Emergency Responses to Debris Flow Disaster at Serizawa District, Nikko City Triggered by the 2015 Torrential Rains in the Kanto and Tohoku Region

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In September 2015, torrential rain hit the Kanto and Tohoku regions causing debris flow in seven mountain streams in the Serizawa District of Nikko City, Tochigi Prefecture, where the greatest rainfall was observed in recorded history. As a result seven houses were completely or partially destroyed and the municipal road was cut off by sediment runoff from the mountain streams. River bed aggradation and swelling of the main Serizawa River eroded river banks and partly washed away the municipal road. As a result, 25 inhabitants from 14 households were temporarily isolated in an upstream village. The Nikko Sabo Office of the Ministry of Land, Infrastructure, Transport and Tourism, immediately began to investigate the damage caused in the Serizawa District. Based on the results of the investigation we first made emergency repairs to the road followed by construction of temporary water channels to divert the water flow from the mountain streams. As the next step, we set up monitoring equipment and created a system to alert vehicles and people traveling on the road of the impending dangers. With these efforts we were able to ensure immediate safety until more permanent measures were constructed.

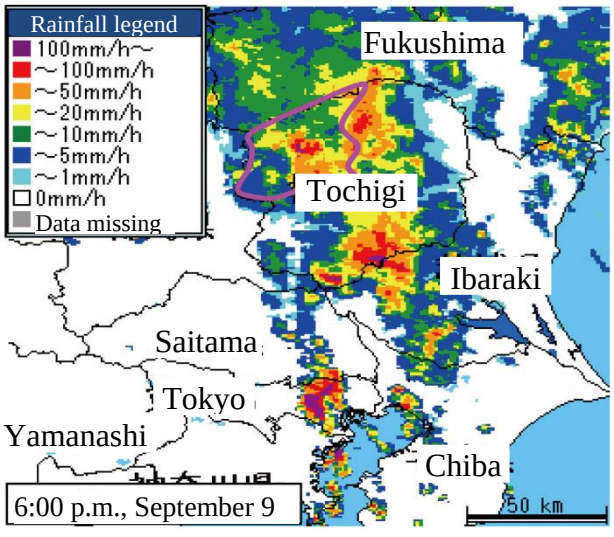
Key words: torrential rains, debris flow, emergency reactions, effects of erosion control facilities

1. INTRODUCTION

In September 2015, torrential rains hit the Kanto and Tohoku regions (hereinafter "the torrential rains"). After Typhoons No. 17 and 18, the resultant atmospheric depression brought record rainfall to the Kanto and Tohoku regions.

In the Kinugawa Basin, which connects with the Tone River, flood damage spread extensively throughout Ibaraki Prefecture, located downstream. Worse, floods and landslides killed and injured people and damaged numerous houses in an upstream area of Tochigi Prefecture resulting in a major disaster.

The following reports the debris flow disaster in the Serizawa District, Nikko City, Tochigi, and the emergency actions taken to counteract it.



*The Nikko City area is highlighted with the pink line.

Fig. 1 Changes in radar rainfall (6:00 p.m., September 9)

2. OUTLINE OF THE DISASTER

2.1 Weather

From the 9th to the 11th in September 2015, southerly winds flowed into the atmospheric depression, which resulted from Typhoon No. 18. In addition, moist air persistently flowed in from the southeast winds around Typhoon No. 17. This led to numerous and continued occurrences of north-south linear rainfall zones from the Kanto to the Tohoku regions (**Fig. 1**), resulting in record rainfall.

Located upstream in the Kinugawa River Basin, Nikko City, Tochigi, suffered more from the torrential rains than most other parts of the country, with the total rainfall ranging between 500 and 600 millimeters or more. Three AMeDAS observation points in Nikko City confirmed the greatest daily rainfall in recorded history (**Fig. 2**) [*Japan*

Meteorological Agency, 2015].

