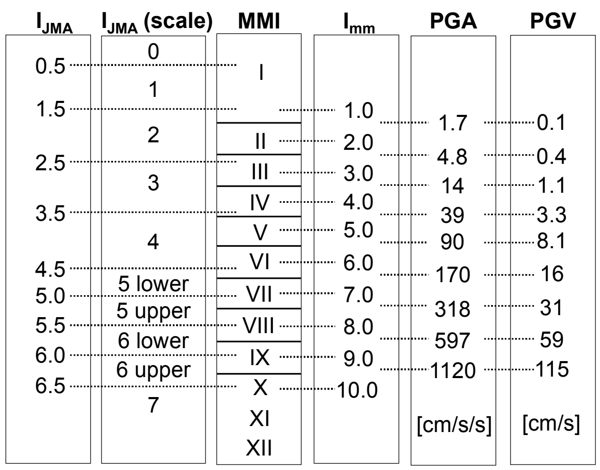

Fig.A1. Relationship between I_{JMA} (JMA seismic intensity) and I_{mm} (Modified Mercalli intensity). (after Shabestari and Yamazaki[18] and Wald et al.[19])

$$I_{mm} = 1.81 \cdot I_{JMA} - 1.95 \tag{A1}$$

$$I_{mm} = \begin{cases} 2.20 \cdot \log PGA + 1.00 & (PGA < 66.4) \\ 3.66 \cdot \log PGA - 1.66 & (PGA \geq 66.4) \end{cases} \tag{A2}$$

$$I_{mm} = \begin{cases} 2.10 \cdot \log PGV + 3.40 & (PGV < 5.8) \\ 3.47 \cdot \log PGV + 2.35 & (PGV \geq 5.8) \end{cases} \tag{A3}$$

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