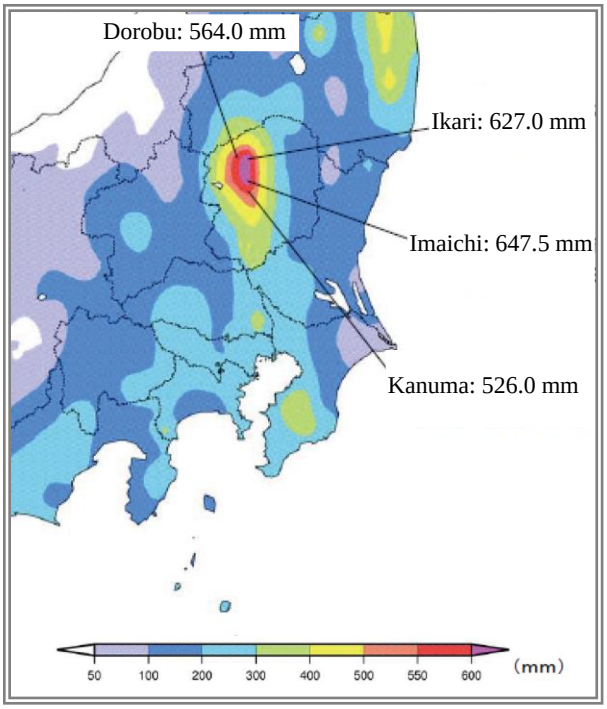


Fig. 2 Overall rainfall distribution (September 7 to 11, 2015) [*Japan Meteorological Agency*, 2015]

2.2 Damage

Tochigi Prefecture, located upstream from the basin, saw more than 500 cases of sediment-related damage mainly in Nikko City and Kanuma City, because these cities had an especially large rainfall. One person was killed and one person was injured in Kanuma City and two people were injured in Nikko City. Some inhabited houses were damaged. The network of roads, railroads and other means of transport were cut off. Some inhabitants were temporarily isolated. Many parts of Tochigi Prefecture were damaged by flooding and other events. The torrential rains caused an enormous amount of damage: three deaths, six injured persons, approximately one thousand houses completely or partially destroyed and approximately five thousand houses flooded in the entire prefecture [Cabinet Office, 2016; Secretariat Office of Tochigi Disaster Control Headquarters, 2015; Secretariat Office of Tochigi Disaster Control Headquarters, 2016].

3. DEBRIS FLOW DISASTER IN THE SERIZAWA DISTRICT, NIKKO CITY

3.1 Information about the Serizawa District

A debris flow disaster occurred in Serizawa District, an area located in Nikko City, which has villages and shares the northern border with

Fig. 3 Location of Serizawa District, the affected district

*This map is based on the 1:1,000,000 INTERNATIONAL MAP published by Geospatial Information Authority of Japan

Fukushima Prefecture (**Fig. 3**).

Seventy-one people from 33 households live in Serizawa District [*Uenaka*, 2016], including some younger people. However, aging and depopulation is progressing in this area.

3.2 Topography and geology of the Serizawa District

3.2.1 Topography

Serizawa District has a mountainous river with an average bed slope of 1/17 that flows down to its confluence where it joins the Ojika River, a main branch of the Kinugawa River. The river flows from its source, with a river basin area of 22.8 square kilometers and a channel length of 11.8 kilometers, sitting at an altitude higher than 1,500 meters, down to a midstream area of the Ojika River nearly 600 meters above sea level. Villages in the Serizawa District are distributed in a downstream valley.

The torrential rains brought debris disasters to seven mountain streams that flow into Serizawa District from behind the villages located along the downstream left bank. Six of these mountain streams are designated as the sediment disaster hazard area. The slopes of the beds in these mountain streams are steep, ranging between 1/6 and 1/3. Most of the mountain streams are small, with a watershed area smaller than 1 square kilometer.

3.2.2 Geology

In terms of geology, Paleogene granites are mainly distributed in the Serizawa District Basin. Slope failures and sediment runoff resultant from

weathering and other phenomena are recognizable and volcanic rocks such as Neogene rhyolite can be found in some areas.

3.3 Weather in Serizawa District

Fig. 4 shows the rainfall before and after the disaster, recorded at the MLIT Nakamiyori Precipitation Station located nearly one kilometer from the Serizawa District. The total amount of rainfall is 603 millimeters (4:00 p.m., September 6 to 10:00 p.m., September 10) with the maximum rainfall per hour of 57 millimeters (2:00 – 3:00 a.m., September 10), both were the highest in recorded history.

Heavy rainfall of over 50 millimeters continued for more than ten hours from the afternoon of September 9 until the early hours of September 10. The cumulative rainfall also rose sharply.

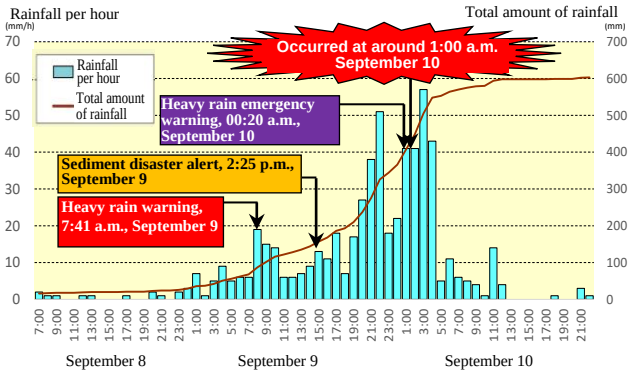


Fig. 4 Rainfall recorded at the MLIT Nakamiyori Precipitation Station (September 8 - 10, 2015)

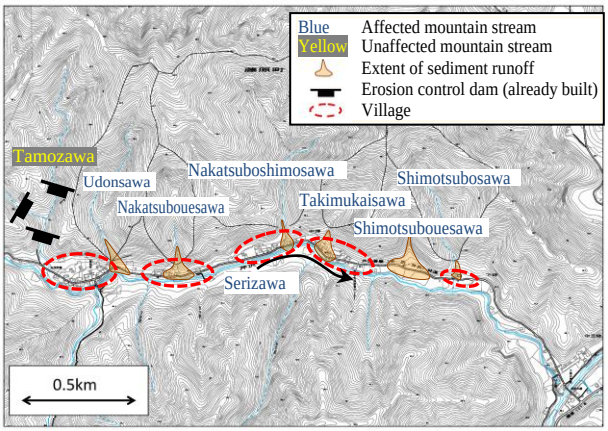


Fig. 5 Planimetric map of Serizawa District

3.4 Damage in the Serizawa District

Before dawn on September 10, debris flows from the seven mountain streams in Serizawa District affected the villages and the damage extended over six of the mountain streams: among the seven, only Tamozawa was unaffected (**Fig. 5**). In Shimotsubosawa, Takimukaisawa and Nakatsuboshimosawa, seven houses were completely or partially destroyed, or washed away (**Fig. 6**).

In Takimukaisawa, two people were injured and their houses were washed away. Debris flows completely or partially destroyed many houses. Luckily there were no deaths. Later we interviewed the inhabitants. “The house tilted after being hit by a debris flow. I was shocked and jumped out of the house.” “A fallen beam fell onto the bed board where it stopped, which created a space and saved me.” “I was covered in mud up to my waist. Somehow I managed to crawl out by following the directions of my neighbors. This is how I survived.” These are some of the stories from the inhabitants whose houses were completely destroyed. Considering these stories, it was clearly miraculous that there were no deaths.

(a)

(b)

Fig. 6 Damage in Takimukaisawa, Serizawa District
(a) Sediment and driftwood run off
(b) A damaged house (two people injured and three houses completely destroyed)

Sediment runoff from the mountain streams cut off traffic on the municipal road. River bed aggradation and swelling of the main river of Serizawa eroded river banks and partly washed away the municipal road (**Fig. 7**). Lifeline utilities installed along the municipal road, such as electric, telephone (land line and mobile), water and communication lines were also severed and 25 inhabitants in 14 households were temporarily isolated in an upstream village [*Uenaka*, 2016; *Nikko City, Tochigi prefecture*, 2016].

3.5 Sediment runoff

3.5.1 Sediment movement in the mountain streams

Traces of sediment production phenomena such as slope failures, longitudinal erosions, gully erosions and bank collapses were recognizable in the mountain streams. These phenomena occurred from torrential rains and the resultant swelling of the water. The swollen water may have combined with the sediment before turning into a debris flow (**Fig. 8**).

Fig. 7 Municipal road washed

Headwaters in Shimotsubouesawa

Fig. 8 Sediment production

Each of the seven mountain streams from which the debris flow occurred lacked gigantic stones and the accumulation of many substances such as fine grains and breccia with particle sizes ranging between 10 and 40 centimeters were identified. A large quantity of driftwood washed away and accumulated in all of the affected areas excluding Shimotsubosawa. Because there was no evidence of deep erosion like exposed bedrock, with the exception of the upper part, we inferred that sediment movement mainly took the form of sediment flow (**Fig. 9**) [*Sakurai*, 2015; *Kanto subgroup of the Japan Society of Civil Engineers/Japanese Geotechnical Society collaborative group for investigation of the 2015 Kanto and Tohoku torrential rain disaster*, 2016; *Sabo Department, National Institute for Land and Infrastructure Management and Erosion and Sediment Control Research Group, Public Works Research Institute*, 2015].

According to interviews with the inhabitants, the sediment runoff occurred in Takimukaisawa around 4:00 a.m. on September 10, in Nakatsuboshimosawa

Shimotsubosawa

Fig. 9 Sediment runoff

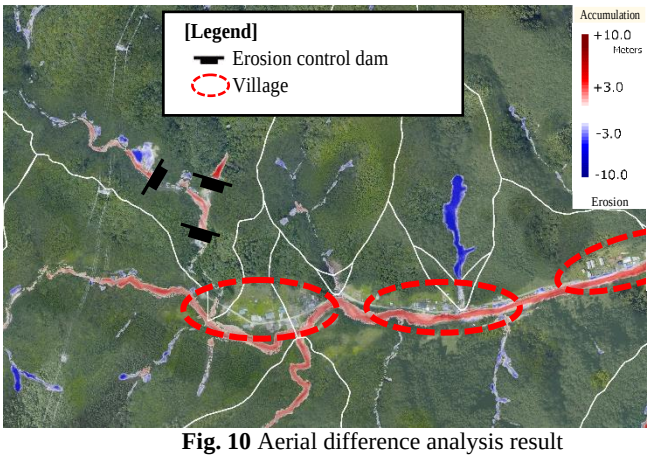


Fig. 10 Aerial difference analysis result

(a)

(b)

Fig. 11 Effect of an erosion control facility (Tamozawa Erosion Control Dam 1)
(a) Before catching the debris flow (August 18, 2015)
(b) After catching the debris flow (September 26, 2015)

around 5:20 a.m. and three times in Udonsawa, at 00:47 a.m., 2:17 a.m. and 3:20 a.m.

3.5.2 Extensive sediment movement

Fig. 10 shows the result of an analysis of the difference between the aerial laser survey measurements obtained in the Serizawa District Basin in 2012 and those obtained right after last year's disaster. The degree of damage is classified according to shades of colors, with accumulations indicated in red and erosions in blue. Upstream areas of the mountain streams, characterized by their steep slopes, underwent sediment runoff due to slope failures and bank erosions, while sediment accumulation is obvious in the downstream areas of the mountain streams, characterized by mild slopes, as well as the main river of Serizawa and the erosion control facilities. Sediment accumulation was remarkable in the main river of Serizawa, where the river bed rose locally three to four meters at its maximum.

Concerning the sediment balance, erosions and accumulations amounted to nearly 876 thousand cubic meters and 689 thousand cubic meters, respectively in the Serizawa District Basin overall (the sediment amount controlled by the eight existing erosion control dams was approximately 140 thousand cubic meters). We inferred that nearly 187 thousand cubic meters of sediment might have entered the Ojika River. Considering that the last survey measurements before the disaster were obtained in 2012, the amount of sediment movement described above may or may not be attributable to the torrential rains. But it may serve as reference data for understanding the tendency of sediment runoff because no significant flood had occurred during the period between 2012 and when the torrential rains came.

3.6 Effects of erosion control facilities

Debris flows also occurred in Tamozawa. Three erosion control dams are in operation (one impermeable dam under the control of Tochigi Prefecture and two steel-permeable dams under the control of the Ministry of Land, Infrastructure, Transport and Tourism). These dams caught and controlled sediment and driftwood and prevented the damage from extending to the village located below. The sediment caught by the steel-permeable erosion control dams was relatively small in size, but was blocked by things such as driftwood, rootstock and small particle gravel (**Fig. 11**).

3.7 Evacuation warning

3.7.1 Issuances of weather warnings, etc.

As shown in **Fig. 4**, Utsunomiya Local Meteorological Office issued a heavy rain warning (sediment disaster) for Nikko City at 7:41 a.m., on September 9. It issued a sediment disaster alert at 2:25 p.m. on the same day with Tochigi Prefecture. A heavy rain emergency warning was issued at 00:20 a.m., on September 10, throughout the entire Tochigi Prefecture.

3.7.2 Issuances of evacuation advisories, etc. in Serizawa District

Concerning the torrential rains, sediment disaster alert was issued for Nikko City at 2:25 p.m., on September 9. According to the real-time landslide risk map, the grid corresponding to Serizawa District showed no excessive risk above the standard for sediment disaster alert. For this reason, the local government of Nikko City (Disaster Control Department) did not issue an evacuation advisory or similar for Serizawa District.

When a heavy rain emergency warning was issued at 00:20 a.m., on September 10, a wide area of Nikko City was hit by torrential rain after midnight. Worse, Serizawa District was far from any shelter, which posed difficulty in securing the evacuees' safety. For these reasons, no evacuation advisory or similar was issued for Serizawa District.

After all, no evacuation advisory or similar had been issued for Serizawa District during the torrential rains. However, an evacuation order was issued at 9:00 a.m., on September 13, when a secondary disaster was feared to occur in the next rain.

Fig. 12 On-site survey

Fig. 13 Aerial view of Serizawa District

4. EMERGENCY REACTIONS TO THE DISASTER

4.1 Survey on damage

4.1.1 Learning the status of damage

Around 8:00 a.m., on September 10, soon after the disaster, a contractor that was then-involved in construction work in Serizawa District reported the occurrence of disaster there. Nikko Sabo Office immediately entered into emergency readiness mode and started gathering information about the status of damage in its jurisdiction including Serizawa District.

Staff was divided into teams and sent via many different routes. However, they found it very difficult to arrive to the affected site because the transportation network had been cut off at many places in Nikko City. One of the staff members took a detour via Nasushiobara City and entered Serizawa District in the evening of September 10, and successfully gathered information about the status of damage on the day of the disaster.

4.1.2 On-site survey

Four construction consultants were urgently mobilized in accordance with the Staff and Disaster Agreement. In the early morning of September 11, they entered the Serizawa District and started a detailed on-site survey of the mountain streams in an effort to stay updated on the status of sediment runoff and damage (**Fig. 12**).

4.1.3 Using a helicopter for the survey

From September 11 to 13, Aozora, a disaster-control helicopter from the MLIT Kanto Regional Development Bureau, was used to extensively survey the damage from above the jurisdiction including Serizawa District, focusing on the upstream areas of the mountain streams where ground-based surveys would be difficult to carry out (**Fig. 13**).

(a)

(b)

(c)

Fig. 14 Removing obstacles from the road
(a) Removing sediment and driftwood
(b) Damaged areas are temporarily repaired with large sandbags
(c) Road temporarily restored

(a)

(b)

Fig. 15 Emergency construction
(a) Right after the disaster
(b) A temporary diversion channel is constructed with large sandbags

4.1.4 Aerial survey

On September 12 and after, four aerial survey companies received an urgent request for aerial photography and aerial laser surveys, in an effort to keep updated on the post-disaster topography and to analyze the differences from the results obtained in previous years. The aerial photographs and the results of the differential analysis helped extensively to quickly learn the status of damage in a way that would have been impossible with ground-based surveys or short-time aerial surveys with a helicopter. Laser survey measurements were very helpful in these emergencies during which swift actions would be required, since they quickly provided the necessary topographical data for such purposes as the construction of facilities.

4.2 Removing obstacles from the road

As the construction of an erosion control dam was underway in the Udonsawa stream of Serizawa District, efforts to remove debris from the municipal road and to temporarily restore the area that had been washed by the flooding started on September 11, with the purpose of solving the isolation problem and securing evacuation routes. The road was opened before September 20 (**Fig. 14**).

4.3 Emergency construction

Unstable sediment continued to accumulate and the collapses kept expanding in the affected mountain streams. This led to the concern that another disaster would result from even a regular amount of rainfall unless construction of the anti-disaster facilities was completed. For the purpose of ensuring a minimum level of safety required in the inhabited houses around the mountain streams and the temporarily-restored municipal road, four constructors were urgently mobilized in accordance with the anti-disaster agreement and the construction of a temporary diversion channel using large sandbags commenced on September 14. The construction was largely completed by September 24 (**Fig. 15**).

4.4 Monitoring equipment

As a means for monitoring the affected site, small devices for the transmission of satellite images (Ku-SAT II; under the control of the Ministry of Land, Infrastructure, Transport and Tourism) were installed in Takimukaisawa and Nakatsuboshimosawa, where inhabited houses had been damaged. On September 26, the devices started transmitting video footage to related organizations such as the municipal office of Nikko City and the Prefectural Office of Tochigi.

For the purpose of helping Serizawa District to establish an effective evacuation warning system, debris flow sensors and alarms were placed in the six affected mountain streams by October 7. In addition, webcams were installed in the three mountain streams neighboring inhabited houses, in order to facilitate the monitoring of the mountain streams and to stay updated on the flow of the main river of Serizawa. The webcams proved to be extremely effective as they could transmit footage using the mobile telephone network and cloud service, thereby eliminating the need for the construction of communication cables or similar. Furthermore, webcams can be quickly installed at a reasonable cost and make it possible to view the images from anywhere in real-time.

(a)

(b)

Fig. 16 Activities of sediment disaster specialists and the Technical Emergency Control Force
(a) Technical guidance at the site
(b) Urgent inspection of a hazardous area

4.5 Activities of sediment disaster specialists and Technical Emergency Control Force

For technical guidance and advice on anti-disaster actions, the Ministry of Land, Infrastructure, Transport and Tourism sent three “sediment disaster specialists” from the National Institute for Land and Infrastructure Management and the Public Works Research Institute to the affected area on September 15.

On September 14, twenty staff members from the MLIT Kanto Regional Development Bureau were sent to Serizawa District as the Technical Emergency Control Force (TEC-FORCE), with the aim to urgently perform an inspection of sediment disaster hazards, including the mountain streams that could be affected by debris flow and steep slopes with the potential to collapse (**Fig. 16**).

Fig. 17 Mayor of Nikko City receives a report and advice

On September 17, the sediment disaster specialists gave the mayor of Nikko City a report on the status of the damage and advice on the readiness for an evacuation warning. The Head of the Technical Emergency Control Force also reported their inspection results (**Fig. 17**) [*Sabo Department, Water and Disaster Management Bureau, Ministry of Land, Infrastructure, Transport and Tourism*, 2015].

5. FUTURE ACTIONS

5.1 Construction of permanent anti-disaster facilities

Preventing the recurrence of the disasters urgently required permanent anti-disaster facilities to be constructed. Immediately after the torrential rain disaster, efforts were started to file an application for the permission for an urgent erosion control project. On October 26, a project for constructing erosion control dams for the four mountain streams (Shimotsubosawa, Takimukaisawa, Nakatsuboshimosawa and Nakatsubouesawa) was adopted.

It was decided that the construction of erosion control dams for Shimotsubouesawa and the groundsills for the damaged parts of the municipal road along the main river of Serizawa would be included in the regular erosion control project for fiscal 2016. In addition to the abovementioned four mountain streams, facilities were designed and sites underwent construction during the short period of time between late fall and winter. Construction successively commenced in and after March 2016 when the snow began to melt.

Construction was underway for Udonsawa, but was temporarily stopped, because, after the damage, the sediment treatment plan needed to be reviewed. The design of the erosion control dam was quickly corrected and construction resumed in March 2016.

5.2 Reviewing the evacuation warning system

Completing the construction of permanent anti-disaster facilities for preventing the recurrence of disasters takes at least one year, even if urgent construction works like those described above are undertaken. Until the completion of the construction of the facilities, the risk of sediment disaster remains higher than before the disaster. Because of this, the municipal government of Nikko City temporarily lowered the standard for the issuance of evacuation information for Serizawa District based on the advice from sediment disaster specialists.

Furthermore, Nikko City provided rules for local people's evacuation activities and reviewed the system of an evacuation warning with the aim of encouraging quick evacuations (**Fig. 18**) [*Uenaka*, 2016; *Sabo Department, National Institute for Land and Infrastructure Management and Erosion and Sediment Control Research Group, Public Works Research Institute*, 2015].

To support the effort, the Utsunomiya Local Meteorological Office is providing restoration personnel and affected people with daily weather forecasts for the Serizawa District and if heavy rain beyond a certain level is expected, rainfall estimates for the affected areas will be sent to those concerned by e-mail.

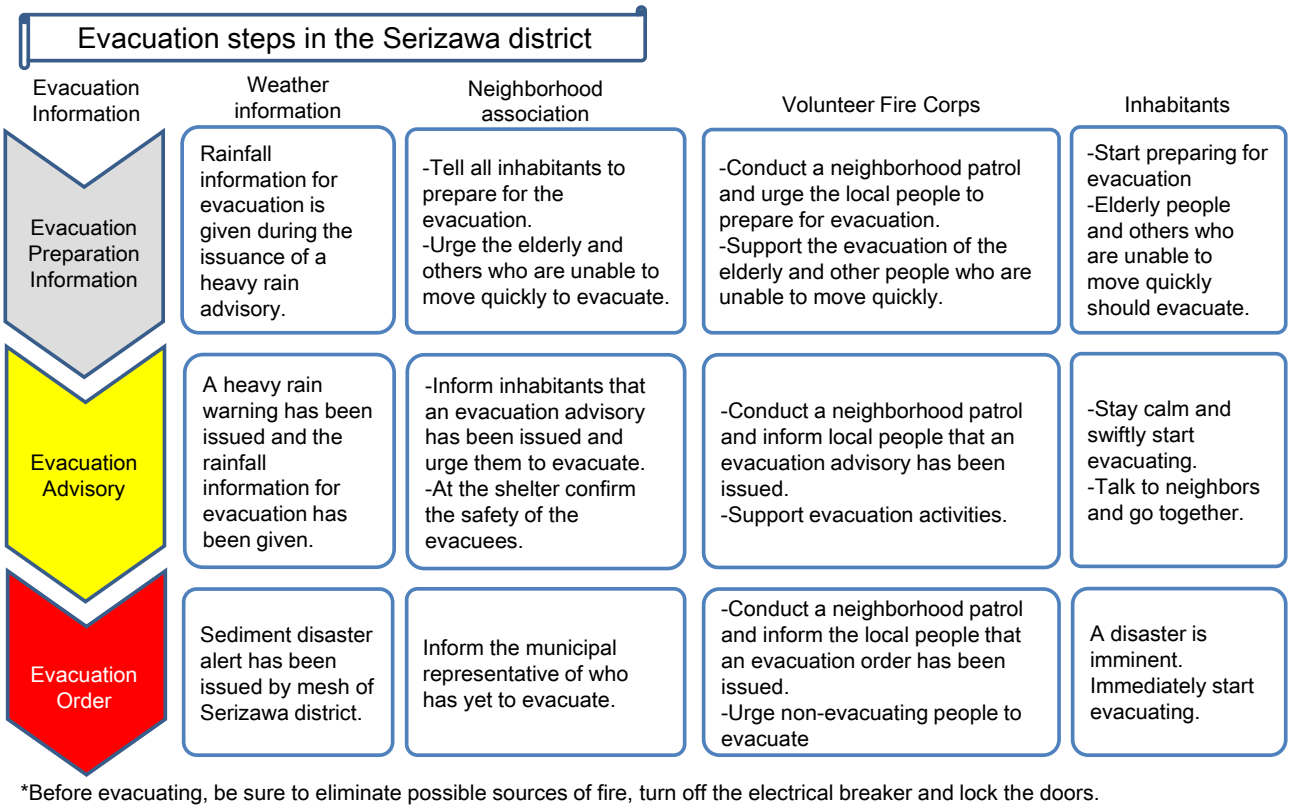


Fig. 18 Post-disaster evacuation warning system in the Serizawa district [Uenaka, 2016]

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